Caterpillar 3600 Marine Engine
Application & Installation Guide

LEKM2005

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3600 Marine Engine Application and Installation Guide

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Introduction

Foreward

Introduction

The information presented in this guide should aid in the planning through customer acceptance phases of a project.

The guide is arranged and designed to enable the information to be kept current, and for the user to easily locate the specific information required.

The technical data included is for ease of reference and will be updated periodically. Dealers can also obtain current engine information by accessing the Caterpillar Technical Marketing Information System (TMI). This system should always be checked for the most up to date engine data available. The TMI System is a corporately oriented computerized system for collecting, preparing, maintaining, and communicating technical data required for marketing Caterpillar Engine Division products. TMI operates in an IMS environment through the Caterpillar Network and functions under a corporate security system.

It must always be emphasized to refer to the TMI System for the latest engine performance information on all Engine Division products.

Foreword

Proper selection and installation of engines for marine application is vital for dependable performance and long, trouble-free life. The purpose of this guide is to help:

- Make knowledgeable choices of power equipment.

- Design and build marine installations that perform reliably at an optimum price/value relationship to the customer.

To ensure engines are installed properly, Caterpillar has support capability unmatched in the industry. From disciplines required for installation, to service and maintenance demanded years after completion, Caterpillar continues its commitment to its customer's successful operation.

Over fifty years of developing marine power equipment has culminated in a broad line of practical equipment, providing cost-effective selection and installation ease. A single source for propulsion engines and marine auxiliaries assures testing and quality for matched packages.

Development of installation knowledge parallels equipment advances. While this Application and Installation Guide summarizes many aspects of installation, Caterpillar Dealers stand ready with complete and detailed assistance.

It is the installer's responsibility to consider and avoid possible hazardous conditions which could develop from the systems involved in a specific engine installation. The suggestions provided in this guide regarding avoidance of hazardous conditions apply to all applications and are necessarily of a general nature since only the installer is familiar with the details of a particular installation. The suggestions provided in this guide should be considered as general examples only, and are in no way intended to cover every possible hazard in all installations.

Use the table of contents as a checklist of subjects affecting engine installations. Using the indexed material during preliminary project planning can avoid the effort and expense of after-installation changes.

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General Information

Model Identification

The basic model number is representative of both the series of particular engine and the number of cylinders. Typically an additional suffix refers to the type of fuel injection method and charge air aspiration.

Example: 3612 DITA

Caterpillar 3600 Family	- 36
12 Cylinder Vee Engine	- 12
Direct Fuel Injected	- DI
Turbocharged Aftercooled	- TA

All Caterpillar engines have three numbers which further define the engine. They are:

Arrangement Number

Used to establish the specific part assemblies representing the basic engine. Components such as cylinder heads, pistons, cylinder blocks and crankshafts can be determined from the arrangement number. It is found on both the Serial Number Plate and Engine Information Plate, Figures 1 & 2. Both plates are located on the engine.

Serial Number

Each engine is assigned a unique serial number. The number typically consists of alpha numeric characters; the first three represent the engine model, i.e.:

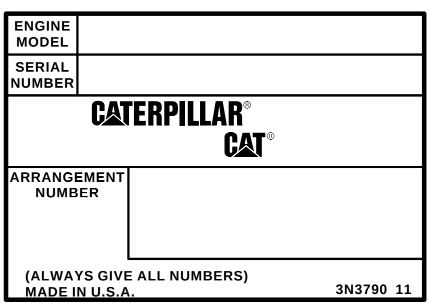
Model	**Serial Number**
3606	8RBXXXXX
3608	6MCXXXXX
3612	9RCXXXXX
3616	1PDXXXXX

The number is found on both the Serial Number Plate and the Information Plate.

Performance Specification Number

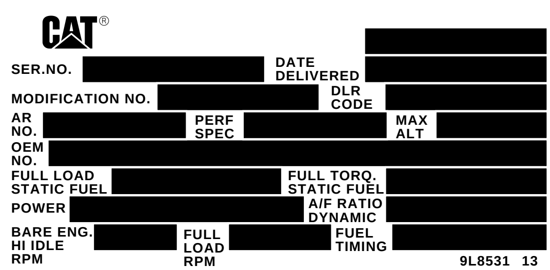
A number describing the engine's fuel system, air induction system, and performance settings. The number is unique to the power rating of each engine. It is found on the Engine Information Plate, Figure 2.

The three numbers are used to reference a specific engine model, application and rating and should always be referred to in correspondence relative to a particular engine or when spare parts are ordered.



Located on the left side of the engine block above one of the crankshaft inspection covers.

Figure 1



Located on the right side of the engine block above one of the crankshaft inspection covers.

Figure 2

Basic Engine Consists

The Caterpillar 3600 Family is configured in a positive-build manner for optimum flexibility in meeting customer requirements and ensures the ability to assemble and test a runnable engine at the factory.

Engine options, from Caterpillar's Selection Guide LEBQ5043, are listed in general code categories. The Selection Guide is included in the 3600 Sales Manual, LEKQ6141, and is available from Caterpillar Dealers or through the Caterpillar Corporate Literature distribution system.

The lists specify functional requirements of an engine resulting in a series of code numbers uniquely describing the complete engine package.

It should be emphasized that each specific engine is optimized in configuration hardware for the intended application, including core hardware such as cylinder liners, fuel injectors, camshafts, turbochargers, etc. The hardware differences to obtain maximum engine durability and performance efficiency, even for various fuel types, are all defined by the engine ordering code system.

Reference Material

LEKQ6141 3600 Sales Manual
LEBQ5043 3600 Attachment Selection Guide

Engine Description

The 3600 Engine Family is a modern, highly efficient engine family consisting of inline 6 and 8 cylinder engines and vee engines of 12 and 16 cylinders. They are 4 stroke non-reversible engines rated at speeds from 720 to 1000 rpm and intended for use as main propulsion and marine auxiliary engines for ship service generators. They are turbocharged and aftercooled with a direct injection fuel system using unit fuel injectors. For specification sheet information see the *Engine Data* section of this guide.

Cylinder Block

The cylinder block is a one piece casting of heavily ribbed, weldable, gray iron alloy. It is cast and machined at Caterpillar’s facilities. Air intake plenums run the full length of the engine providing even air distribution to the cylinders. Inspection covers provide easy inspection and service access to internal engine components, such as the camshaft, rod and main bearings, valve train, etc. The crankcase covers are equipped with explosion relief valves. The cylinder block is designed for four, six, or eight point mounting.

Cylinder Head

The unit cylinder head is poured in compacted graphite iron at Caterpillar’s foundry. The material approaches the strength of nodular iron, yet retains the heat transfer and sound damping properties of gray iron. It is a four valve, quiescent, uniflow port design with a central cast port for the unit fuel injector. The top deck is thick to carry gas loading while the buttressed bottom deck is thinner for good heat transfer. The replaceable valve guides are threaded to provide close tolerance with the valves and still have good lubrication control. All valves are fitted with positive rotators and seat on replaceable inserts. Fuel connections are made on the outside of the head with drillings to the unit fuel injectors. The head is retained by four hydraulically tensioned studs.

Valves

The valves seat on replaceable induction-hardened inserts. Positive rotators on all valves maintain a uniform temperature and wear pattern across the valve face and seat. Exhaust valves used in heavy fuel engines are given required special attention. By using a Nimonic 80A material in the valves and reducing the exhaust gas temperature, vanadium induced corrosion is significantly minimized. Increased valve overlap, water cooling the insert seats, and applying a ceramic coating to the valves maintains low valve head temperature.

Unit Fuel Injectors

The fuel injectors combine the pumping, metering and injecting elements into a single unit mounted directly in each cylinder head. This system has proven ideal not only when distillate and marine diesel oils are used, but also on heavy fuel; high injection pressure and precise injection timing, even at light loads, assure efficient combustion. Injection pressures of 1620 bar (23,500 psi) completely atomizes even the heaviest of fuels for more complete combustion and accelerated engine response. External manifolds supply fuel at low pressure from the transfer pump to drilled passages in the cylinder head. High pressure lines and double wall high pressure fuel injection lines are not needed. A 100 micron (.004 in.) edge type filter within each injector prevents contaminants from entering the injector during maintenance procedures. The hot water surrounding the injector location in the head aids in starting and stopping on heavy fuel. Individual control racks for each cylinder permits precise injector timing and minimizes fuel waste. Field calibration is eliminated and factory rebuilt injectors are available for engine overhaul.

An injector tip cooling system is used for heavy fuel operation.

Crankshaft

The crankshaft is a continuous grain flow forging, induction hardened, and regrindable. Counterweights at each cylinder are welded to the crankshaft and ultrasonically inspected to assure weld integrity. The crankshaft end flanges are identical, allowing full power to be taken from either end. A visconic crankshaft damper is fitted outside the engine housing at the free end of the engine.

Connecting Rods

Connecting rods are forged, heat treated, and shotpeened before machining. The special four bolt design and elimination of bearing grooves allows for an extra large bearing with reduced loads, and maximum oil film thickness. These factors extend bearing life and improve crankshaft strength and stiffness. The four bolt design also reduces bolt torque needed to achieve proper clamping load, and allows the rods to be withdrawn through the liner for service. Oil hole drilling in the critical rod shank area is eliminated by the use of piston cooling jets.

Bearings

All main, rod, and camshaft bearings are steel backed aluminum with a lead-tin overlay copper bonded to the aluminum. Piston cooling jets eliminate oil grooves in the highly loaded portion of the rod bearings.

Pistons

Pistons have a steel crown bolted to a light weight forged aluminum skirt for excellent strength and durability. Each piston has four rings, two in hardened grooves in the crown and two in the skirt. The top compression ring is barrel faced and plasma coated for greater hardness. The coating, in conjunction with the induction hardened liner, gives excellent oil control and life even with heavy fuel. The two middle rings are taper faced and chrome coated. The oil ring is chrome faced and uses a spring expander. Cooling oil for the crown and ring belt areas is sprayed from a cylinder block mounted jet through passageways in the piston.

Cylinder Liners

Cylinder liners are high alloy iron castings, induction hardened on the wearing surface, plateau honed and water jacketed over their full length.

Camshaft

The camshaft is segmented (one per cylinder) to permit easy removal and reduce service time. Each segment is made from case hardened, unique cleanliness controlled steel and bolted between two induction hardened journals. Only four unique camshaft segments are used for the entire engine family: (1) inline and vee right bank, (2) vee left bank, (3) standard overlap, and (4) high overlap for heavy fuel. Reverse rotation is accomplished by rearranging the segments.

Turbocharger

High efficiency turbochargers are used, one on the inline engines and two on the vee engines. The turbochargers have radial flow compressors and axial flow turbines. They are exhaust gas driven so that gear drives are not required. The turbocharger, combined with good “breathing” and efficient aftercooling, produces a high air/fuel ratio, providing more complete burning for maximum efficiency and improved cooling of the combustion chamber and valves. The turbochargers are water cooled and the bearings are pressure lubricated with engine oil.The turbochargers are mounted at the flywheel end of the engine. If a front mounted exhaust system is required, the engine can be turned end for end with full power taken from the front.

Exhaust System

The 3606 and 3612 Engines use a pulse exhaust manifold system. The manifold piping arrangement for the inline 3606 and each bank of the vee 3612 is identical. The front and rear three cylinders are connected to separate turbine inlet housing entries. The inline 3608 and the vee 3616 Engines use constant pressure exhaust systems. The 3608 has one manifold and the 3616 has one manifold for each bank.

Dry shielding assures surface temperatures meet Classification Society requirements.

Air Intake System

All engines are turbocharged and freshwater aftercooled. A variety of air cleaners can be supplied. The aftercoolers are mounted in air plenums cast directly in the cylinder blocks. Depending on the application, air shutoffs may be located in the air stream between the turbocharger and aftercooler.

Gear Trains

Gear trains are used at both the front and rear of the engines.

A. The rear gear group has 5 base HCR (High Contact Ratio) spur gears. The idler gear shafts are mounted to the rear of the block. The entire gear train can be removed with the rear housing in place. The vee gear train consists of seven gears with 5 being unique. The inline gear train consists of 4 unique gears.

B. The front gear group, identical for all four engines, is helical. The right idler drives the jacket water pump and the sea water pump. The left idler drives the water pump for the oil cooler and aftercooler. The gear train can be removed with the front housing in place.

Lube Oil System

The lube oil system, standard with the engine, features a prelube pump and a priority valve regulating oil pressure at the oil manifold rather than at the pump. This allows the engine to have continuous lubrication independent of pressure drop across the oil filters.

Oil Cooler and Filters

The oil cooler and filters are factory installed, tested and warranted, thus avoiding mixed responsibility for piping and components and significantly lowering installation costs. Duplex filters have replaceable elements allowing service without engine shutdown. The primary filter is 178 micron (.007 in.), while the final secondary filters are a media type of 5 micron (.0002 in.) size.

Oil Sump

The oil sump is of a light mild steel weldment bolted to the cylinder block. A wet type sump is normally used; a dry type can be provided to fit specific applications.

Bypass Oil Centrifuges

Bypass oil centrifuges, driven by main engine oil pump bypass flow, can be mounted on the side of the engine to remove very small, solid, micron size particles, and in some cases can be used to extend oil filter change periods. They can be cleaned and serviced with the engine running. They do not replace the need for separate lube oil centrifuges on heavy fuel burning engines.

Cooling System

Two basic cooling system configurations are available, single circuit and separate circuit. Both are designed for coolant supply temperatures of 90°C (194°F) (inlet control) to the water jacket, 32°C (90°F) to the aftercooler and 83°C (181°F) regulated temperature for the oil supply to the bearings. Both circuits include an engine mounted plate-fin aftercooler suitable for corrosive (salt air) environment. Both circuits include two water pumps that are engine driven from the front gear train and connections for vent lines to the high points in the system. The right-hand pump supplies coolant to the cylinder block, heads, and turbochargers. The left-hand pump supplies coolant to the aftercooler and oil cooler. An optional front gear train driven raw water pump for use with a remote heat exchanger is also available. Weld flanges are provided at all customer connection points.

Single Circuit

Single Circuit is typically used with a single heat exchanger and also with heavy fuel applications. The cylinder block/head/turbocharger cooling circuit is in series with the aftercooler/oil cooler circuit. It requires two main connections to the engine and includes 90°C (194°F) jacket water and 83°C (181°F) lubricating oil temperature regulators and two external circuit connections. The single circuit uses an external circuit temperature regulator and one external heat exchanger.

Separate Circuit

Separate Circuit is typically used for applications requiring small heat exchangers and/or heat recovery systems. The cylinder block/head/turbocharger cooling circuit is separate from the aftercooler/oil cooler circuit, and requires four main connections to the engine. This circuit includes a lubrication oil temperature regulator and external connections for both circuits. It requires a 90°C (194°F) and a 32°C (90°F) external circuit temperature regulator and two external heat exchangers.

Water Pumps

Water pumps are gear driven and located at the front of the engine. A special housing and impeller allow reverse rotation without changing the pumps. A gear driven raw water pump is also available to provide sea water to the heat exchanger.

Accessory Module

The accessory module shown in Figure 2 in the *Drawings* section provides standard locations for accessory mounting. The accessories are factory premounted on the module, with the complete module installed in one piece. This concept reduces installation time and cost. On diesel generator set applications the module will be floor mounted. It is used to mount the expansion tank, heat exchangers, instrument panel, engine controls, annunciator panel, alarm contactors, shutdown contactors and fuel strainers. On diesel generator set applications it is compatible with the 450 mm (17.72 in.) engine mounting feet dimension; connection lines to the accessories can be factory installed. Custom accessories can also be mounted on the accessory module on a space available basis.

Normally, the accessory module is mounted on the floor foundation directly in front of the engine. Flexible connections must be provided for the lines connecting the engine and the auxiliaries located on the separately mounted module.

When the module is mounted to other structures, and particularly when the engine is resiliently mounted, connections with increased flexibility may be necessary to accommodate engine motion. Flexible connections are provided by Caterpillar for the lines connecting the engine and the accessory module. Temperature contactors are available with 8 meter capillary tubes if the accessory module is to be remotely mounted. All other connections require custom modification to accommodate remote locations of the module.

Auxiliary Pumps

The oil and water pumps are gear driven and located at the front of the engine. A special housing and impeller allow reverse rotation without changing the water pumps. A gear driven sea (raw) water pump is available to supply cooling water to the fresh water heat exchanger.

Fuel Transfer Pump

Engines built for distillate fuel or marine diesel oils are equipped with an engine driven gear type transfer pump. For high viscosity fuels, an off engine mounted electrically driven pump is used to circulate fuel prior to engine start up.

Coupling

Marine torsional couplings are normally specified by the customer. They are available from Caterpillar. The selection for each marine application is dependent upon the Torsional Vibration Analysis. Customer specified couplings require Caterpillar approval.

Crankshaft Damper

Visconic crankshaft dampers are mounted outside the engine housing for optimum cooling and accessibility. Bolted covers and replaceable nylon bearings permit rebuilding in the field.

Flywheel

The flywheel is mounted at the rear of the engine and includes a ring gear for starting or barring. The high inertia flywheel is usually used for marine propulsion applications to permit the use of a single element flexible coupling.

Manual Turning Provision

Barring devices are provided to permit manual engine crankshaft rotation for service.

Engine Testing

Standard dynamometer production testing of 3600 Engines includes a comprehensive analysis of all engine systems. The following are standard points monitored during the test:

Engine Speed
Observed Power
Observed Torque
Observed Fuel Rate
Corrected Torque
Corrected Power
Corrected Fuel Rate
Corrected Specific Fuel Consumption
Full Load Correction Factor
Full Load Static Fuel Setting
High Idle Engine Speed
High Idle Stability
Low Idle Engine Speed
Low Idle Stability
Torque Check Speed
Inlet Air Pressure
Dry Barometric Pressure
Dew Point
Ambient Air Temperature
Inlet Air Temperature
Compressor Air Outlet Temperature
Inlet Air Manifold Temperature
Adjusted Boost Pressure
Oil Pressure
Oil Pressure at Low Idle
Bearing Oil Temperature
Fuel Pressure
Supply Fuel Pressure
Fuel Temperature
Return Fuel Temperature
Fuel Density
Jacket Water Inlet Temperature
Jacket Water Outlet Temperature
Delta T Jacket Water
AC/OC Inlet Water Temperature
AC/OC Outlet Water Temperature
Delta T AC/OC Water
Exhaust Manifold Temperature
Exhaust Stack Temperature

Depending on customer requirements, a variety of other engine tests are available including the following:

Marine Limit Line Test provides fuel rate, turbocharger boost pressure, specific fuel consumption, exhaust manifold gas temperature, turbocharger speed and fuel rack position at the engine's advertised rating limit line. Data is provided at 50 or 100 rpm increments from rated speed to 400 rpm. The test is intended for controllable pitch propeller applications.

Propeller Demand Curve Test provides fuel rate, turbocharger boost pressure, specific fuel consumption, exhaust manifold gas temperature, turbocharger speed and fuel rack position at the engine's advertised fixed pitch propeller demand curve. Data is provided at 50 or 100 rpm increments from rated speed to 400 rpm.

Overload Test provides fuel rate, turbocharger boost pressure, specific fuel consumption and fuel rack position at a customer specified temporarily increased power setting (overload). The engine fuel rack stop is reset to the proper power level upon test completion.
A full description of standard available tests is found in the Selection Guide, LEBQ5043-01.

Marine Classification Society Certification

Caterpillar has approvals for 3600 engines from the major marine Classification Societies listed below:

Approvals	**Type**	**Works**
American Bureau of Shipping (United States)	x	x
Lloyd's Register of Shipping (Great Britain)	x	x
Bureau Veritas (France)	x	x
Det Norske Veritas (Norway)	x	x
Germanischer Lloyd (Germany)	x	x
Nippon Kaiji Kyokai (Japan)	x	x
Registro Italiano Navale (Italy)	x	x
USSR Register of Shipping (Soviet Union)	x	x
Canadian Coast Guard (formerly CBSI)		x
Zhong Chuan (China) —3606 & 3608 only		x

Certifications from other Societies are available on request.

Torsional Vibration Analysis

To ensure the compatibility of an engine and driven equipment, a theoretical torsional vibration analysis is required. Disregarding the compatibility of the engine and driven equipment can result in extensive and costly damage to drive train components.

Conducted during the design stage of a project, the torsional analysis can avoid torsional vibration problems through modification of driven equipment shafts, masses or couplings. The torsional report will show natural frequencies, significant resonant speeds, relative amplitudes and a determination of stress levels, and the approximate nodal locations in the mass elastic system for each significant natural frequency.

The following technical data is required to perform a torsional analysis:

1. Is the application a variable or a constant speed operation? If variable, what is the operating speed range?
2. Load curve on installations for applications using load dependent variable stiffness couplings.
3. Horsepower requirements of each set of equipment is required when driving equipment from both ends of the engine. Are front and rear loading occurring simultaneously?
4. A general sketch of the complete system showing the relative location of each piece of equipment and type of connection.
5. Identification of all couplings by make and model along with rotating inertia (WR^2) and torsional rigidity values.
6. Rotating inertia (WR^2) or principal dimensions of each rotating mass and the location of the mass on the attached shaft.
7. Weight or principal dimensions of driven reciprocating mass.
8. Torsional rigidity and minimum shaft diameter or detailed dimensions of all shafting in the driven system, whether separately mounted or installed in a housing.
9. The number of propeller blades in addition to the rotating inertia (WR^2) in water.
10. The ratio of the speed reducer or increaser. The rotating inertia (WR^2) and rigidity submitted for a speed reducer or increaser should state whether or not they have been adjusted by the speed ratio squared.

Since compatibility of the installation is the customer's responsibility, it is also his responsibility to obtain the theoretical Torsional Vibration Analysis. Data on mass elastic systems of items furnished by Caterpillar is shown in the following tables. Damper selection for marine propulsion engines is shown in Figure 3. Always consult TMI for current data. The customer can calculate theoretical torsional vibration analysis or hire Caterpillar Inc. to complete the analysis. A *3600 Torsional Vibration Analysis Request* form is provided as a guide to the type of information required to complete the analysis (see Figure 4).

Marine Propulsion Damper Criteria				
rpm	3606	3608	3612	3616
750	A1	A2		B3
800	A1	A2	C2	B3
900	A1	C1	C2	B3
1000	A1	C1	C2	B3

Marine Auxiliary Damper Criteria				
rpm	3606	3608	3612	3616
720	A1	A2	B1	B3
750	A1	A2	B1	B3
900	A1	C1	C2	A3
1000	A1	C1	C2	A3

Two bearing generators only

Damper Data	A1	A2	A3	B1	B2	B3	C1	C2
Lumped mass J*	6.1	6.1	6.1	23.1	23.1	23.1	26.2	26.2
Separated Damper Data								
Damper Housing J*	3.2	3.2	3.2	8.6	8.6	8.6	11.6	11.6
Damper Flywheel J	5.8	5.8	5.8	28.9	28.9	28.9	29.2	29.2
Damper Constant C	1243	1000	1550	5100	6600	8100	14123	7000
Damper Rigidity K	0.73	0.41	0.60	1.80	1.60	1.35	4.52	2.85

* Add to Front of Crank
J (N-m -sec^2)
K (N-m x 10^6/radian)
C (N-m-sec sec/radian)

Torsional Calculation Values

Reciprocating Mass per Cylinder = 68.36 kg
Rotating Mass per Cylinder = 39.61 kg
Connecting Rod Length (between pin centers) = 600 mm

Cyclic Irregularity

The calculated cyclic irregularities for 3600 are:

Engine	Speed-rpm 900	1000
3606	1:152	1:188
3608	1:145	1:179
3612	1:254	1:314
3616	1:450	1:556

Figure 3

Empirical Damping

For torsional calculations involving empirical damping the empirical damping values are:

Engine	N-m-sec per radian
3606	384
3608	441
3612	531
3616	531

Note: *The damping values for the inline engines are for each cylinder; the 3612 and 3616 damping values are for a pair of cylinders since the vee engines have two cylinders on each crankshaft throw.*

Flywheel Inertia Data

Most marine propulsion applications use the high inertia flywheel to allow the use of a single element torsional coupling. A lighter weight standard flywheel is also available. Inertia valves include the ring gear and should be added to the rear crank inertia.

Standard flywheel inertia:
74.90 N-m-sec^2

High inertia flywheel: 140.29 N-m- sec^2

Torsional Vibration Data - Model 3606

Front Driven Equipment Visconic Damper – See page 18

3606 Mass Elastic System

Degrees to Firing After #1 Fires	Engine	J	K
	Front Crank	7.50	
			72.53
0	Cyl #1	9.743	
			42.85
480	Cyl #2	8.685	
			42.85
240	Cyl #3	8.685	
			42.85
600	Cyl #4	8.685	
			42.85
120	Cyl #5	8.685	
			42.85
360	Cyl #6	9.743	
			72.53
	Rear Crank	7.42	

Units

J = N-m-sec^2

K = $\frac{\text{N-m x } 10^6}{\text{Radian}}$

C = $\frac{\text{N-m-sec}}{\text{Radian}}$

Diameter in Millimeters

For Harmonic Component of Tangential Pressure See TD3310

Total Inertia Without Flywheel and Damper: J = 69.15 N-m-sec^2

Torsional Vibration Data - Model 3608

Front Driven Equipment Visconic Damper – See page 18

3608 Mass Elastic System

Degrees to Firing After #1 Fires	Engine	J	K	Min. Dia.
	Front Crank	7.50		
			69.28	216
0	Cyl #1	12.95		
			41.50	216
180	Cyl #2	4.79		
			41.50	216
450	Cyl #3	4.79		
			41.50	216
630	Cyl #4	12.21		
			41.50	216
270	Cyl #5	12.21		
			41.50	216
90	Cyl #6	4.79		
			41.50	216
540	Cyl #7	4.79		
			41.50	216
360	Cyl #8	12.95		
			69.28	216
	Rear Crank	7.42		

Units

J = N-m-sec^2

K = $\frac{\text{N-m x } 10^6}{\text{Radian}}$

C = $\frac{\text{N-m-sec}}{\text{Radian}}$

Diameter in Millimeters

For Harmonic Component of Tangential Pressure See TD3310

Total Inertia Without Flywheel and Damper: J = 84.40 N-m-sec^2

Torsional Vibration Data - Model 3612

Front Driven Equipment Visconic Damper – See page 18

3612 Mass Elastic System

Degrees to Firing After #1 Fires		Engine	J	K	Min. Dia.
		Front Crank	7.50		
				67.79	216
1R-0	1L-410	Throw #1	17.00		
				40.11	216
2R-480	2L-170	Throw #2	16.31		
				40.11	216
3R-240	3L-650	Throw #3	16.31		
				40.11	216
4R-600	4L-290	Throw #4	16.31		
				40.11	216
5R-120	5L-530	Throw #5	16.31		
				40.11	216
6R-360	6L-50	Throw #6	17.00		
				67.79	216
		Rear Crank	7.42		

Units

J = N-m-sec²

$K = \dfrac{\text{N-m} \times 10^6}{\text{Radian}}$

$C = \dfrac{\text{N-m-sec}}{\text{Radian}}$

Diameter in Millimeters

For Harmonic Component of Tangential Pressure See TD3310

Total Inertia Without Flywheel and Damper: J = 114.16 N-m-sec²

Torsional Vibration Data - Model 3616

Front Driven Equipment Visconic Damper – See page 18

3616 Mass Elastic System

Degrees to Firing After #1 Fires		Engine	J	K	Min. Dia.
		Front Crank	7.50		
				67.79	216
1R-0	1L-50	Throw #1	17.17		
				40.11	216
2R-180	2L-230	Throw #2	16.5		
				40.11	216
3R-90	3L-140	Throw #3	16.5		
				40.11	216
4R-630	4L-680	Throw #4	16.5		
				40.11	216
5R-270	5L-320	Throw #5	16.5		
				40.11	216
6R-450	6L-500	Throw #6	16.5		
				40.11	216
7R-540	7L-590	Throw #7	16.5		
				40.11	216
8R-360	8L-410	Throw #8	17.17		
				67.79	216
		Rear Crank	7.42		

Units

J = N-m-sec²

$K = \dfrac{\text{N-m} \times 10^6}{\text{Radian}}$

$C = \dfrac{\text{N-m-sec}}{\text{Radian}}$

Diameter in Millimeters

For Harmonic Component of Tangential Pressure See TD3310

Total Inertia Without Flywheel and Damper: J = 148.26 N-m-sec²

3600 Torsional Vibration Analysis Request

Project Number ______________________________

Project/Customer Name ______________________________

Dealer Name ______________________________

The information on this form is to be used for a specific request for a torsional vibration analysis on the above 3600 Diesel Engine application. Please provide a timely verbal response followed by a written report to the responsible project engineer. The following information describes the major components and performance data for this application:

Engine Model and Rating:

E29 ________ (36 ________); ________ kW (________ bhp)

Low Idle rpm ________ Rated Speed rpm ________

Engine Regulation: Isochronous (Y/N) ________, or Percent Droop ________ %

Application Specifics: ______________________________

____

____

(quantity engines -- custom base -- front driven equipment, etc.)

Engine Room Maximum Ambient Temperature ______________________________

Generator (____); and/or **Marine Gear** (____); plus **Other Driven Equipment** (____)

Supplier Name and Model Number ______________________________

Rotating Inertia/Drawing(s) ______________________________

Rotating Stiffness/Shaft Drawing(s) ______________________________

Gearbox Drawing ____________________ Propeller Inertia ____________________

Description (e.g. two bearing or single bearing) ______________________________

____

(attached are supplier data sheets)

Part Numbers of Components:

Engine Ship Date (RTS) ______________________________

Flywheel Group	__________	Coupling Group	__________
Drive Group	__________	Damper Group	__________
Ring Gear Group	__________	Other Groups	__________
3161 Governor Group	__________	Heinzmann Governor	__________
EGB29P Actuator Assembly	__________	Electronic Control Group	__________

Torsional Completion Date Required ______________________________

Caterpillar Project Engineer ______________________________

(Revised 4-25-97)

Figure 4

Engine Preservation and Packaging

The Caterpillar factory has four standard levels of engine preservation and shipment protection.

- *Plastic Shrink Wrap Protection* provides approximately one year of external protection from moisture, sun and wind under storage conditions. If the engine is to be stored for longer periods of time, consider specifying Storage Preservation as described below.

- *Tarpaulin and Plastic Shrink Wrap* – Same as previous point above except this package includes a factory supplied tarpaulin on the engine, which remains on the engine after arrival.

- *Storage Preservation* – Protects the engine and accessories from functional deterioration for a minimum of one year under outside storage conditions. It includes standard protective measures plus vapor corrosion inhibitor (VCI) in all internal compartments and glycol solution in the cooling system. The shipper must provide tarpaulin coverage during transportation to prevent the plastic from being destroyed.

- *Export Boxing* – Protects engine and accessories from functional deterioration for a minimum of one year under outside storage conditions. Includes standard protective measures plus vapor corrosion inhibitor in all internal compartments, and a glycol solution in the cooling system. The exterior box provides protection against mechanical damage during shipment and storage. All marine engines are placed upon wooden skids prior to shipment. All ship loose parts are prepainted, oiled and placed in VCI paper lined boxes, with desiccant packages placed in the box. On arrival, open all boxes and review their contents against the packing list. The parts should then be repackaged and preserved for protection.

Shipbuilder's Responsibility

Unless otherwise specified, the engine buyer shall be responsible for the following:

- Provide electrical wiring and the necessary piping to the engine, i.e., exhaust piping, fuel oil piping to and from the engine, air piping to the starting motor(s), air filter ducting/piping, crankcase fumes disposal ducting, etc.

  All of the above noted interconnections need to be designed in such a way so as to comply with acceptable vibratory levels of excitation throughout the entire range of engine operation. No primary resonances in the interface hardware are acceptable. See ISO 4868 and 4867.
- Furnish and install standby pumps as required by Classification Societies.
- Furnish accurate data for a torsional vibration analysis.
- Install adequate engine foundation and provide proper chocking and alignment between the engine and marine gear.
- See ISO 10816-6 and ISO 6954. Typically, vibratory velocities under 10 mm/s with no structural resonances are required.
- Ensure all lube oil piping, fuel oil piping, exhaust piping and intake air ducting are free of rust, scale, weld spatter and foreign material prior to startup of the engines.
- Provide all labor, equipment and hardware to install the equipment.
- Provide all coolants, water treatment chemicals (if used), lubricating oil, and fuel oils necessary to operate the engine.
- Warehouse and protect engines, accessories and miscellaneous ship-loose equipment until their installation. Caterpillar engines are protected against corrosion for inside dry storage for a period up to six months. Provisions for additional storage periods are available from the factory.

Customer Application Information

Customer:____________________________ Address: ______________________________________

Contact: ________________________________ Telephone: _____________________________

Shipyard: _______________________________ Contact: _______________________________

Address: ________________________________ Telephone: _____________________________

1. Main Engine: ____

   Engine output: ______________________ kW (hp) Speed: ______________________rpm

   Direction of rotation (flywheel viewed from rear): ________________________________

   Fuel Type: ____

   Builder: ____

   Special testing Yes/No: ____

2. Propulsion controls:

   Type (pneumatic/electronic): ____

   Manufacturer: ____

3. Combined clutch/flexible coupling (type): ____

   Flexible coupling: ____

4. Reduction gear box, manufacturer and type: _______________________________________

   Reduction ratio: _____________________________

   Integral disc clutch? Yes____ No____ Clutch type: pneumatic/hydraulic

   PTO? Yes____ No____ Manufacturer ______________________________

   Shaft Brake? Yes____ No____

5. Propeller manufacturer: ____

   Type: Fixed pitch ____________________

   Controllable pitch ____________________

   Number of blades ____________________ Propeller Diameter:________mm_________in.

   P/D Ratio: __________________________ Blade Area Ratio: ________________________

   Propeller speed at MCR rating __________________________rpm

   Direction of propeller rotation ____

   Designed for constant rpm? Yes______________________No______________________

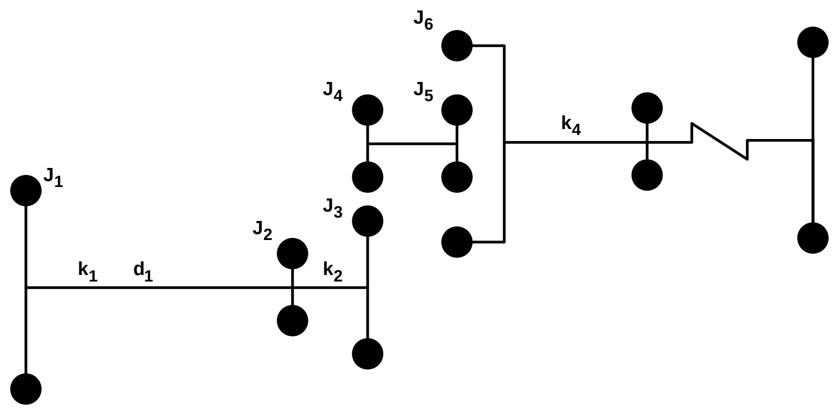


Figure 5

6. Data For Torsional Vibration Calculations

J_1 Propeller	J_2 Gear box flange	J_3 Gear wheel
J_4 Gear wheel	J_5 Clutch	J_6 Clutch

Propeller Inertia J (N-m-sec^2) without entrained water____________________N-m-sec^2

7. Vessel hull type____

Length:______mm ______in.   Beam: ______mm ______in.   Draft:_____mm______in

Displacement______________________m.t.   Class of service: ______________________

Hull speed_________________________kts.   Classed by:___________________________

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- Engine Data
- Engine Performance

LEKM8461 8-98

CATERPILLAR®

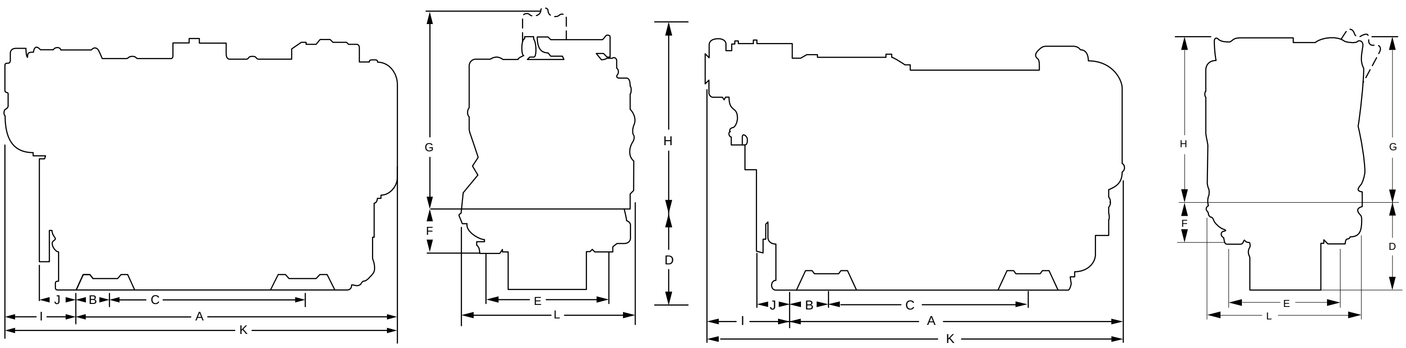
Engine Data

Dimensions and Weights
Center of Gravity
Technical Data
Noise
Vibration

Dimensions and Weights

The dimensions and weights of 3600 Marine Propulsion Engines are shown below. Engine outline drawings are included in the *Drawings* section of this guide. Marine auxiliary dimensions, weights and outline drawings are included in the *Technical Data* section of the EPG A&I guide (LEKX6559).

3600 Marine Propulsion



In-Line Vee

Dimensions

3606 In-Line

	A	B	C	D	E	F1	F2	G	H	I	J	K	L		W
mm	3261	265	2050	841	1120	405	450	2035	1785	727	360	3988	1748	kg	15,680
in	128.39	10.43	80.71	33.11	44.09	15.95	17.72	80.12	70.28	28.62	14.17	157.01	68.82	lb	34,500

3608 In-Line

	A	B	C	D	E	F1	F2	G	H	I	J	K	L		W
mm	4081	265	2870	841	1120	405	450	2035	1785	727	360	4808	1748	kg	19,000
in	160.67	10.43	112.99	33.11	44.09	15.95	17.72	80.12	70.28	28.62	14.17	189.29	68.82	lb	41,800

3612 VEE

	A	B	C	D	E	F1	F2	G	H	I	J	K	L		W
mm	3657	300	2300	976	1120	405	450	1850	2255	905	360	4562	1714	kg	25,740
in	143.98	11.81	90.55	38.43	44.09	15.95	17.72	72.84	88.78	35.63	14.17	179.61	67.48	lb	56,630

3616 VEE

	A	B	C	D	E	F1	F2	G	H	I	J	K	L		W
mm	4577	300	3220	976	1120	405	450	1850	2255	905	360	5482	1714	kg	30,750
in	180.2	11.81	126.77	38.43	44.09	15.95	17.72	72.84	88.78	35.63	14.17	215.83	67.48	lb	67,650

C	centerline distance between mounting feet
F1 and F2	optional mounting dimensions
G	removal distance for piston
J	distance from flywheel mounting face to cylinder block rear face
W	approximate dry weight of engine with attachments such as filters, oil cooler, flywheel, pumps, etc.

Center of Gravity

Center of gravity locations apply to dry runable engines:

Model	Distance From Cylinder Block Rear Face	Vertical Distance Above Crankshaft Centerline	Transverse Distance from Crankshaft Centerline
3606	1290 mm 50.8 in.	350 mm 13.8 in.	On Crank Center
3608	1700 mm 66.9 in.	350 mm 13.8 in.	On Crank Center
3612	1411 mm 55.6 in.	380 mm 14.9 in.	On Crank Center
3616	1858 mm 73.1 in.	380 mm 14.9 in.	On Crank Center

Technical Data

Distillate Fuel

Pages 7 through 23 are Marine Propulsion technical data sheets for distillate fuel engines. The data is given at 750, 800, 900, and 1000 rpm. Technical data for distillate fuel Marine Auxiliary generator sets is in the 3600 EPG A&I guide (LEKX6559). See the *Engine Performance* section of this guide for a complete description of ratings and limitations.

Heavy Fuel

Pages 24 through 43 are Marine Propulsion technical data sheets for heavy fuel engines. See the *Engine Performance* section of this guide for a complete description of ratings and limitations.

TECHNICAL DATA

Engine: 3606 In-Line
Rating: CSR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	1490	(2000)	1560	(2090)	1730	(2320)	1850	(2480)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2152	(312)	2111	(306)	2081	(302)	2003	(291)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-5-3-6-2-4				1-5-3-6-2-4			
Firing Order - CW			1-4-2-6-3-5				1-4-2-6-3-5			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	145.2	(5128)	160.9	(5682)	164.3	(5802)	181.4	(6406)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	52.9	(127)	51	(124)	52.9	(127)	53.5	(128)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	201	(29.2)	242	(35.1)	220	(31.9)	232	(33.6)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	309	(10912)	334.3	(11806)	372.1	(13141)	412.6	(14571)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	530	(986)	514	(957)	563	(1045)	564	(1047)
Exhaust Stack Temperature @ 100% load	°C	(°F)	362	(684)	347	(657)	403	(757)	406	(763)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	160	(9099)	168	(9554)	185	(10521)	205	(11658)
Jacket Water Circuit	kW	(Btu/min.)	307	(17459)	323	(18369)	373	(21212)	381	(21667)
Aftercooler	kW	(Btu/min.)	396	(22535)	430	(24470)	402	(22877)	496	(28226)
Total Heat rejected to Raw Water	kW	(Btu/min.)	863	(49093)	921	(52393)	960	(54610)	1082	(61551)
Exhaust Gas[2]	kW	(Btu/min.)	974	(55428)	1007	(57305)	1256	(71475)	1360	(77394)
Radiation	kW	(Btu/min.)	67	(3813)	68	(3870)	73	(4154)	74	(4211)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	31.5	(8.3)	33.6	(8.85)	38	(10)	41.5	(11)
Flow Rate, return	Lpm	(gpm)	24.5	(6.5)	26.2	(6.9)	30	(7.9)	32.4	(8.6)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	191.7	(.315)	191.8	(.315)	195.5	(.321)	198.6	(.326)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	697	(184)	697	(184)	697	(184)	697	(184)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3606 In-Line
Rating: CSR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

TECHNICAL DATA

Engine: 3606 In-Line
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	1640	(2200)	1720	(2310)	1900	(2550)	2030	(2720)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2368	(343)	2328	(338)	2286	(332)	2198	(319)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-5-3-6-2-4				1-5-3-6-2-4			
Firing Order - CW			1-4-2-6-3-5				1-4-2-6-3-5			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	159.7	(5640)	172	(6074)	179.9	(6353)	196.4	(6936)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	53.1	(128)	52.7	(127)	54.6	(130)	55	(127)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	232	(33.6)	268	(38.9)	254	(36.8)	261	(37.9)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	339.6	(11993)	363.7	(12844)	407.5	(14391)	450.1	(15895)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	540	(1004)	540	(1004)	574	(1065)	580	(1076)
Exhaust Stack Temperature @ 100% load	°C	(°F)	362	(684)	358	(676)	403	(757)	411	(772)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	169	(9611)	175	(9952)	196	(11146)	215	(12227)
Jacket Water Circuit	kW	(Btu/min.)	327	(18596)	340	(19336)	397	(22577)	411	(23374)
Aftercooler	kW	(Btu/min.)	473	(26917)	507	(28852)	511	(29080)	624	(35510)
Total Heat rejected to Raw Water	kW	(Btu/min.)	969	(55124)	1022	(58140)	1104	(62803)	1250	(71111)
Exhaust Gas[2]	kW	(Btu/min.)	1039	(59126)	1136	(64646)	1332	(75800)	1464	(83312)
Radiation	kW	(Btu/min.)	70	(3983)	71	(4040)	74	(4211)	76	(4325)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	31.5	(8.3)	33.6	(8.85)	38	(10)	41.5	(11)
Flow Rate, return	Lpm	(gpm)	22.1	(5.8)	23.6	(6.2)	27	(7.1)	29.2	(7.7)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	190.8	(.314)	193.2	(.318)	195.3	(.321)	199.8	(.328)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	697	(184)	697	(184)	697	(184)	697	(184)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3606 In-Line*
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 1000	
General Data				
Engine Output[1]	bkW	(bhp)	2030	(2720)
Cylinder Bore	mm	(in)	280	(11.0)
Stroke	mm	(in)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)
Compression Ratio			13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)
BMEP	kPa	(psi)	2198	(319)
Mean Piston Speed	m/s	(f/s)	10.0	(32.8)
Idle Speed	rpm	rpm	350	
Crash Reversal Speed, minimum	rpm	rpm	300	
Firing Order - CCW			1-5-3-6-2-4	
Firing Order - CW			1-4-2-6-3-5	
Combustion Air System				
Flow of air @ 100% load	cmm	(cfm)	200.7	(7088)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	48.0	(118)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	261	(37.9)
Exhaust Gas System				
Exhaust Gas Flow @ 100% load	cmm	(cfm)	459.2	(16216)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	573	(1063)
Exhaust Stack Temperature @ 100% load	°C	(°F)	410	(770)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)
Heat Balance @ 100% Load				
Lube Oil Cooler	kW	(Btu/min.)	215	(12227)
Jacket Water Circuit	kW	(Btu/min.)	411	(23374)
Aftercooler	kW	(Btu/min.)	662	(37673)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1288	(73274)
Exhaust Gas[2]	kW	(Btu/min.)	1450	(82515)
Radiation	kW	(Btu/min.)	76	(4325)
Fuel System				
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	41.5	(11)
Flow Rate, return	Lpm	(gpm)	29.2	(7.7)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	200.8	(.330)
Lubricating Oil System				
Manifold Pressure, minimum	kPa	(psi)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)
Sump Capacity (marine)	L	(gal)	697	(184)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)

* Data for 3606 engine with 3608 aftercooler installed

TECHNICAL DATA

Engine: 3606 In-Line
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

TECHNICAL DATA

Engine: 3608 In-Line
Rating: CSR
Fuel: MDO

	Units		750		800		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	1980	(2660)	2080	(2790)	2300	(3080)	2460	(3300)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2144	(311)	2111	(306)	2075	(301)	1998	(290)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-6-2-5-8-3-7-4				1-6-2-5-8-3-7-4			
Firing Order - CW			1-4-7-3-8-5-2-6				1-4-7-3-8-5-2-6			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	193.3	(6826)	205.4	(7254)	213.8	(7550)	225.3	(7956)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	53.4	(128)	54.9	(131)	55.4	(132)	53.8	(129)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	238	(34.5)	247	(35.8)	219	(31.8)	209	(30.3)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	410.7	(14504)	437.6	(15454)	482.8	(17050)	520.1	(18367)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	519	(966)	524	(975)	559	(1038)	564	(1047)
Exhaust Stack Temperature @ 100% load	°C	(°F)	361	(682)	363	(685)	401	(754)	416	(781)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	222	(12625)	218	(12398)	247	(14047)	273	(15525)
Jacket Water Circuit	kW	(Btu/min.)	414	(23544)	420	(23885)	494	(28094)	504	(28662)
Aftercooler	kW	(Btu/min.)	681	(38754)	638	(36307)	595	(33860)	745	(42396)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1317	(74923)	1276	(72590)	1336	(76001)	1522	(86583)
Exhaust Gas[2]	kW	(Btu/min.)	1036	(58956)	1231	(70053)	1643	(93498)	1709	(97254)
Radiation	kW	(Btu/min.)	74	(4211)	77	(4382)	81	(4609)	85	(4837)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	31.5	(8.3)	33.8	(8.9)	38	(10)	41.5	(11)
Flow Rate, return	Lpm	(gpm)	22.6	(6)	24.5	(6.5)	27.6	(7.3)	30	(7.9)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	187.3	(.308)	188.7	(.310)	196.1	(.322)	197.6	(.325)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	760	(200)	760	(200)	760	(200)	760	(200)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3608 In-Line
Rating: CSR
Fuel: MDO

	Units		750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

Engine Speed Ratings: 750, 800, 900, 1000

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

TECHNICAL DATA

Engine: 3608 In-Line
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	2180	(2920)	2290	(3070)	2530	(3390)	2710	(3630)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2360	(342)	2324	(337)	2283	(331)	2201	(319(
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-6-2-5-8-3-7-4				1-6-2-5-8-3-7-4			
Firing Order - CW			1-4-7-3-8-5-2-6				1-4-7-3-8-5-2-6			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	209.3	(7391)	220.1	(7773)	230.8	(8151)	240.8	(8504)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	55.6	(132)	56.9	(134)	59.2	(139)	57.7	(136)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	270	(39.2)	275	(39.9)	244	(35.4)	233	(33.8)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	449.4	(15870)	477.0	(16845)	529.0	(18681)	567.1	(20027)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	537	(999)	547	(1017)	582	(1080)	590	(1094)
Exhaust Stack Temperature @ 100% load	°C	(°F)	368	(694)	374	(705)	411	(772)	430	(806)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	236	(13421)	253	(14388)	262	(14900)	288	(16379)
Jacket Water Circuit	kW	(Btu/min.)	446	(25364)	460	(26160)	528	(30027)	547	(31108)
Aftercooler	kW	(Btu/min.)	788	(44843)	636	(36193)	720	(40973)	884	(50306)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1470	(83628)	1349	(76741)	1510	(85900)	1719	(97793)
Exhaust Gas[2]	kW	(Btu/min.)	1145	(65159)	1451	(82572)	1813	(103173)	1869	(106359)
Radiation	kW	(Btu/min.)	80	(4553)	80	(4553)	85	(4837)	88	(5008)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	31.5	(8.3)	33.8	(8.9)	38	(10)	41.5	(11)
Flow Rate, return	Lpm	(gpm)	20.3	(5.4)	22.1	(5.8)	24.5	(6.5)	27	(7.1)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	188.2	(.309)	190	(.312)	197.5	(.325)	198.3	(.326)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	760	(200)	760	(200)	760	(200)	760	(200)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3608 In-Line
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

TECHNICAL DATA

Engine: 3612 Vee
Rating: CSR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	2980	(4000)	3120	(4180)	3460	(4640)	3700	(4960)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2152	(312)	2111	(306)	2081	(302)	2003	(291)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-12-9-4-5-8-11-2-3-10-7-6				1-12-9-4-5-8-11-2-3-10-7-6			
Firing Order - CW			1-6-7-10-3-2-11-8-5-4-9-12				1-6-7-10-3-2-11-8-5-4-9-12			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	290.4	(10255)	321.7	(11361)	328.6	(11604)	362.8	(12812)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	52.9	(127)	51	(124)	52.9	(127)	53.5	(128)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	190	(27.6)	233	(33.8)	226	(32.8)	219	(31.8)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	617.9	(21821)	668.3	(23601)	744.2	(26281)	825.3	(29145)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	530	(986)	514	(957)	563	(1045)	564	(1047)
Exhaust Stack Temperature @ 100% load	°C	(°F)	362	(684)	347	(657)	403	(757)	406	(763)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	320	(18198)	335	(19051)	371	(21099)	398	(22634)
Jacket Water Circuit	kW	(Btu/min.)	612	(34804)	644	(36624)	746	(42425)	721	(41003)
Aftercooler	kW	(Btu/min.)	702	(39949)	760	(43249)	713	(40575)	733	(41713)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1634	(92951)	1739	(98924)	1830	(104099)	1852	(105350)
Exhaust Gas[2]	kW	(Btu/min.)	2015	(114668)	2143	(121952)	2605	(148243)	2984	(169811)
Radiation	kW	(Btu/min.)	92	(5235)	94	(5349)	102	(5805)	104	(5918)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	61.2	(16.2)	68.8	(18.1)	72	(19)	78.5	(20.7)
Flow Rate, return	Lpm	(gpm)	47.3	(12.5)	53.2	(14)	55.4	(14.6)	60.1	(15.9)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	189.8	(.312)	191.4	(.315)	194.5	(.320)	196.5	(.323)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	910	(240)	910	(240)	910	(240)	910	(240)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3612 Vee
Rating: CSR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(618)	2630	(695)	2920	(771)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	194	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

TECHNICAL DATA

Engine: 3612 Vee
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	3280	(4400)	3440	(4610)	3800	(5100)	4060	(5440)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2368	(343)	2328	(338)	2286	(332)	2198	(319)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-12-9-4-5-8-11-2-3-10-7-6				1-12-9-4-5-8-11-2-3-10-7-6			
Firing Order - CW			1-6-7-10-3-2-11-8-5-4-9-12				1-6-7-10-3-2-11-8-5-4-9-12			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	319.4	(11280)	343.9	(12145)	360.0	(12713)	392.9	(13875)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	53.1	(128)	52.7	(127)	54.6	(130)	55	(131)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	218	(31.6)	258	(37.4)	261	(37.9)	246	(35.7)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	679.5	(23996)	727.1	(25677)	815.3	(28792)	900.4	(31797)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	540	(1004)	540	(1004)	574	(1065)	580	(1076)
Exhaust Stack Temperature @ 100% load	°C	(°F)	362	(684)	358	(676)	403	(757)	411	(772)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	338	(19222)	350	(19904)	392	(22293)	416	(23658)
Jacket Water Circuit	kW	(Btu/min.)	652	(37079)	678	(38558)	793	(45098)	774	(44017)
Aftercooler	kW	(Btu/min.)	838	(47688)	899	(51159)	906	(51558)	927	(52753)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1828	(103989)	1927	(109621)	2091	(118949)	2117	(120428)
Exhaust Gas[2]	kW	(Btu/min.)	2157	(122749)	2413	(137317)	2778	(158088)	3208	(182558)
Radiation	kW	(Btu/min.)	98	(5577)	101	(5748)	105	(5975)	110	(6260)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	61.2	(16.2)	68.8	(18.1)	72	(19)	78.5	(20.7)
Flow Rate, return	Lpm	(gpm)	42.6	(11.3)	47.9	(12.7)	49.9	(13.2)	54.1	(14.3)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	188.9	(.311)	192.8	(.317)	194.3	(.319)	196.8	(.324)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	910	(240)	910	(240)	910	(240)	910	(240)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3612 Vee
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(618)	2630	(695)	2920	(771)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	194	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

TECHNICAL DATA

Engine: 3616 Vee
Rating: CSR
Fuel: MDO

	Units		750		800		900		1000	
			Engine Speed Ratings							
General Data										
Engine Output[1]	bkW	(bhp)	3960	(5310)	4160	(5580)	4600	(6170)	4920	(6600)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2144	(311)	2111	(306)	2075	(301)	1998	(290)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8				1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8			
Firing Order - CW			1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2				1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	398.9	(14087)	423.7	(14963)	441.1	(15577)	464.7	(16411)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	43.4	(110)	44.9	(113)	45.4	(114)	43.8	(111)
Air Temperature after Aftercooler, alarm	°C	(°F)	61	(142)	61	(142)	61	(142)	61	(142)
Intake Manifold Pressure @ 100% load	kPa	(psi)	230	(33.4)	227	(32.9)	210	(30.5)	195	(28.3)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	839.3	(29640)	894.3	(31582)	987.1	(34859)	1063.4	(37554)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	509	(948)	514	(957)	549	(1020)	554	(1029)
Exhaust Stack Temperature @ 100% load	°C	(°F)	355	(671)	357	(675)	395	(743)	410	(770)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	410	(23317)	429	(24397)	463	(26331)	532	(30255)
Jacket Water Circuit	kW	(Btu/min.)	757	(43050)	840	(47771)	918	(52207)	968	(55050)
Aftercooler	kW	(Btu/min.)	977	(55598)	1212	(68971)	1075	(61175)	1265	(71987)
Total Heat rejected to Raw Water	kW	(Btu/min.)	2144	(121965)	2481	(141139)	2456	(139713)	2765	(157292)
Exhaust Gas[2]	kW	(Btu/min.)	2813	(160080)	3005	(171006)	3746	(213174)	3778	(214995)
Radiation	kW	(Btu/min.)	109	(6203)	112	(6374)	120	(6829)	125	(7113)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	61.2	(16.2)	68.8	(18.1)	72	(19)	78.5	(20.7)
Flow Rate, return	Lpm	(gpm)	43.2	(11.4)	48.6	(12.8)	51.1	(13.5)	55.2	(14.6)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	191.8	(.315)	197.4	(.325)	199.8	(.328)	198.2	(.326)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	1060	(280)	1060	(280)	1060	(280)	1060	(280)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3616 Vee
Rating: CSR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(618)	2630	(695)	2920	(771)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	194	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

[5]All 3616 engines come equipped with a High Performance Aftercooler (HPAC) to reduce the air inlet manifold temperature.

TECHNICAL DATA

Engine: 3616 Vee
Rating: MCR
Fuel: MDO

	Units		750		800		900		1000	
			Engine Speed Ratings							
General Data										
Engine Output[1]	bkW	(bhp)	4360	(5850)	4580	(6140)	5060	(6790)	5420	(7270)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			13:1		13:1		13:1		13:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2360	(342)	2324	(337)	2283	(331)	2201	(319)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.0	(26.2)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8				1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8			
Firing Order - CW			1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2				1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	431.7	(15245)	453.9	(16029)	475.9	(16806)	496.5	(17534)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler	°C	(°F)	45.6	(114)	46.9	(116)	49.2	(121)	47.7	(118)
Air Temperature after Aftercooler, alarm	°C	(°F)	61	(142)	61	(142)	61	(142)	61	(142)
Intake Manifold Pressure @ 100% load	kPa	(psi)	259	(37.6)	253	(36.7)	235	(34.1)	218	(31.6)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	918.4	(32433)	974.8	(34425)	1081.1	(38179)	1159.5	(40947)
Exhaust Manifold Temperature @ 100% load	°C	(°F)	527	(981)	537	(999)	572	(1062)	580	(1076)
Exhaust Stack Temperature @ 100% load	°C	(°F)	362	(684)	368	(694)	405	(761)	424	(795)
Exhaust Manifold Temperature, alarm	°C	(°F)	630	(1166)	630	(1166)	630	(1166)	630	(1166)
Exhaust Stack Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	435	(24738)	455	(25876)	488	(27753)	558	(31733)
Jacket Water Circuit	kW	(Btu/min.)	812	(46178)	896	(50955)	979	(55676)	1046	(59486)
Aftercooler	kW	(Btu/min.)	1188	(67607)	1423	(80979)	1285	(73126)	1494	(85019)
Total Heat rejected to Raw Water	kW	(Btu/min.)	2435	(138523)	2774	(157810)	2752	(156555)	3098	(176238)
Exhaust Gas[2]	kW	(Btu/min.)	3068	(174591)	3347	(190468)	4111	(233945)	4157	(236563)
Radiation	kw	(Btu/min.)	116	(6601)	119	(6772)	127	(7227)	136	(7739)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	61.2	(16.2)	68.8	(18.1)	72	(19)	78.5	(20.7)
Flow Rate, return	Lpm	(gpm)	38.9	(10.3)	43.7	(11.5)	46	(12.2)	49.7	(13.1)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	192.6	(.317)	198.8	(.327)	200.4	(.329)	198.9	(.327)
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	1060	(280)	1060	(280)	1060	(280)	1060	(280)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)	0.486	(0.0008)

TECHNICAL DATA

Engine: 3616 Vee
Rating: MCR
Fuel: MDO

	Units		Engine Speed Ratings 750		800		900		1000	
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	90	(194)	90	(194)	90	(194)	90	(194)
Inlet Temperature, maximum	°C	(°F)	95	(203)	95	(203)	95	(203)	95	(203)
Inlet Temperature, minimum	°C	(°F)	83	(181)	83	(181)	83	(181)	83	(181)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(618)	2630	(695)	2920	(771)
Pump Inlet Pressure, minimum[3]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	194	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[4]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[4]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[4]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Separate circuit

[4]Measured at starter inlet

[5]All 3616 engines come equipped with a High Performance Aftercooler (HPAC) to reduce the air inlet manifold temperature.

TECHNICAL DATA

Engine: 3606 In-Line
Rating: CSR
Fuel: HEAVY

	Units		750		825		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	1350	(1810)	1355	(1820)	1570	(2110)	1680	(2260)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	1949	(283)	1778	(258)	1889	(274)	1819	(264)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-5-3-6-2-4				1-5-3-6-2-4			
Firing Order - CW			1-4-2-6-3-5				1-4-2-6-3-5			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	150	(5298)	164	(5792)	202	(7135)	214	(7558)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	175	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	263	(38)	265	(38)	250	(36)	241	(35)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	288	(10172)	303	(10702)	373	(13174)	403	(14234)
Exhaust Stack Temperature @ 100% load	°C	(°F)	320	(608)	297	(567)	299	(570)	308	(586)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	158	(8993)	163	(9277)	177	(10074)	194	(11042)
Jacket Water Circuit	kW	(Btu/min.)	318	(18099)	337	(19180)	330	(18782)	387	(22026)
Aftercooler	kW	(Btu/min.)	430	(24474)	478	(27205)	530	(30165)	571	(32500)
Total Heat rejected to Raw Water	kW	(Btu/min.)	906	(51566)	978	(55662)	1037	(59021)	1152	(65568)
Exhaust Gas[2]	kW	(Btu/min.)	922	(52468)	889	(50590)	1112	(63281)	1250	(71134)
Radiation	kW	(Btu/min.)	63	(3585)	63	(3585)	68	(3870)	71	(4040)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	15.2	(4.0)	15.5	(4.1)	18	(4.8)	19.4	(5.1)
Flow Rate, return	Lpm	(gpm)	10.2	(2.7)	10.4	(2.8)	12.1	(3.2)	12.9	(3.4)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	202	(.332)	204	(.336)	203	(.334)	208	(.342)
Unit Injector Tip Cooling System[3]	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. Before Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Coolant Temp. After Engine, nominal	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Heat rejection/Unit injector	Lpm	(gpm)	36	(9.5)	36	(9.5)	36	(9.5)	36	(9.5)
Coolant Flow (SAE 10W oil)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Coolant Pressure Low, alarm										

TECHNICAL DATA

Engine: 3606 In-Line
Rating: CSR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	697	(184)	697	(184)	697	(184)	697	(184)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.5	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nomina[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel. A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used. The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

TECHNICAL DATA

Engine: 3606 In-Line
Rating: MCR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
General Data										
Engine Output¹	bkW	(bhp)	1485	(1995)	1490	(2000)	1730	(2320)	1850	(2485)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2144	(311)	1955	(282)	2081	(302)	2003	(290)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-5-3-6-2-4				1-5-3-6-2-4			
Firing Order - CW			1-4-2-6-3-5				1-4-2-6-3-5			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	159	(5616)	172	(6075)	213	(7523)	229	(8088)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	175	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	290	(42)	284	(41)	273	(40)	266	(39)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	307	(10843)	320	(11302)	399	(14093)	433	(15294)
Exhaust Stack Temperature @ 100% load	°C	(°F)	320	(608)	302	(576)	306	(583)	313	(595)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	171	(9732)	176	(10017)	194	(11042)	212	(12066)
Jacket Water Circuit	kW	(Btu/min.)	335	(19067)	347	(19750)	355	(20205)	385	(21912)
Aftercooler	kW	(Btu/min.)	477	(27149)	526	(29937)	592	(33694)	653	(37166)
Total Heat rejected to Raw Water	kW	(Btu/min.)	983	(55948)	1049	(59704)	1141	(64941)	1250	(71144)
Exhaust Gas²	kW	(Btu/min.)	977	(55598)	935	(53208)	1188	(67606)	1377	(78361)
Radiation	kW	(Btu/min.)	67	(3813)	67	(3813)	73	(4154)	74	(4211)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	16.5	(4.4)	17	(4.5)	20	(5.3)	22	(5.8)
Flow Rate, return	Lpm	(gpm)	11.0	(2.9)	11.4	(3)	13.5	(3.6)	15	(4.0)
BSFC (with pumps)¹	g/kW-hr	(lb/hp-hr)	199	(.327)	200	(.329)	201	(.330)	207	(.340)
Unit Injector Tip Cooling System³										
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	36	(9.5)	36	(9.5)	36	(9.5)	36	(9.5)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3606 In-Line
Rating: MCR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	697	(184)	697	(184)	697	(184)	697	(184)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.5	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel. A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used. The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

TECHNICAL DATA

Engine: 3608 In-Line
Rating: CSR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	1800	(2415)	1800	(2415)	2090	(2805)	2110	(2830)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	1949	(283)	1772	(257)	1886	(273)	1713	(264)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-6-2-5-8-3-7-4				1-6-2-5-8-3-7-4			
Firing Order - CW			1-4-7-3-8-5-2-6				1-4-7-3-8-5-2-6			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	197	(6958)	205	(7241)	244	(8619)	255	(9007)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	175	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	261	(37.8)	243	(35)	240	(34.8)	246	(35.7)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	380	(13422)	387	(13669)	467	(16495)	489	(17272)
Exhaust Stack Temperature @ 100% load	°C	(°F)	322	(612)	310	(590)	318	(604)	319	(606)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	207	(11781)	213	(12123)	236	(13432)	245	(13944)
Jacket Water Circuit	kW	(Btu/min.)	447	(25441)	485	(27604)	527	(29994)	563	(32043)
Aftercooler	kW	(Btu/min.)	525	(29880)	567	(32271)	641	(36483)	701	(39898)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1179	(67102)	1265	(71998)	1404	(79909)	1509	(85885)
Exhaust Gas[2]	kW	(Btu/min.)	1206	(68630)	1184	(67378)	1496	(85133)	1569	(89287)
Radiation	kW	(Btu/min.)	72	(4097)	72	(4097)	77	(4382)	78	(4439)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	20	(5.3)	21	(5.5)	24	(6.3)	25	(6.6)
Flow Rate, return	Lpm	(gpm)	13.4	(3.5)	14.3	(3.8)	16	(4.2)	16.8	(4.4)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	199	(.327)	202	(.332)	204	(.336)	210	(.345)
Unit Injector Tip Cooling System[3]										
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	48	(12.7)	48	(12.7)	48	(12.7)	48	(12.7)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3608 In-Line
Rating: CSR
Fuel: HEAVY

	Units		Engine Speed Ratings							
			750		825		900		1000	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	760	(200)	760	(200)	760	(200)	760	(200)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.5	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel. A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used. The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

TECHNICAL DATA

Engine: 3608 In-Line
Rating: MCR
Fuel: HEAVY

	Units		750		825		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	1980	(2660)	1980	(2660)	2300	(3090)	2320	(3115)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2144	(311)	1949	(283)	2075	(301)	1884	(273)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-6-2-5-8-3-7-4				1-6-2-5-8-3-7-4			
Firing Order - CW			1-4-7-3-8-5-2-6				1-4-7-3-8-5-2-6			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	209	(7382)	217	(7664)	257	(9077)	266	(9395)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	175	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	286	(41.5)	268	(38.9)	261	(37.8)	264	(38.3)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	408	(14410)	417	(14728)	500	(17660)	519	(18331)
Exhaust Stack Temperature @ 100% load	°C	(°F)	328	(622)	319	(606)	327	(621)	330	(626)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	228	(12977)	234	(13318)	258	(14684)	267	(15196)
Jacket Water Circuit	kW	(Btu/min.)	470	(26750)	497	(27262)	541	(30791)	618	(35174)
Aftercooler	kW	(Btu/min.)	606	(34491)	649	(36938)	721	(41036)	740	(42117)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1304	(74218)	1380	(77518)	1520	(86511)	1625	(92487)
Exhaust Gas[2]	kW	(Btu/min.)	1301	(74036)	1295	(73695)	1647	(93726)	1708	(97197)
Radiation	kW	(Btu/min.)	74	(4211)	74	(4211)	81	(4609)	81	(4609)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	22	(5.8)	22	(5.8)	26	(6.9)	27	(7.1)
Flow Rate, return	Lpm	(gpm)	14.7	(3.9)	14.6	(3.8)	17.4	(4.6)	18	(4.7)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	198	(.326)	201	(.331)	203	(.334)	208	(.342)
Unit Injector Tip Cooling System[3]										
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	48	(12.7)	48	(12.7)	48	(12.7)	48	(12.7)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3608 In-Line
Rating: MCR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	760	(200)	760	(200)	760	(200)	760	(200)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.5	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	1095	(289)	1168	(308.5)	1315	(347)	1460	(386)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	295	(42.1)
Pump capacity	Lpm	(gpm)	900	(238)	960	(254)	1080	(285)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel. A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used. The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

TECHNICAL DATA

Engine: 3608 In-Line
Rating: CSR & MCR**
Fuel: HEAVY

	Units		Engine Speed Ratings 1000 (CSR)		1000 (MCR)	
General Data						
Engine Output[1]	bkW	(bhp)	2240	(3005)	2460	(3300)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	20	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)
Compression Ratio				12.4:1	12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	1819	(264)	1998	(290)
Mean Piston Speed	m/s	(f/s)	10.0	(32.8)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300	
Firing Order - CCW			1-6-2-5-8-3-7-4			
Firing Order - CW			1-4-7-3-8-5-2-6			
Combustion Air System						
Flow of air @ 100% load	cmm	(cfm)	246	(8689)	259	(9148)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	248	(36)	271	(39.3)
Exhaust Gas System						
Exhaust Gas Flow @ 100% load	cmm	(cfm)	494	(17448)	533	(18826)
Exhaust Stack Temperature @ 100% load	°C	(°F)	347	(657)	361	(682)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)
Exhaust System Backressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load						
Lube Oil Cooler	kW	(Btu/min.)	258	(14684)	280	(15936)
Jacket Water Circuit	kW	(Btu/min.)	647	(36824)	632	(35970)
Aftercooler	kW	(Btu/min.)	658	(37450)	738	(42003)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1563	(88958)	1650	(93909)
Exhaust Gas[2]	kW	(Btu/min.)	1654	(94124)	1798	(102319)
Radiation	kW	(Btu/min.)	80	(4553)	85	(4837)
Fuel System						
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	26	(6.9)	28	(7.4)
Flow Rate, return	Lpm	(gpm)	17.4	(4.6)	18.7	(4.9)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	208	(.342)	205	(.337)
Unit Injector Tip Cooling System[3]						
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	48	(12.7)	48	(12.7)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3608 In-Line
Rating: CSR & MCR**
Fuel: HEAVY

	Units		Engine Speed Ratings 1000 (CSR)		1000 (MCR)	
Lubricating Oil System						
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	760	(200)	760	(200)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.55	(0.0009)	0.55	(0.0009)
Cooling Water System - Block Cooling						
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	295	(42.1)	295	(42.1)
Pump capacity	Lpm	(gpm)	1460	(386)	1460	(386)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling						
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	295	(42.1)	295	(42.1)
Pump capacity	Lpm	(gpm)	1200	(317)	1200	(317)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)
Starting Air System						
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values have been corrected to an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel.
A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used.
The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

****Always requires CP propeller. See guide section on Engine Performance.**

TECHNICAL DATA

Engine: 3612 Vee
Rating: CSR
Fuel: HEAVY

	Units		750		825		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	2700	(3625)	2710	(3640)	3140	(4215)	3360	(4510)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	1949	(283)	17778	(258)	1889	(274)	1819	(264)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-12-9-4-5-8-2-3-4-10-7-6				1-12-9-4-5-8-11-2-3-10-7-6			
Firing Order - CW			1-6-7-10-3-2-11-8-5-4-9-12				1-6-7-10-3-2-11-8-5-4-9-12			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	299	(10560)	329	(11620)	403	(14234)	429	(15152)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	175	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	263	(38)	265	(38.4)	250	(36)	250	(36)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	575	(20309)	606	(21404)	745	(26313)	794	(28045)
Exhaust Stack Temperature @ 100% load	°C	(°F)	320	(608)	297	(567)	299	(570)	299	(570)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	315	(17428)	326	(18554)	355	(20205)	388	(22083)
Jacket Water Circuit	kW	(Btu/min.)	636	(36198)	674	(38361)	659	(37507)	773	(43995)
Aftercooler	kW	(Btu/min.)	709	(S40353)	788	(44849)	874	(49744)	943	(53671)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1660	(94479)	1788	(101764)	1888	(107456)	2104	(119749)
Exhaust Gas[2]	kW	(Btu/min.)	2001	(113871)	1951	(111026)	2415	(137431)	2742	(156039)
Radiation	kW	(Btu/min.)	88	(5008)	88	(5008)	94	(5349)	99	(5634)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	30.5	(8.1)	31	(7.8)	35.5	(9.4)	39	(10.3)
Flow Rate, return	Lpm	(gpm)	20.4	(5.4)	21	(5.3)	23.7	(6.3)	26	(6.9)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	201	(.330)	203	(.334)	202	(.332)	208	(.342)
Unit Injector Tip Cooling System[3]										
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	72	(19)	72	(19)	72	(19)	72	(19)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3612 Vee
Rating: CSR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	910	(240)	910	(240)	910	(240)	910	(240)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.5	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	290	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(6`8)	2630	(695)	2920	(711)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	104	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel.
A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used.
The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

TECHNICAL DATA

Engine: 3612 Vee
Rating: MCR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	2970	(3985)	2980	(4000)	3460	(4645)	3700	(4965)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2144	(311)	1955	(284)	2081	(302)	2003	(290)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-12-9-4-5-8-11-2-3-4-10-7-6				1-12-9-4-5-8-11-2-3-10-7-6			
Firing Order - CW			1-6-7-10-3-2-11-8-5-4-9-12				1-6-7-10-3-2-11-8-5-4-9-12			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	320	(11302)	343	(12115)	426	(15046)	457	(16141)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)	75	(167)	175	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	289	(42)	284	(41)	273	(40)	273	(40)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	614	(21686)	640	(22605)	798	(28185)	857	(30270)
Exhaust Stack Temperature @ 100% load	°C	(°F)	320	(608)	302	(576)	306	(582)	306	(583)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	341	(19408)	352	(20034)	387	(22076)	424	(24132)
Jacket Water Circuit	kW	(Btu/min.)	670	(38133)	695	(39556)	711	(40467)	770	(43825)
Aftercooler	kW	(Btu/min.)	849	(48321)	936	(53273)	1054	(59987)	1162	(66135)
Total Heat rejected to Raw Water	kW	(Btu/min.)	1860	(105862)	1983	(112863)	2152	(122480)	2356	(134092)
Exhaust Gas[2]	kW	(Btu/min.)	2066	(117570)	1992	(113359)	2509	(142780)	2941	(167364)
Radiation	kW	(Btu/min.)	92	(5235)	92	(5235)	102	(5805)	104	(5918)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	33	(8.7)	33	(8.7)	39	(10.3)	43	(11.4)
Flow Rate, return	Lpm	(gpm)	22	(5.8)	22	(5.8)	26	(6.9)	28.8	(7.6)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	198	(.326)	199	(.327)	200	(.329)	207	(.340)
Unit Injector Tip Cooling System[3]										
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	72	(19)	72	(19)	72	(19)	72	(19)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3612 Vee
Rating: MCR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	910	(240)	910	(240)	910	(240)	910	(240)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.55	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	290	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(6`8)	2630	(695)	2920	(711)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	194	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel.
A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used.
The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

TECHNICAL DATA

Engine: 3616 Vee
Rating: CSR
Fuel: HEAVY

	Units		750		825		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	3600	(4830)	3600	(4830)	4180	(5610)	4220	(5665)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	1949	(283)	1772	(257)	1886	(273)	1713	(248)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8				1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8			
Firing Order - CW			1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2				1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2			
Combustion Air System										
Flow of air	cmm	(cfm)	411.5	(14532)	429.3	(15161)	511.0	(18046)	534.1	(18862)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	61	(142)	61	(142)	61	(142)	61	(142)
Intake Manifold Pressure @ 100% load	kPa	(psi)	248	(36.0)	231	(33.5)	223	(32.3)	234	(33.9)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	812.0	(28676)	829.9	(29308)	1001.5	(35368)	1048.6	(37031)
Exhaust Stack Temperature @ 100% load	°C	(°F)	316	(601)	304	(579)	312	(594)	313	(595)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	415	(23620)	426	(24246)	472	(26864)	491	(27945)
Jacket Water Circuit	kW	(Btu/min.)	895	(50939)	970	(55208)	1054	(59989)	1125	(64030)
Aftercooler	kW	(Btu/min.)	1069	(60834)	1194	(67947)	1358	(77280)	1480	(84221)
Total Heat rejected to Raw Water	kW	(Btu/min.)	2379	(135393)	2590	(147401)	2884	(164133)	3096	(176196)
Exhaust Gas[2]	kW	(Btu/min.)	2262	(128724)	2308	(131342)	2584	(147048)	2890	(164462)
Radiation	kW	(Btu/min.)	101	(5748)	101	(5748)	113	(6431)	114	(6487)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	40	(10.6)	41	(10.8)	47.5	(12.5)	49	(12.9)
Flow Rate, return	Lpm	(gpm)	26.8	(7.1)	27.6	(7.3)	31.8	(8.4)	32.7	(8.6)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	195.0	(.321)	201.0	(.330)	196.5	(.323)	205.8	(.338)
Unit Injector Tip Cooling System[3]										
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	96	(25.4)	96	(25.4)	96	(25.4)	96	(25.4)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3616 Vee
Rating: CSR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	1060	(280)	1060	(280)	1060	(280)	1060	(280)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.55	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	290	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(6`8)	2630	(695)	2920	(711)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	194	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel.
A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used.
The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

[6]All 3616 engines come equipped with a High Performance Aftercooler (HPAC) to reduce the air inlet manifold temperature.

TECHNICAL DATA

Engine: 3616 Vee
Rating: MCR
Fuel: HEAVY

	Units		Engine Speed Ratings 750		825		900		1000	
General Data										
Engine Output[1]	bkW	(bhp)	3960	(5315)	3960	(5315)	4600	(6175)	4640	(6230)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	300	(11.8)	300	(11.8)	300	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)	18.5	(1127)	18.5	(1127)
Compression Ratio			12.4:1		12.4:1		12.4:1		12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	2144	(311)	1949	(283)	2076	(301)	1884	(273)
Mean Piston Speed	m/s	(f/s)	7.5	(24.6)	8.25	(27.1)	9.0	(29.5)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350		350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300		300		300	
Firing Order - CCW			1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8				1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8			
Firing Order - CW			1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2				1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2			
Combustion Air System										
Flow of air @ 100% load	cmm	(cfm)	437.7	(15457)	454.5	(16051)	538.2	(19006)	556.0	(19635)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	61	(142)	61	(142)	61	(142)	61	(142)
Intake Manifold Pressure @ 100% load	kPa	(psi)	272	(39.5)	255	(37.0)	243	(35.2)	251	(36.4)
Exhaust Gas System										
Exhaust Gas Flow @ 100% load	cmm	(cfm)	872.5	(30812)	892.3	(31511)	1071.1	(37826)	1112.1	(39273)
Exhaust Stack Temperature @ 100% load	°C	(°F)	322	(612)	313	(595)	321	(610)	324	(615)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load										
Lube Oil Cooler	kW	(Btu/min.)	457	(26010)	467	(26580)	515	(29311)	534	(30393)
Jacket Water Circuit	kW	(Btu/min.)	941	(53557)	993	(56517)	1083	(63639)	1235	(70290)
Aftercooler	kW	(Btu/min.)	1260	(71703)	1370	(77963)	1430	(81377)	1540	(87637)
Total Heat rejected to Raw Water	kW	(Btu/min.)	2658	(151270)	2830	(161060)	3028	(174327)	3309	(188320)
Exhaust Gas[2]	kW	(Btu/min.)	2454	(139650)	2513	(143008)	2993	(170323)	3173	(180566)
Radiation	kW	(Btu/min.)	109	(6203)	109	(6203)	120	(6829)	121	(6886)
Fuel System										
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	44	(11.6)	44	(11.6)	52	(13.7)	54	(14.2)
Flow Rate, return	Lpm	(gpm)	29.5	(7.8)	29.3	(7.7)	34.8	(9.2)	36.2	(9.6)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	195.1	(.321)	200.0	(.329)	196.5	(.323)	203.9	(.335)
Unit Injector Tip Cooling System[3]										
Coolant Temp. Before Engine, nominal	°C	(°F)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. After Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)	56-71	(133-160)
Heat rejection/Unit injector	kW	(Btu/min.)	1.0	(57)	1.0	(57)	1.0	(57)	1.0	(57)
Coolant Flow (SAE 10W oil)	Lpm	(gpm)	96	(25.4)	96	(25.4)	96	(25.4)	96	(25.4)
Coolant Pressure Low, alarm	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)

TECHNICAL DATA

Engine: 3616 Vee
Rating: MCR
Fuel: HEAVY

			Engine Speed Ratings							
	Units		**750**		**825**		**900**		**1000**	
Lubricating Oil System										
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)	85	(1985)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	1060	(280)	1060	(280)	1060	(280)	1060	(280)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.45	(0.0007)	0.50	(0.0008)	0.50	(0.0008)	0.55	(0.0009)
Cooling Water System - Block Cooling										
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	170	(24.3)	190	(27.1)	240	(34.3)	290	(41.4)
Pump capacity	Lpm	(gpm)	2190	(579)	2338	(6`8)	2630	(695)	2920	(711)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling										
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	170	(24.3)	194	(27.7)	245	(35)	305	(43.6)
Pump capacity	Lpm	(gpm)	1300	(343)	1387	(366)	1560	(412)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)	-5	(-1.48)
Starting Air System										
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values are based on an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is required with heavy fuel. A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used. The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

[6]All 3616 engines come equipped with a High Performance Aftercooler (HPAC) to reduce the air inlet manifold temperature.

TECHNICAL DATA

Engine: 3616 Vee
Rating: CSR & MCR**
Fuel: HEAVY

	Units		Engine Speed Ratings 1000 (CSR)		1000 (MCR)	
General Data						
Engine Output[1]	bkW	(bhp)	4480	(6015)	4920	(6600)
Cylinder Bore	mm	(in)	280	(11.0)	280	(11.0)
Stroke	mm	(in)	300	(11.8)	20	(11.8)
Displacement/Cylinder	L	(in^3)	18.5	(1127)	18.5	(1127)
Compression Ratio				12.4:1	12.4:1	
Firing Pressure, maximum	kPa	(psi)	16200	(2350)	16200	(2350)
BMEP	kPa	(psi)	1819	(264)	1998	(290)
Mean Piston Speed	m/s	(f/s)	10.0	(32.8)	10.0	(32.8)
Idle Speed	rpm	rpm	350		350	
Crash Reversal Speed, minimum	rpm	rpm	300		300	
Firing Order - CCW		1-2-5-6-3-4-9-10-15-16-11-12-13-14-7-8				
Firing Order - CW		1-8-7-14-13-12-11-16-15-10-9-4-3-6-5-2				
Combustion Air System						
Flow of air @ 100% load	cmm	(cfm)	514.2	(18159)	541.4	(19119)
Air Temperature @ Air Cleaner, maximum	°C	(°F)	45	(113)	45	(113)
Air Temperature after Aftercooler, alarm	°C	(°F)	75	(167)	75	(167)
Intake Manifold Pressure @ 100% load	kPa	(psi)	236	(34.2)	257	(37.3)
Exhaust Gas System						
Exhaust Gas Flow @ 100% load	cmm	(cfm)	1057.8	(37356)	1139.1	(40227)
Exhaust Stack Temperature @ 100% load	°C	(°F)	341	(646)	355	(671)
Exhaust Manifold Temperature, alarm	°C	(°F)	550	(1022)	550	(1022)
Exhaust Stack Temperature, alarm	°C	(°F)	450	(842)	450	(842)
Exhaust System Backpressure, maximum	kPa	(in H_2O)	2.5	(10)	2.5	(10)
Heat Balance @ 100% Load						
Lube Oil Cooler	kW	(Btu/min.)	517	(29425)	559	(31816)
Jacket Water Circuit	kW	(Btu/min.)	1293	(73591)	1264	(71941)
Aftercooler	kW	(Btu/min.)	1387	(78930)	1460	(83084)
Total Heat rejected to Raw Water	kW	(Btu/min.)	3197	(181946)	3283	(186841)
Exhaust Gas[2]	kW	(Btu/min.)	2785	(158486)	3336	(189842)
Radiation	kW	(Btu/min.)	116	(6601)	125	(7113)
Fuel System						
Pump Suction Restriction, maximum	kPa	(psi)	-39	(-5.7)	-39	(-5.7)
Return Line Backpressure, maximum	kPa	(psi)	350	(51)	350	(51)
Manifold Pressure @ 100% load	kPa	(psi)	430-676	(62.4-98)	430-676	(62.4-98)
Flow Rate, supply	Lpm	(gpm)	52	(13.7)	56	(14.8)
Flow Rate, return	Lpm	(gpm)	34.8	(9.2)	37.4	(9.9)
BSFC (with pumps)[1]	g/kW-hr	(lb/hp-hr)	198.7	(.327)	199.5	(.328)
Unit Injector Tip Cooling System[3]	°C	(°F)	50-65	(122-149)	50-65	(122-149)
Coolant Temp. Before Engine, nominal	°C	(°F)	56-71	(133-160)	56-71	(133-160)
Coolant Temp. After Engine, nominal	kW	(Btu/min.)	1.0	(57)	1.0	(57)
Heat rejection/Unit injector	Lpm	(gpm)	96	(25.4)	96	(25.4)
Coolant Flow (SAE 10W oil)	kPa	(psi)	260	(38)	260	(38)
Coolant Pressure Low, alarm						

TECHNICAL DATA

Engine: 3616 Vee
Rating: CSR & MCR**
Fuel: HEAVY

	Units		Engine Speed Ratings 1000 (CSR)		1000 (MCR)	
Lubricating Oil System						
Manifold Pressure, minimum	kPa	(psi)	380	(55)	380	(55)
Manifold Pressure, alarm (650-1000 rpm)	kPa	(psi)	320	(46)	320	(46)
Manifold Pressure, alarm (0-650 rpm)	kPa	(psi)	120	(17)	120	(17)
Manifold Pressure, stop (650-1000 rpm)	kPa	(psi)	260	(38)	260	(38)
Manifold Pressure, stop (0-650 rpm)	kPa	(psi)	105	(15)	105	(15)
Manifold Temperature, alarm	°C	(°F)	92	(198)	92	(198)
Manifold Temperature, stop	°C	(°F)	98	(208)	98	(208)
Manifold Temperature, nominal	°C	(°F)	85	(185)	85	(185)
Prelube Pump Capacity - intermittent	Lpm	(gpm)	76	(20)	76	(20)
Prelube Pump Capacity - continuous	Lpm	(gpm)	23	(6)	23	(6)
Sump Capacity (marine)	L	(gal)	1060	(280)	1060	(280)
BSOC @ 100% load (nominal)	g/kW-hr	(lb/hp-hr)	0.55	(0.0009)	0.55	(0.0009)
Cooling Water System - Block Cooling						
Inlet Temperature, nominal	°C	(°F)	93	(199)	93	(199)
Inlet Temperature, maximum	°C	(°F)	96	(205)	96	(205)
Inlet Temperature, minimum	°C	(°F)	85	(185)	85	(185)
Outlet Temp., before Regulator, maximum	°C	(°F)	99	(210)	99	(210)
Pump Rise (Delta P) @ 90°C (194°)	kPa	(psi)	290	(41.4)	290	(41.4)
Pump capacity	Lpm	(gpm)	2920	(771)	2920	(771)
Pump Inlet Pressure, minimum[4]	kPa	(psi)	30	(4.3)	30	(4.3)
Outlet Temperature, alarm	°C	(°F)	100	(212)	100	(212)
Outlet Temperature, stop	°C	(°F)	104	(219)	104	(219)
Cooling Water System - AC/OC Cooling						
Inlet Temperature, nominal	°C	(°F)	32	(90)	32	(90)
Inlet Temperature, maximum	°C	(°F)	38	(100)	38	(100)
Pump Rise (Delta P) @ 32°C (90°F)	kPa	(psi)	305	(43.6)	305	(43.6)
Pump capacity	Lpm	(gpm)	1730	(457)	1730	(457)
Pump Inlet Pressure, minimum	kPa	(in-Hg)	-5	(-1.48)	-5	(-1.48)
Starting Air System						
Air Pressure, nominal[5]	kPa	(psi)	1225	(175)	1225	(175)
Air Pressure, minimum[5]	kPa	(psi)	620	(90)	620	(90)
Air Pressure, maximum[5]	kPa	(psi)	1575	(225)	1575	(225)
Low Air Pressure, alarm	kPa	(psi)	850	(125)	850	(125)

[1]Performance based on SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in-Hg) and 25°C (77°F). BSFC values are shown with a Caterpillar tolerance of ±6 g/kW-hr (.010 lbs/hp-hr). For an ISO fuel consumption, subtract 4 g/kW-hr (.007 lbs/hp-hr) from the values shown. This takes into account the ±5% tolerance allowed by ISO. BSFC values have been corrected to an LHV of 42780 kJ/kg (18390 Btu/lb.)

[2]Exhaust heat rejection is based on fuel LHV although TMI values are based on fuel HHV. The fuel HHV includes the latent heat of vaporization of water in the exhaust gas which is not recoverable in diesel engine applications.

[3]Injector tip cooling is not required with MDO fuel. A separate external injector tip cooling module is required when heavy fuels above 40 cSt @ 50°C (122°F) are used. The coolant flow is based upon a separate circuit system.

[4]Separate circuit

[5]Measured at starter inlet

[6]All 3616 engines come equipped with a High Performance (HPAC) to reduce the air inlet manifold temperature.

****Always requires CP propeller. See guide section on Engine Performance.**

Noise

Sound Waves — Behavior and Measurement

As sound waves radiate their strength diminishes. As distance traveled doubles, the wave amplitude is reduced by one-half. This rule applies if the first measuring point is at least two or three times the largest dimension of the noise source, usually about three feet.

Distance	Sound Strength
X	100%
2X	50%
4X	25%

Sound waves impinging on a microphone produce voltages proportional to sound pressures. The signals measure amplitude or strength of the *sound pressure* waves. Amplitude and frequency are the only sound properties measurable using ordinary techniques.

The extensive audible range of sound complicates noise ratings. The human ear hears pressure levels 100,000 times stronger than the lowest detectable level without damage. Noise measuring instruments have extraordinary range and are scaled in decibels (dB).

Sound Terms

Sound strength, or sound pressure level (SPL), is rated in the logarithmic decibel scale. The scale allows rating over the entire sound pressure range of interest with two to three digit numbers (e.g., 90 dB or 100 dB). For illustration, 80 dB is a sound pressure of only 0.00003 psi as shown in Figure 38.

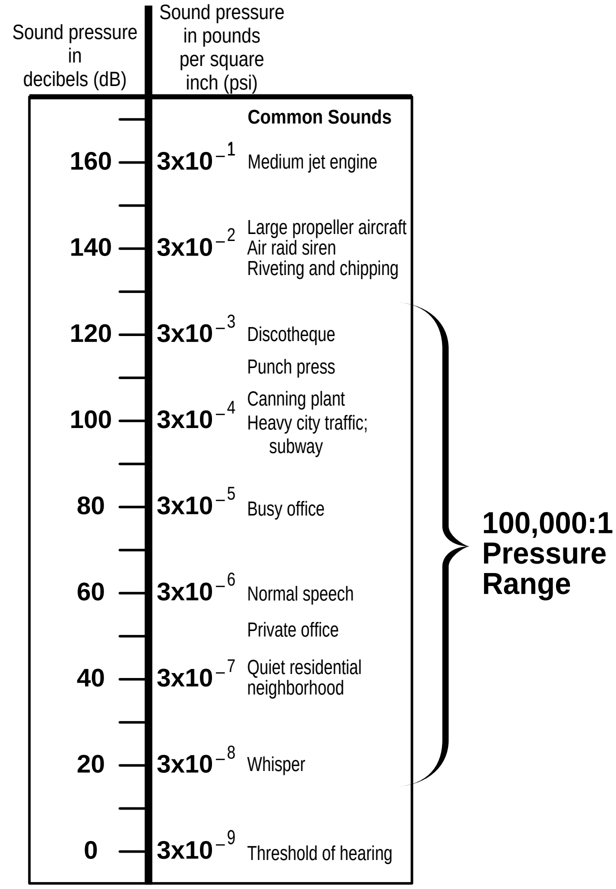


Figure 1

The system provides a meaningful human reference as the average ear first detects noise at 0 dB.

Humans can comfortably tolerate sound levels of 80 dB (10,000 times the sound pressure at 0 dB). Between 80 dB and 90 dB they show some intolerance to the noise, and above 90 dB the level becomes intense.

Sound pressure levels of common exposures to noise are shown in Figure 1.

Because of the logarithmic nature, differences in two decibel ratings indicate the wave strength ratio between the two measured levels. The following relations are noted from the scale.

Difference In Two Signal Levels In Decibels	Pressure Level Ratio
1	1.12 to 1
3	1.41 to 1
6	2.00 to 1
10	3.1 to 1
12*	4.00 to 1
20	10.00 to 1
40	100.00 to 1

*See example in Figure 2.

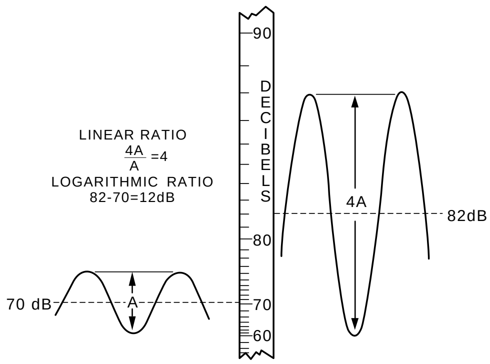


Figure 2

Loudness

The human ear does not use sound pressure decibels to judge loudness. Rating noise loudness is a complex operation because human hearing is also frequency sensitive.

Sounds with frequencies in the 5,000-10,000 Hz range are the easiest to hear; sounds with very low frequencies are the hardest. Hearing loss from exposure to noise is similarly frequency sensitive.

An example of the frequency selectivity of the human ear is shown in Figure 3.

It considers three single-frequency sounds at 50 Hz, 500 Hz, and 5000 Hz. When their strength is adjusted until they sound equally loud, the 50 Hz sound must be 19 dB stronger than the 5000 Hz sound and 8 dB stronger than the 500 Hz sound.

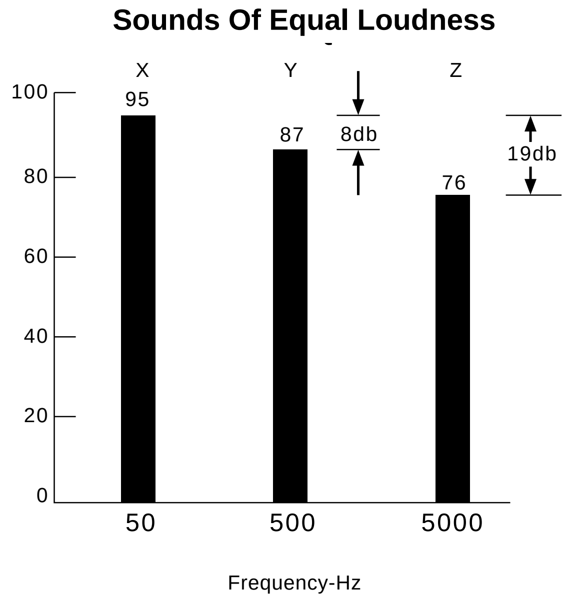


Figure 3

A-Weighted, dB(A) Measurements

Loudness can be measured by filtering the microphone signal to reduce the strength of the low frequency signals and give more weight to frequencies in the 5,000-10,000 Hz range. (These are the frequencies to which the ear is most sensitive). This is done with a standardized (international) “A” filter network to make adjustments throughout the frequency range according to Figure 4. The result is a total decibel rating with a correction approximating the ear’s sensitivity. The measurements are A-scale, A-weighted or dB(A) levels.

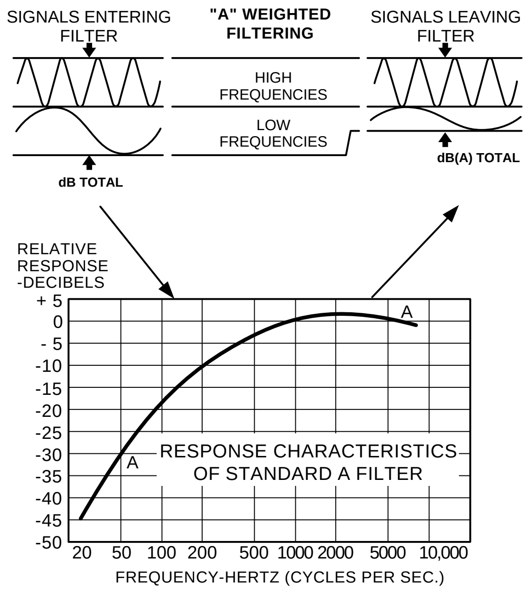


Figure 4

The previously discussed equal loudness sounds have the following dB and dB(A) ratings:

	Frequency	dB	dB(A)
(X)	50 Hz	95	65
(Y)	500 Hz	87	84
(Z)	5000 Hz	76	76

Note the A-weighted ratings are overcorrected for sound X, while slight or no corrections were made in Y and Z.

Since differences in sound pressure levels are small for noises of practical interest, the dB(A) scale is widely used throughout the world.

Octave Band Levels

More detail is required of the frequency distribution of a noise than provided by a A-weighted measurement. Measurements are made with filters subdividing sounds over the entire audible range into standardized frequency bands, permitting the pressure levels of only the sound within each subdivision to be measured. Each filter spans an octave; that is, the upper frequency limit is twice the lower limit as shown in Figure 5. Sound levels in each octave are measured in decibels and are referred to as octave band levels.

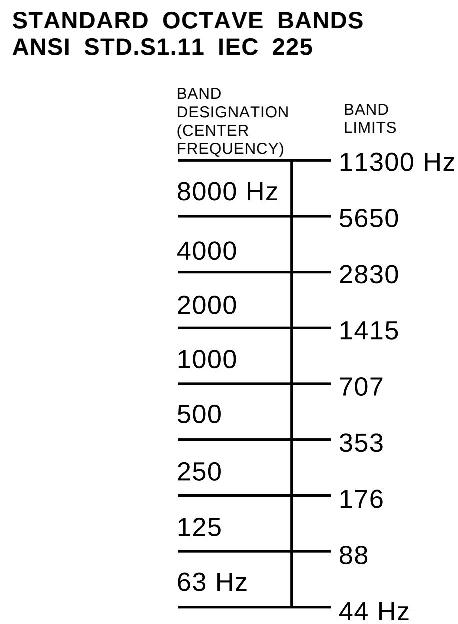


Figure 5

Loudness Calculations

Loudness can be calculated from octave band data by a number of methods. The most popular in the United States was developed by S.S. Stevens at Harvard University and is documented in ANSI Standard S3.4 and in ISO R532, Method A.

The method uses the unit SONE calculated by adjusting each octave band level according to human ear sensitivity in that band and then adding the effect of all of the bands. Once a sones value is obtained, loudness comparisons with other noises can be made linearly.

A noise judged to be twice as loud as another will probably have a sones rating twice that of the other noise.

Sones-Loudness Comparison	
Sones	Loudness Category
Below 30	Very Quiet
30-40	Quiet
40-45	Medium Quiet
45-50	Medium Loud
50-60	Loud
Above 60	Very Loud

Sones and dB(A) are both loudness ratings, and care must be used to convert from one to the other. When one is plotted against the other for actual noises, their relationship is evident. However, the scatter on the plot in Figure 6 is so great that it is not practical to calculate one from the other. If this conversion must be used, errors of ±10% sones or ±1.5 dB(A) must be accepted.

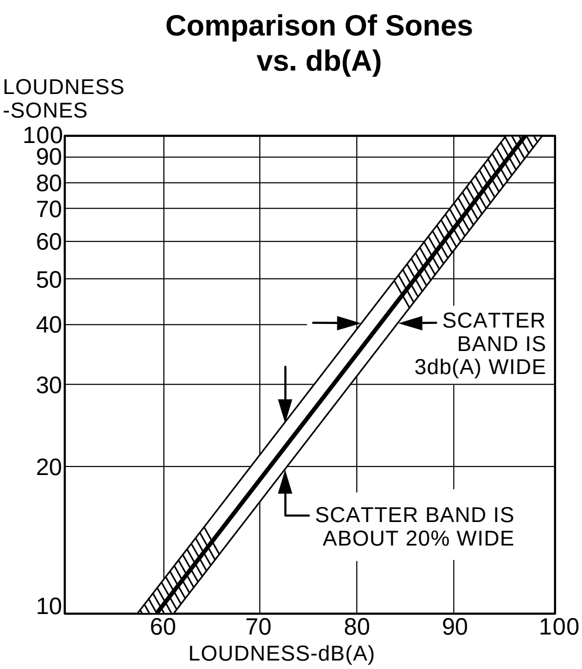


Figure 6

Sound Power

When combining the effect of several noise sources at a given distance from machinery, sound power being radiated is of more concern than sound pressure at that distance. Confusion arises as a decibel scale is also used to rate sound power.

With sound power, 80 dB expresses an acoustic radiation of 0.0003 watts. In this scale, a difference of 3 dB is a ratio of 2:1; 10 dB a ratio of 10:1.

The chart in Figure 7 illustrates differences in decibels and ratios in sound pressure and power. Sound power in decibels is a measure of the total sound radiation from a unit, while sound pressure, also in decibels, is the strength of a sound wave after it travels a specified distance from the unit.

The two decibel scales are related despite the discussed differences. The change in one will produce the same numerical change in the other.

For example: If the sound power of a engine was increased by 10 dB, the sound pressure of that noise at any given point would also increase 10 dB.

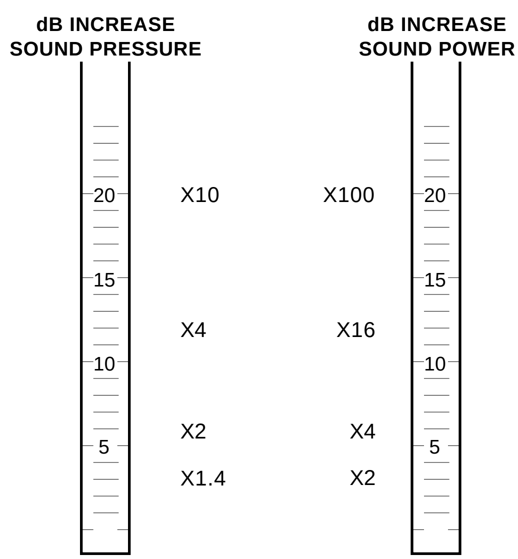


Figure 7

Noise Addition

When standing by an engine, the noise heard from other engines operating in the same area will depend on the spacing of the engines and where the person is in relation to the spacing.

Example: At a point equidistant among four identical engines with one operating at a measured 80 dB(A) at the reference point, what will the measurement be when a second engine is running?

As doubling sound pressure increases the decibel level by 6 dB, a meter will read 83 dB(A) after the second engine is started. The second machine doubles sound power, not sound pressure. Noise addition is made on the basis of sound power.

Starting the second pair of engines would double the sound power again and the level would rise another 3 dB to 86 dB(A). The sound pressure is now twice that of a single engine.

A chart showing the combined effect of up to ten equal sound sources is shown in Figure 8. Note that loudness is changed less than sound pressure as additional units are considered. Two sources are 20% and four sources are 40% louder than a single source when considered in sones.

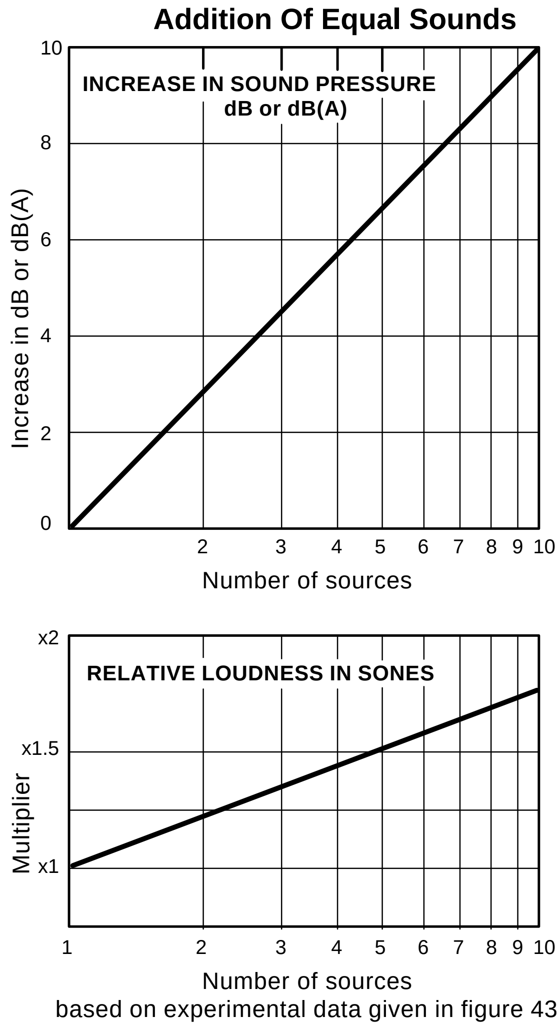


Figure 8

The example selected is easy to visualize. However, it is no more difficult when considering engines with different sound power levels or if the measurement point is not an equal distance from all machines. In such cases, the chart of Figure 9 can be used.

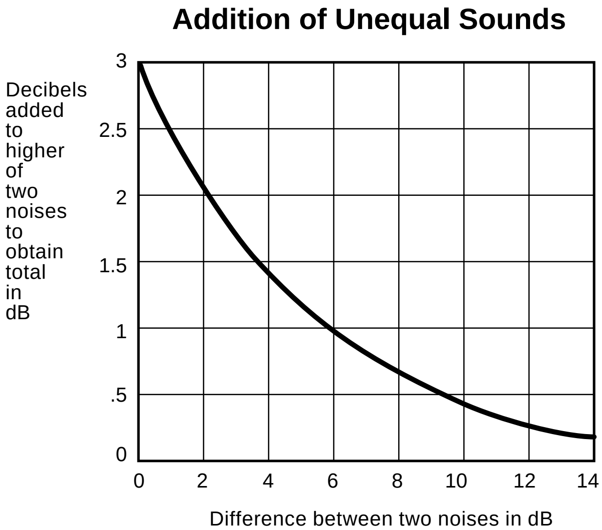


Figure 9

Figure 9 shows the versatility of the decibel system. Although calculations are made on the basis of sound power, the system uses measured or calculated sound pressures. Use the difference in the pressure levels of two sounds to find how their combined level exceeds the higher of the two. First adjust the levels for the distances from the source to the spot where the noises are being added, as explained on page 46. To add a third level, use the same process to combine it with the total of the first two. Figure 9 can be used to check the data in Figure 8.

Noise Exposure

Exposure to excessive noise causes permanent hearing damage and adversely affects working efficiency and comfort. Recognizing this, the U.S. Government created the Occupational Safety and Health Act (OSHA) which established limits for industrial environments.

When an individual's daily noise exposure, designated D(8), is composed of two or more periods of noise at different levels, the combined effect is calculated by: D(8) = (C1/T1) + (C2/T2) + ... + (Cn/Tn). Cn is the duration of exposure at a specified sound level and Tn is the total time of exposure permitted at a specified sound level as shown in Figure 10. The noise exposure is acceptable when equal to or less than 1.

Duration of Daily Exposure Hours	Allowable level dB(A)
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Figure 10

Noise Control

Noise can be either airborne or structureborne transmitted. Structureborne noise is vibration transmitted through a structure, typically that supporting the engine. Noise control methods are different for the two sources.

Mechanical Noise Control

Structureborne noise can be controlled by isolating the engine from the supporting structure using Caterpillar's resilient mounts for propulsion engines and spring isolators for ship set generator engines. See the Mounting section of this guide for details. Airborne noise can be controlled through baffles, sound enclosures, absorption materials, or any combination of the above methods. An approximate guide comparing various isolation methods is illustrated in Figure 11.

Free-field mechanical airborne noise plots for various 3600 Engines and ratings are plotted on pages 51 through 54.

The top curve indicates sound *power* level in dB. The three lower curves are the sound *pressure* levels in *dB* at distances of 1, 7, and 15 meters (arranged top to bottom). The *dB* levels are plotted at octave band center frequencies of 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Below the charts the number in parentheses is the overall *dB(A)* level at the indicated distance. The abbreviation SP stands for Sound Power.

The mechanical noise plots are valid for all power settings at a given engine speed.

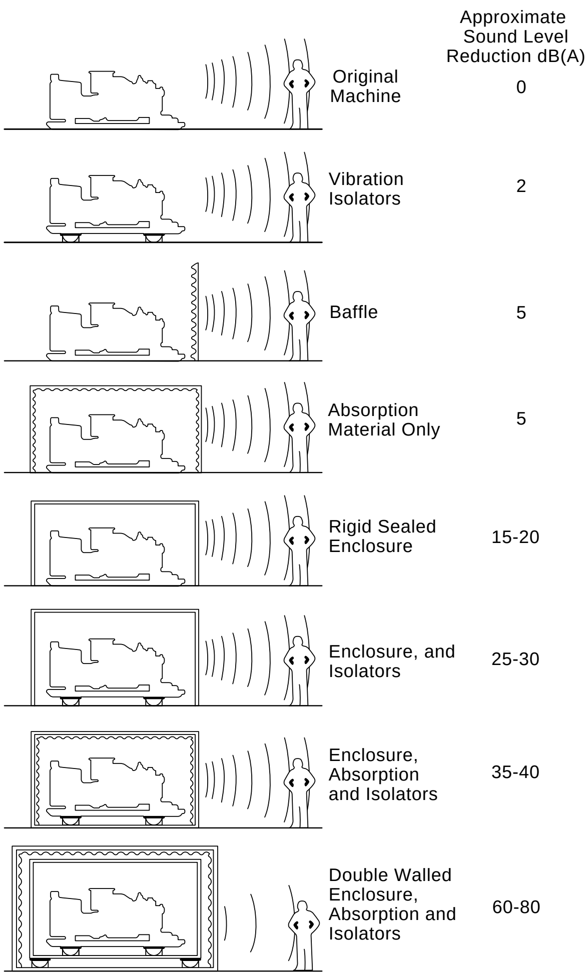
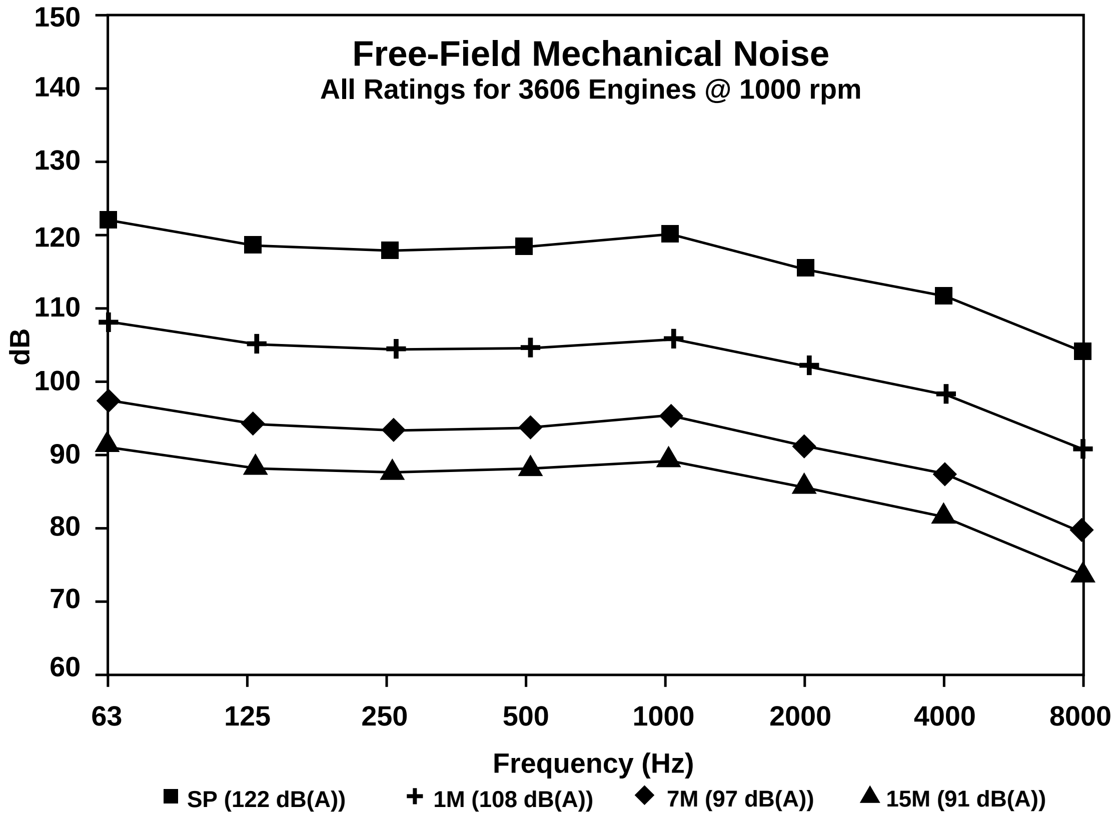


Figure 11

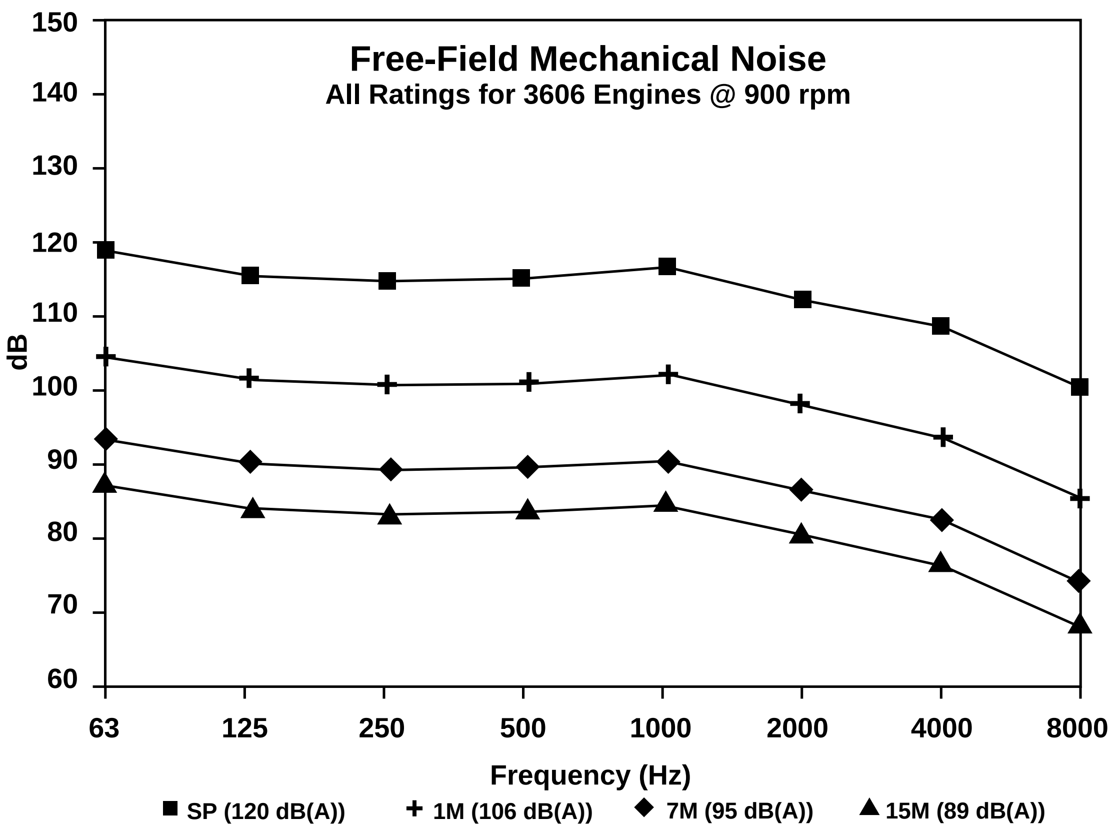
Exhaust Noise Control

Exhaust noise is typically airborne. Exhaust noise attenuation is commonly achieved with a silencer typically capable of reducing exhaust noise 15 dB(A) when measured 3.3 m (10 ft) perpendicular to the exhaust outlet. See guide section on *Exhaust* for exhaust silencer information.

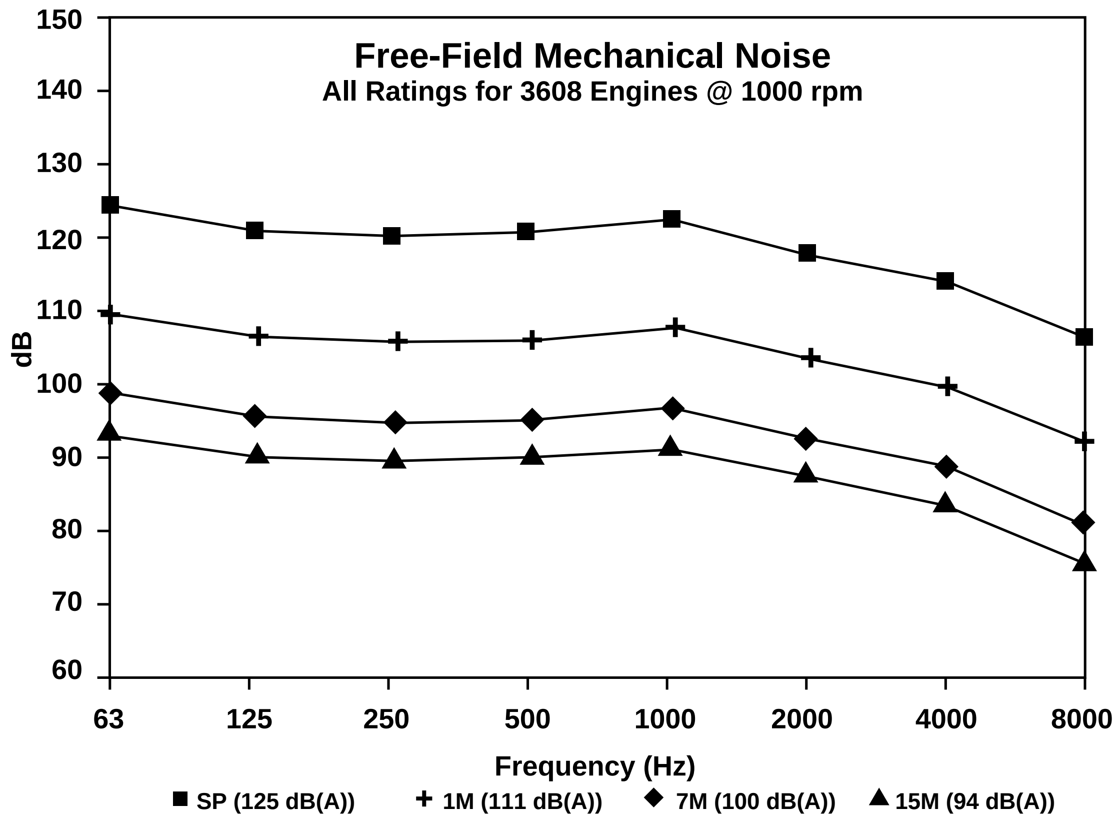
Free-field exhaust noise plots for 3600 Engines with MCR and CSR ratings are shown on pages 55 and 56. The exhaust noise plots are valid only at the indicated power and speed. Only plots for the 3606 are shown with dB(A) modifications for the other engines listed on each 3606 chart. The format is identical to the mechanical noise curves except that sound pressure levels are shown at distances of 1.5, 7, and 15 meters.

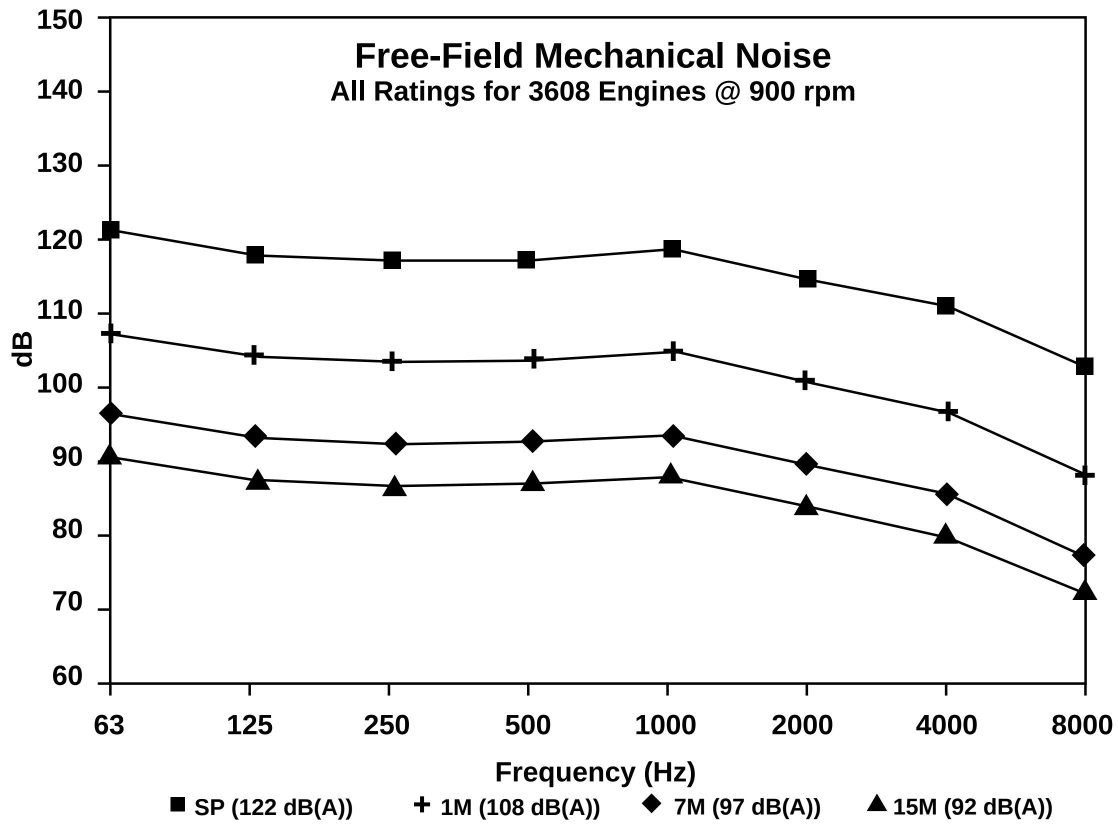


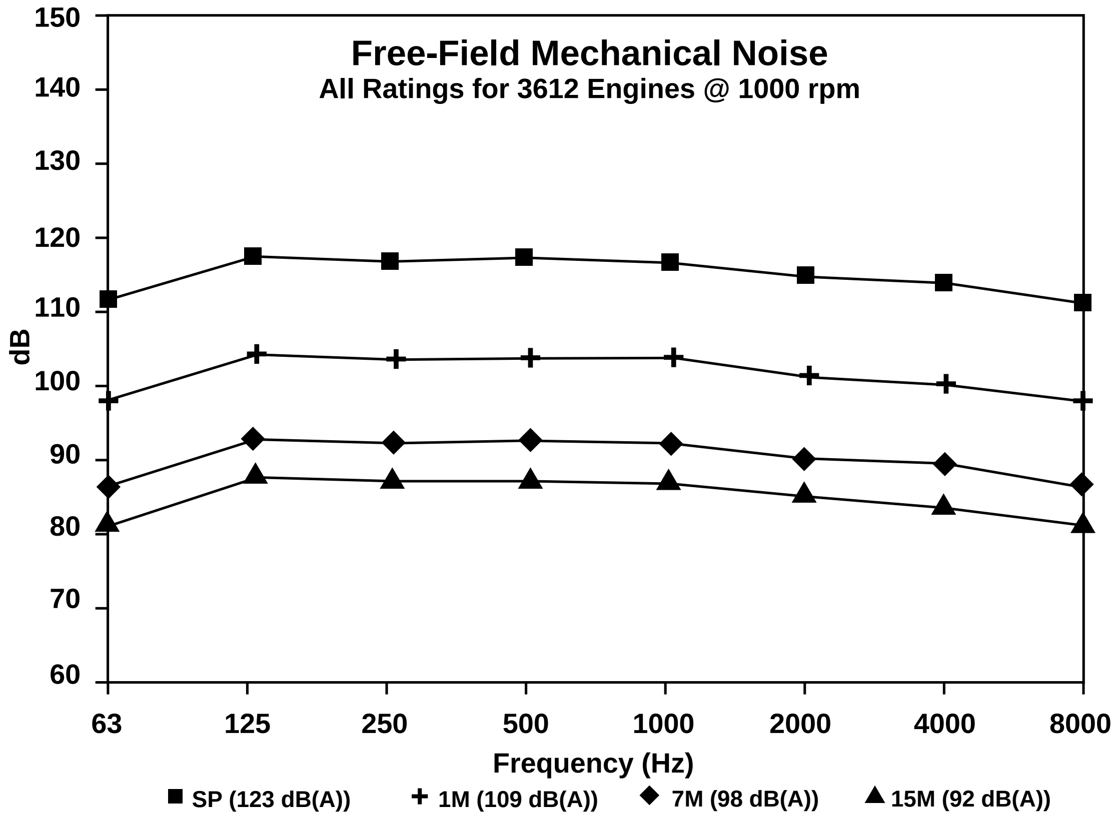
Free-Field Mechanical Noise
All Ratings for 3606 Engines @ 1000 rpm
150
140
130
120
110
100
90
80
70
60
dB
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (122 dB(A))
1M (108 dB(A))
7M (97 dB(A))
15M (91 dB(A))

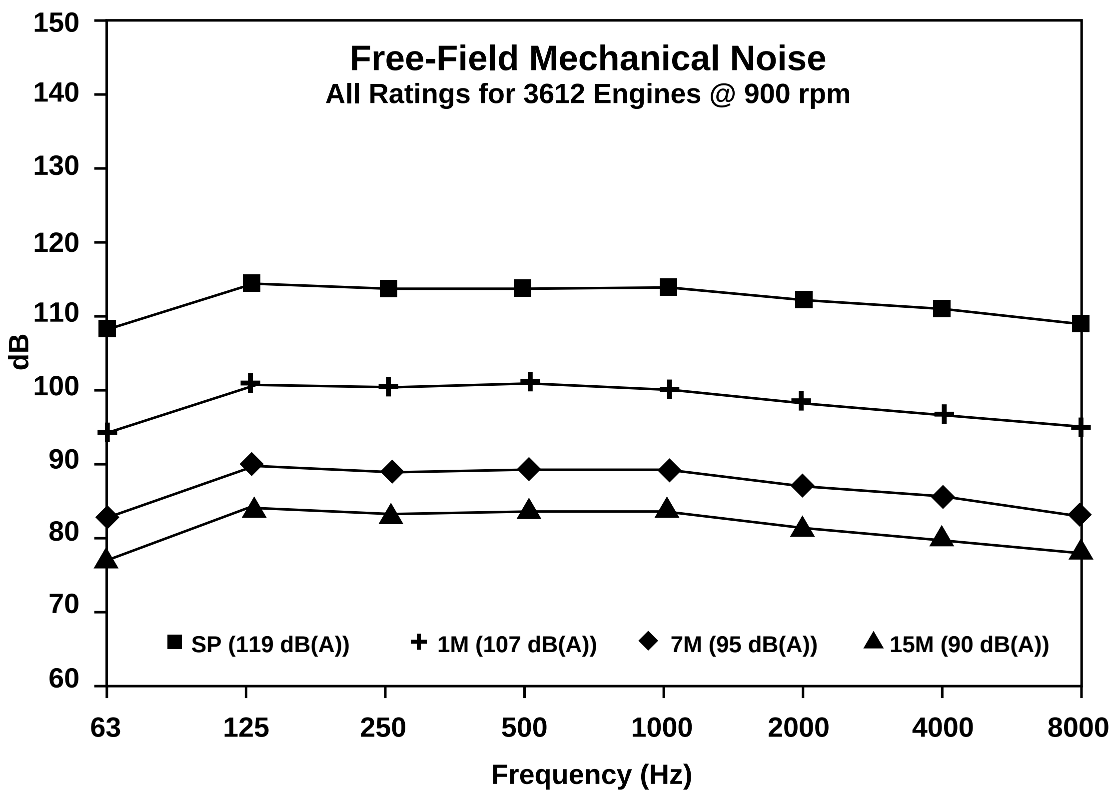


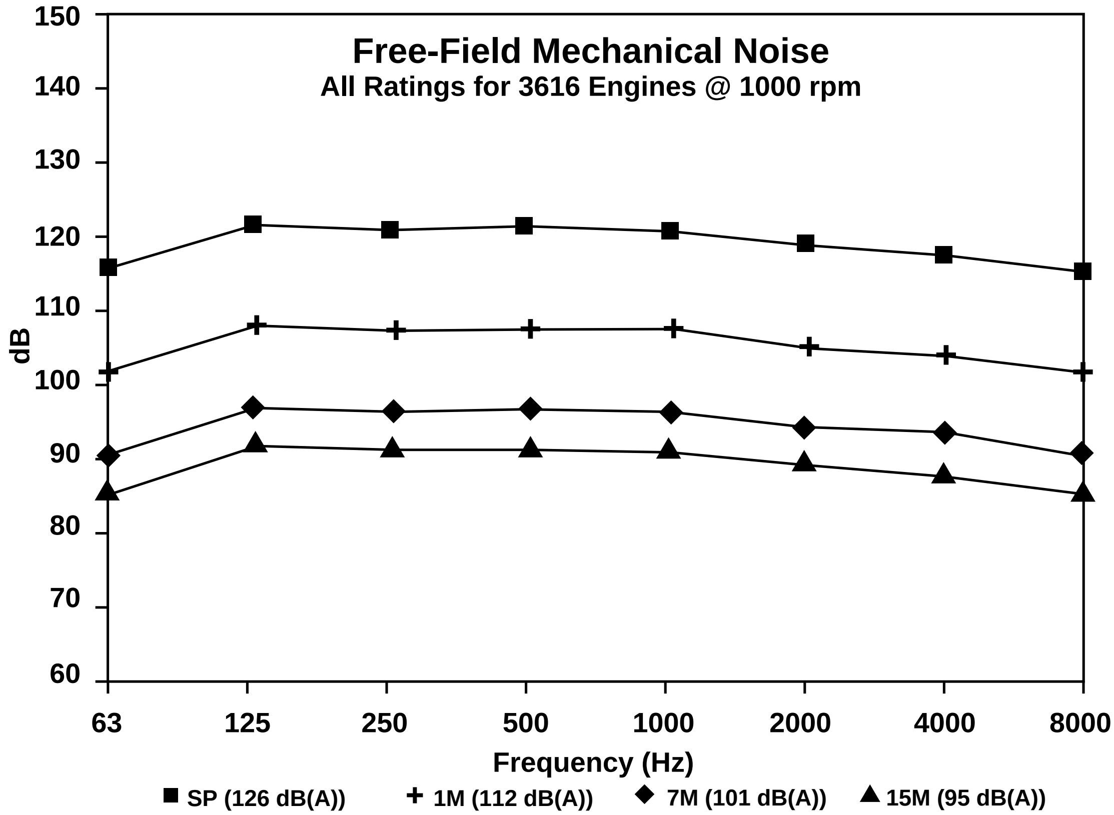
Free-Field Mechanical Noise
All Ratings for 3606 Engines @ 900 rpm
150
140
130
120
110
100
90
80
70
60
dB
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (120 dB(A))
1M (106 dB(A))
7M (95 dB(A))
15M (89 dB(A))


Free-Field Mechanical Noise
All Ratings for 3608 Engines @ 1000 rpm
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (125 dB(A))
1M (111 dB(A))
7M (100 dB(A))
15M (94 dB(A))

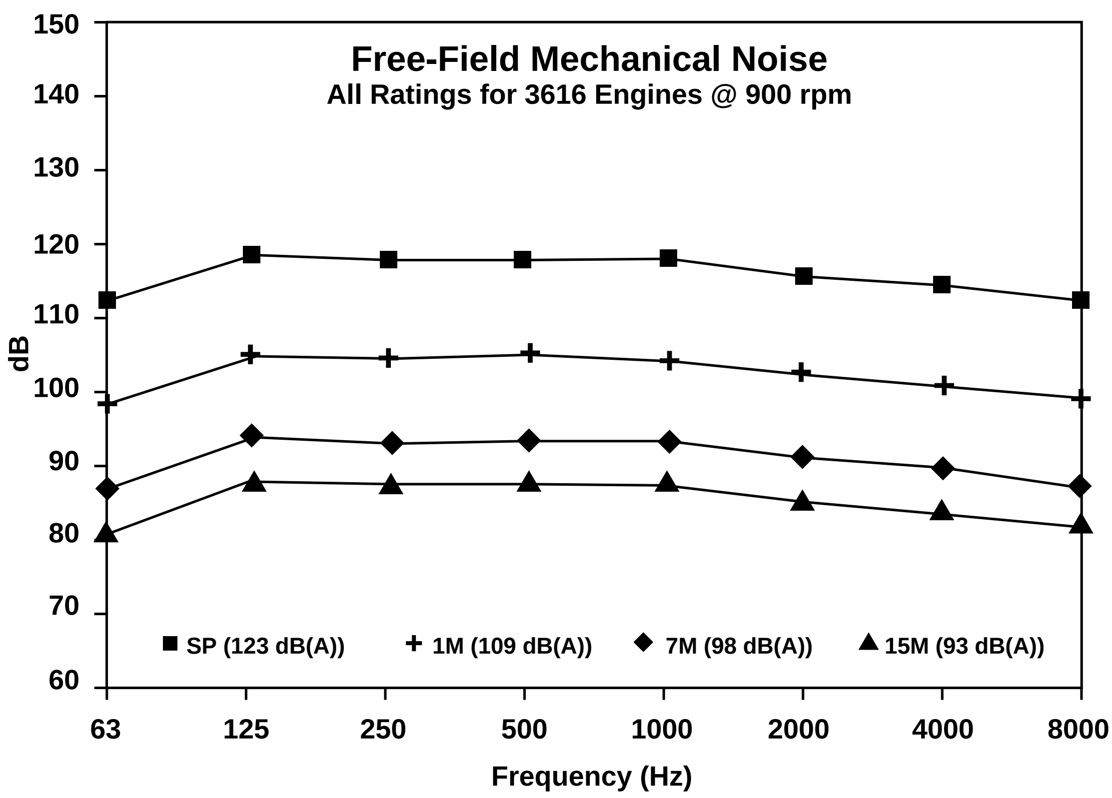

Free-Field Mechanical Noise
All Ratings for 3608 Engines @ 900 rpm
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (122 dB(A))
1M (108 dB(A))
7M (97 dB(A))
15M (92 dB(A))


Free-Field Mechanical Noise
All Ratings for 3612 Engines @ 1000 rpm
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (123 dB(A))
1M (109 dB(A))
7M (98 dB(A))
15M (92 dB(A))

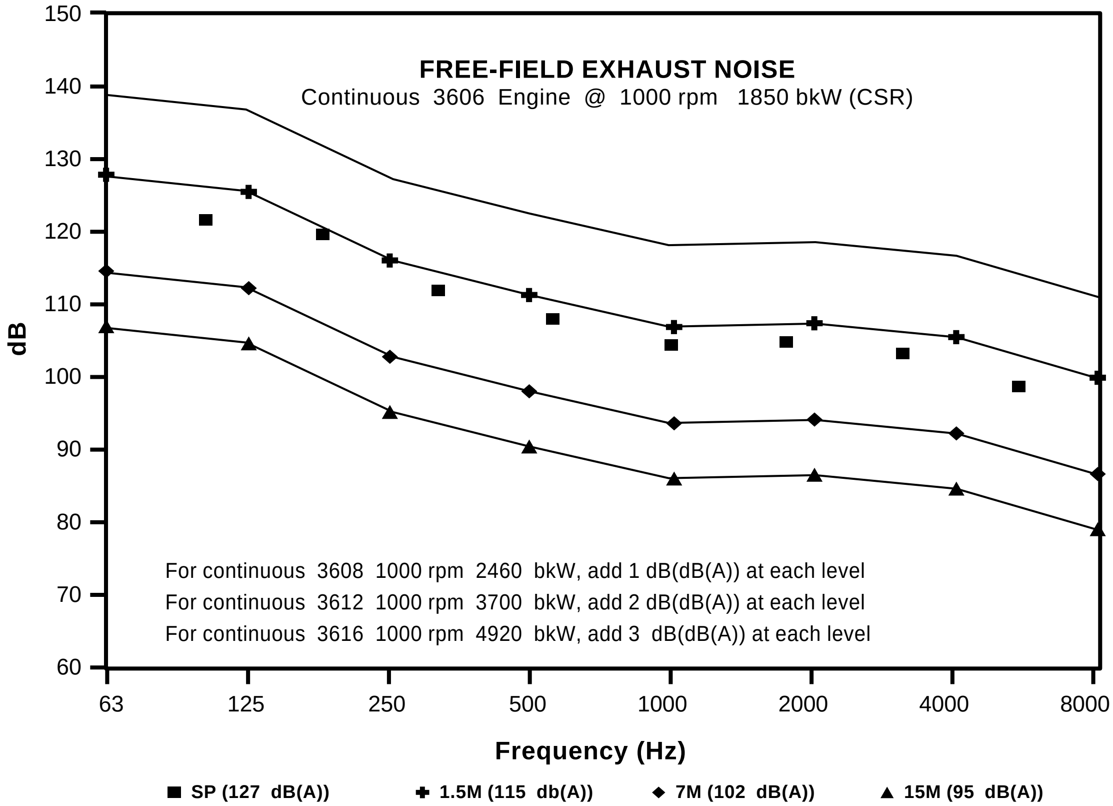

Free-Field Mechanical Noise
All Ratings for 3612 Engines @ 900 rpm
dB
150
140
130
120
110
100
90
80
70
60
SP (119 dB(A))
1M (107 dB(A))
7M (95 dB(A))
15M (90 dB(A))
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)

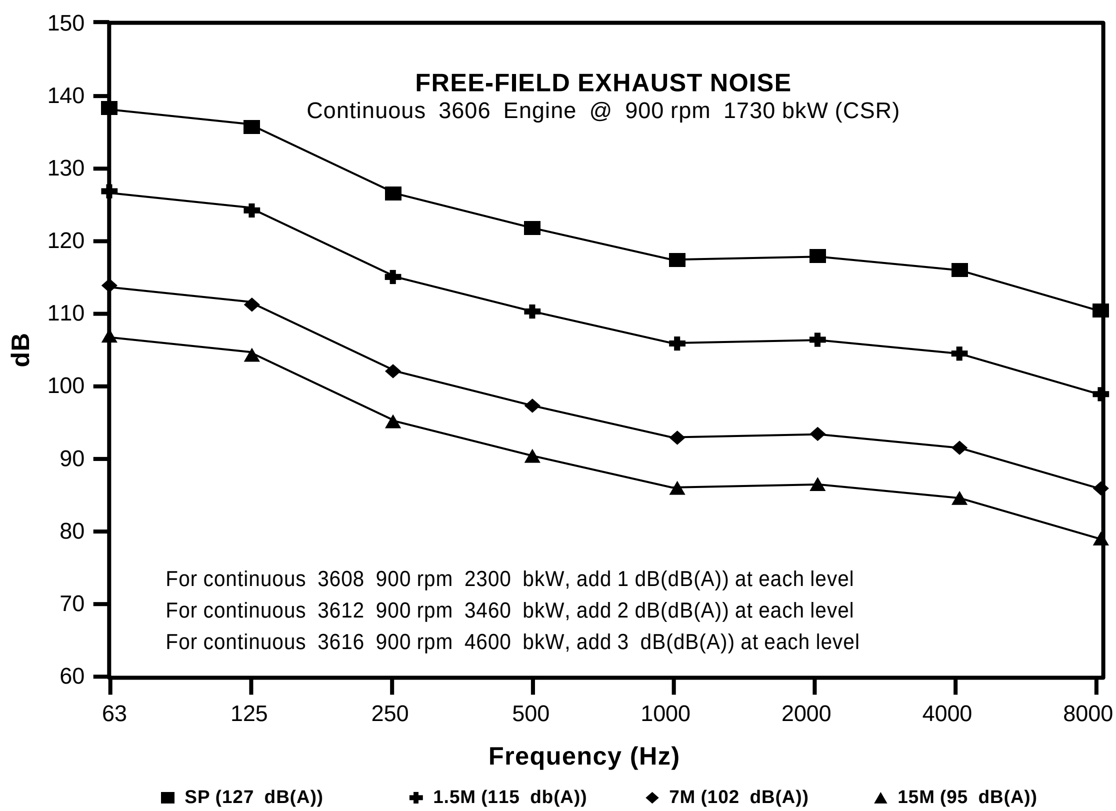


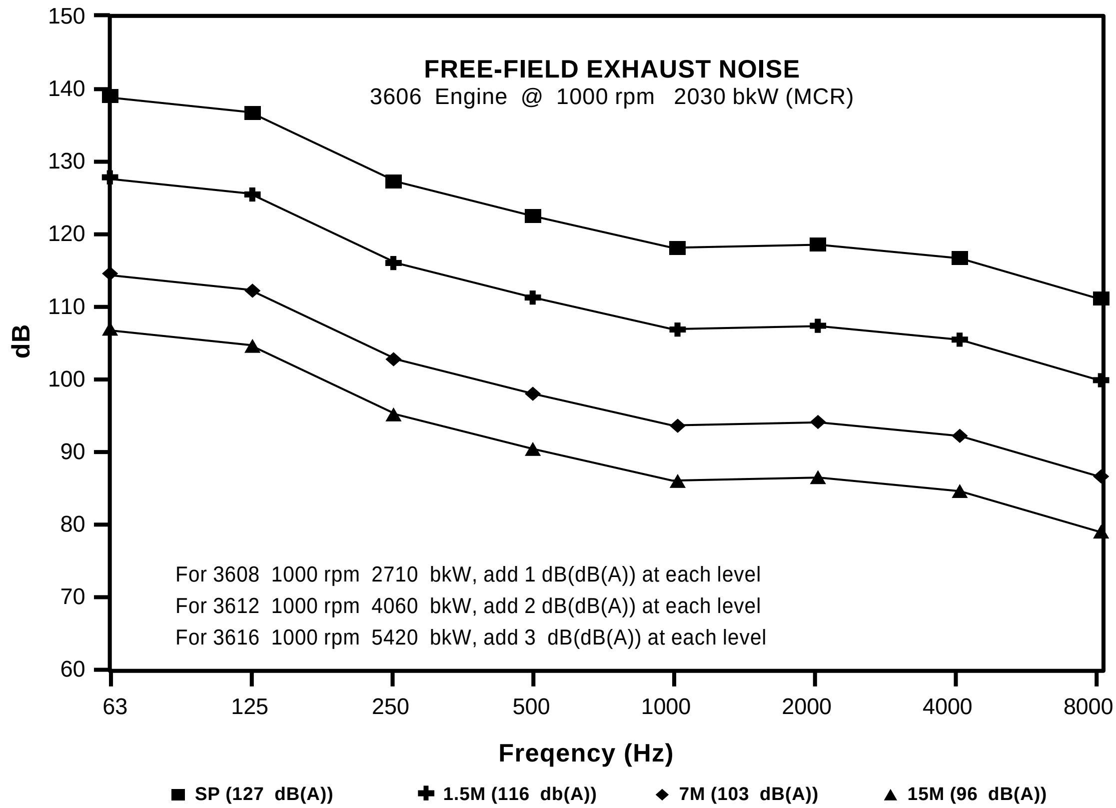
Free-Field Mechanical Noise
All Ratings for 3616 Engines @ 1000 rpm
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (126 dB(A))
1M (112 dB(A))
7M (101 dB(A))
15M (95 dB(A))

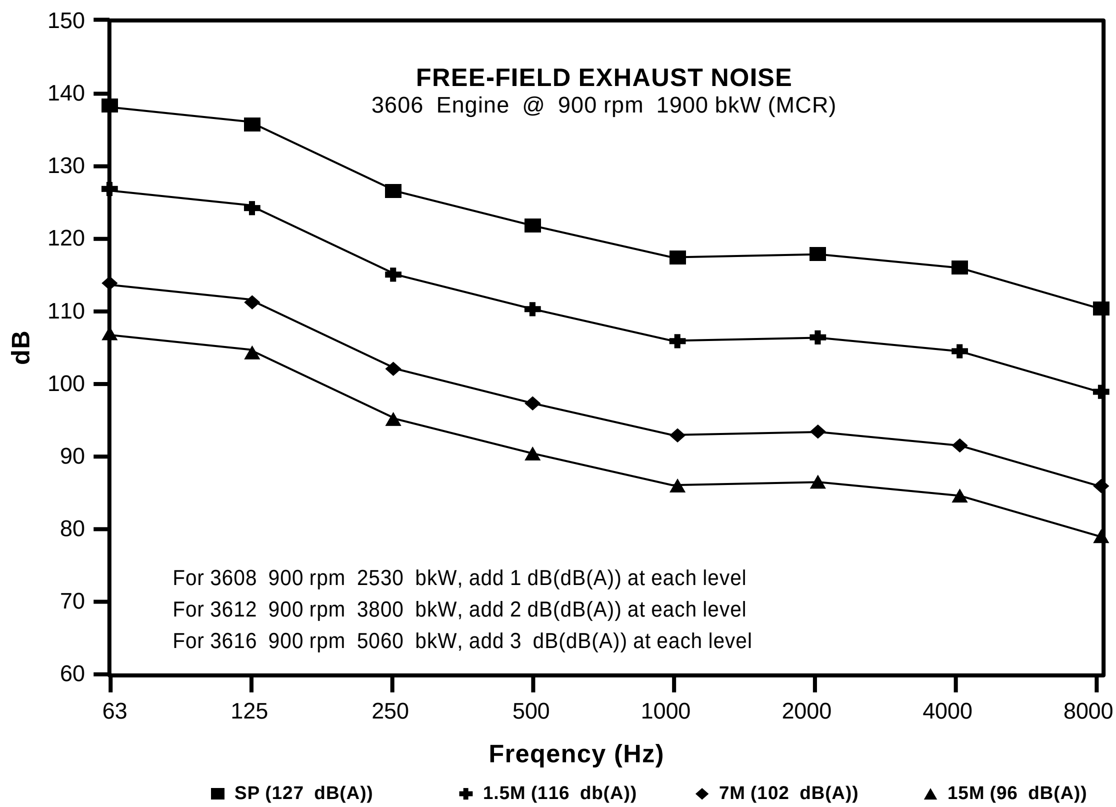


Free-Field Mechanical Noise
All Ratings for 3616 Engines @ 900 rpm
dB
150
140
130
120
110
100
90
80
70
60
SP (123 dB(A))
1M (109 dB(A))
7M (98 dB(A))
15M (93 dB(A))
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)


FREE-FIELD EXHAUST NOISE
Continuous 3606 Engine @ 1000 rpm 1850 bkW (CSR)
For continuous 3608 1000 rpm 2460 bkW, add 1 dB(dB(A)) at each level
For continuous 3612 1000 rpm 3700 bkW, add 2 dB(dB(A)) at each level
For continuous 3616 1000 rpm 4920 bkW, add 3 dB(dB(A)) at each level
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (127 dB(A))
1.5M (115 db(A))
7M (102 dB(A))
15M (95 dB(A))


FREE-FIELD EXHAUST NOISE
Continuous 3606 Engine @ 900 rpm 1730 bkW (CSR)
For continuous 3608 900 rpm 2300 bkW, add 1 dB(dB(A)) at each level
For continuous 3612 900 rpm 3460 bkW, add 2 dB(dB(A)) at each level
For continuous 3616 900 rpm 4600 bkW, add 3 dB(dB(A)) at each level
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Frequency (Hz)
SP (127 dB(A))
1.5M (115 db(A))
7M (102 dB(A))
15M (95 dB(A))


FREE-FIELD EXHAUST NOISE
3606 Engine @ 1000 rpm 2030 bkW (MCR)
For 3608 1000 rpm 2710 bkW, add 1 dB(dB(A)) at each level
For 3612 1000 rpm 4060 bkW, add 2 dB(dB(A)) at each level
For 3616 1000 rpm 5420 bkW, add 3 dB(dB(A)) at each level
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Freqency (Hz)
SP (127 dB(A))
1.5M (116 db(A))
7M (103 dB(A))
15M (96 dB(A))


FREE-FIELD EXHAUST NOISE
3606 Engine @ 900 rpm 1900 bkW (MCR)
For 3608 900 rpm 2530 bkW, add 1 dB(dB(A)) at each level
For 3612 900 rpm 3800 bkW, add 2 dB(dB(A)) at each level
For 3616 900 rpm 5060 bkW, add 3 dB(dB(A)) at each level
dB
150
140
130
120
110
100
90
80
70
60
63
125
250
500
1000
2000
4000
8000
Freqency (Hz)
SP (127 dB(A))
1.5M (116 db(A))
7M (102 dB(A))
15M (96 dB(A))

Intake Noise Control

Intake noise is typically airborne. Intake noise attenuation is achieved through either air cleaner elements or intake silencers. Noise attenuation due to various air cleaners and silencers can be supplied by the component manufacturer.

Sound Level Conversion

3600 sound level information is presented both in terms of sound power level dB(A) and sound pressure level dB(A) at a given distance from the noise source.

Sound power level is the total sound power being radiated from a source and its magnitude is independent of the distance from the source. Relative loudness comparisons between engines is simply a comparison of their sound power levels at equivalent operating conditions. When the sound power level is known, the sound pressure level at any distance from a point source (such as exhaust noise) can be easily calculated. A disadvantage of this system is that sound pressure level conversion is valid for a point source only. It cannot be used for mechanical noise since the source (overall engine) is quite large.

The equation for determining the sound pressure level of exhaust noise is:

Sound Pressure Level, dB(A) = Sound POWER Level, dB(A) - 10 X Log_{10} ($C\pi D^2$)

Where C = 2 For exhaust source adjacent to a flat surface. such as a horizontal exhaust pipe adjacent to a flat roof.

or C = 4 For exhaust source some distance from surrounding surfaces.

D = Distance from exhaust noise source, (m).

If the sound pressure level of a point source at some distance is known, the sound pressure level at a second distance can be calculated using this formula:

$SPL_2 = SPL_1 - 20 \text{ X } \text{Log}_{10} (D2 \div D_1)$

Where SPL_1 = known sound pressure level, dB(A)

SPL_2 = desired sound pressure level, dB(A)

D_1 = known distance, m (ft)

D_2 = desired distance, m (ft)

Vibration

All engines produce vibration due to combustion forces, torque reactions, and foundation designs. Vibrations can create conditions ranging from unwanted noise to excessive stress levels.

Vibrating stresses can reach destructive levels at engine speeds which cause resonance. Resonance occurs when natural system frequencies coincide with engine excitation frequencies. *Each 3600 application must be analyzed for critical linear and torsional vibration.*

Linear Vibration

Linear vibration is difficult to define without instrumentation. Human senses cannot detect relationships between the magnitude of vibration and period of occurrence. A first order (1 x rpm) vibration of 0.254 mm (0.010 in.) displacement may feel the same as third order (3 x rpm) measurement of 0.051 mm (0.002 in.).

Vibration occurs when a mass is deflected and returned along the same path, as illustrated in Figure 12. The mass travels through its original position until stopped by frictional forces. When external forces, such as the engine, continue to affect the vibrating system, *"forced vibration"* occurs.

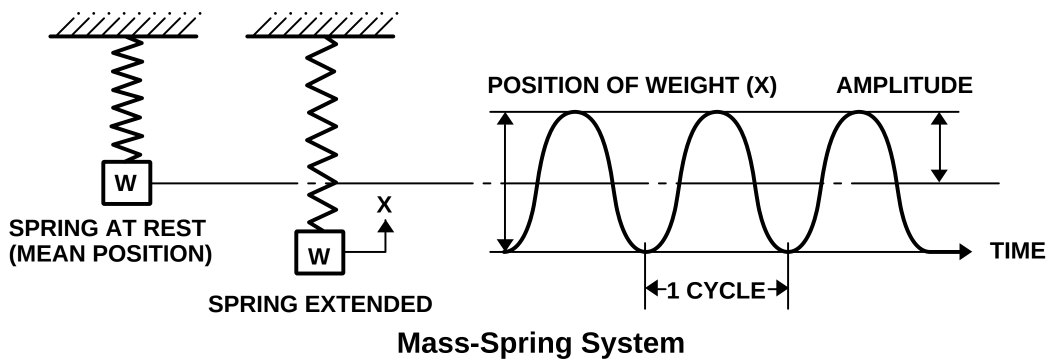


Figure 12

The time required for the weight to complete one movement is a *period* (see Figure 13).

Amplitude is the maximum displacement from the mean position. A *cycle* is the interval for the motion to repeat.

If the weight completes a cycle in one second, the *frequency* is one cycle per second or one *Hertz*.

A system completing full motion 20 times a minute has a frequency of 20 cycles per minute (20 cpm) or .33 cycles per second (.33 Hertz).

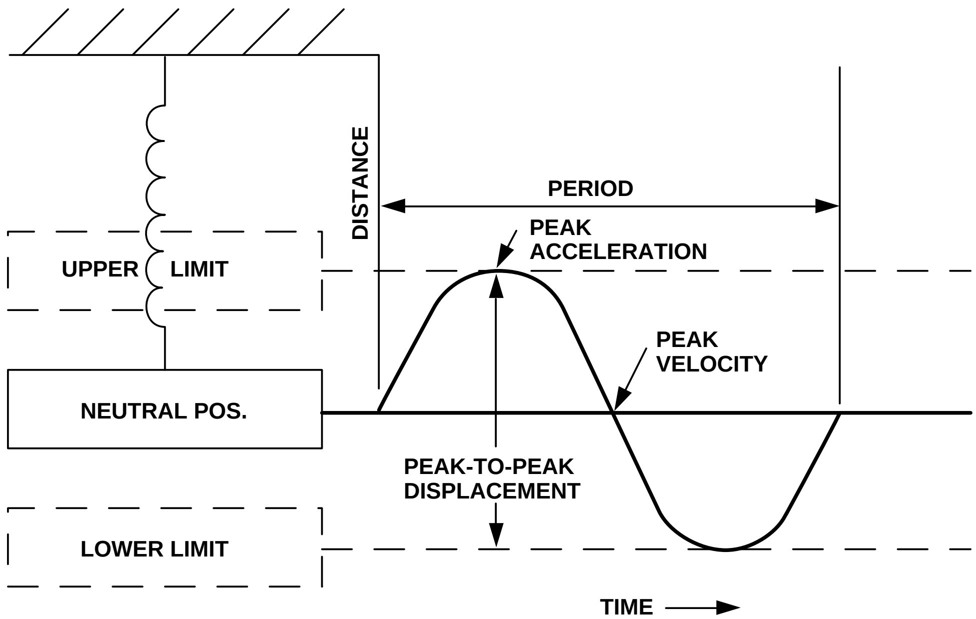


Figure 13

Total distance traveled is *peak-to-peak displacement*, usually expressed in mm or mils. (One mil equals 0.00l in. (.025 mm)). It is a guide to vibration severity.

Average and *root-mean-square* (rms) amplitudes are used to measure vibration (rms = 0.707 times peak amplitudes.)

Mass velocity measurement is another method of analyzing vibration. Note the example is changing direction as it moves. The mass speed is also constantly changing. At the displacement limit the speed is "0." The velocity is greatest while passing through the neutral position.

Velocity is important but because of its changing nature, peak velocity is the point selected for measurement. It is normally expressed in mm per second or inches per second. The relationship between peak velocity and peak-to-peak displacement is:

Metric Units: V Peak = 3.138 D F

Where:

V Peak = Vibration velocity in mm per sec, (peak).

D = Peak-to-peak displacement, in mm.

F = Frequency in hertz, (cps).

English Units:

V Peak = 52.3 D F x 10^{-6}

Where:

V Peak = Vibration velocity in in. per sec,(peak).

D = Peak-to-peak displacement, in mils.

F = Frequency in cycles per minute (cpm).

Acceleration is another characteristic of vibration. In the example, peak acceleration is at the extreme limit of travel where velocity is "0." As velocity increases, acceleration decreases until it reaches "0" at the neutral point.

Acceleration is dimensioned in units of "g" (peak), where "g" equals gravitational acceleration 9.8 m/s^2 = 32.2 ft/s^2.

Acceleration measurements, or "g's," are used to express large forces. At very high frequencies, e.g., 1000 Hz (60,000 cpm), it is perhaps the best indicator of vibration.

Vibration acceleration can be calculated from peak displacement as follows:

Metric Units:

Number of g's (Peak) = 2.01 DF x 10^{-3}

Where:

D = Peak to peak displacement in mm

F = Frequency in Hertz (cycles/sec)

English Units:

Number of gs (Peak) = $1.42\ D\ F^2 \times 10^{-8}$

Where:

D = Peak-to-peak displacement, in mils

F = Frequency in cycles per minute (cpm).

Machinery vibration is complex and consists of many frequencies. Displacement, velocity, and acceleration are all used to diagnose particular problems. Displacement measurements are commonly used as indicators of dynamic stresses.

Isolation

Isolation is required if (1) engine vibration must be separated from vessel structures, or (2) vibrations from nearby equipment are transmitted to inoperative engines.

Running units are rarely affected by exterior vibrations. Methods of isolation are the same for external or self-generated vibrations.

Piping connected to engines requires isolation, particularly when resilient mounting is used. Fuel and water lines, exhaust pipes, and conduit can transmit vibrations long distances. Isolator pipe hangers should have springs to attenuate low frequencies, and rubber or cork to minimize high frequency transmissions. To prevent buildup of resonant pipe vibrations, long piping runs must be supported at unequal distances (see Figure 14).

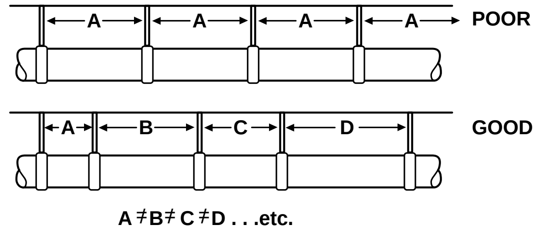


Figure 14

Isolation-Propulsion Engines

Caterpillar offers two types of isolation mounting systems for marine propulsion engines.

1. Silicon shear pads located between the engine mounting feet and the ship foundation.

2. Christie and Grey spring and rubber mounts also located between the engine mounting feet and the ship foundation.

These systems are covered in detail in the *Mounting and Alignment* section of this guide.

Linear Vibration Measurement

Equipment measurements should be made using the Caterpillar vibration analyzer (Part No 4C3030). If Caterpillar measuring equipment is not available, an equivalent device capable of measuring peak-to-peak displacement at selected frequencies, overall velocity, and overall displacement should be used.

Measurement Location

Vibration should be measured at eight points on propulsion engine and ship set generator packages. The points are illustrated in Figure 15 for propulsion engines and Figure 16 for ship set generator packages.

Point 1
Vertical direction at the front of the engine; locate probe on the top deck of the block in the plane of the crank centerline for inline engines, and at the base of the aftercooler housing at the crank centerline on vee engines.

Point 2
Horizontal direction at the front of the engine; locate probe on the side of the block at the crank centerline.

Point 3
Vertical direction at the rear of the engine; locate probe on the top deck of the block in the plane of the crank centerline for inline engines, and at the top of the rear housing at the crank centerline on vee engines.

Point 4
Horizontal direction at the rear of the engine; locate probe on the side of the block at the crank centerline.

Point 5
Vertical direction at the rear of the marine gear (or at the rear of the generator); locate probe on the top of the output shaft bearing (or generator frame) at the shaft centerline.

Point 6
Horizontal direction at the rear of the marine gear (generator); locate probe on the side of the marine gear (generator frame) at the shaft centerline.

Point 7
Vertical direction at the right rear engine foot.

Point 8
Axial direction at the rear of the marine gear (generator); locate the probe on the rear of the marine gear housing (generator frame) on a rigid member — not sheet metal — at the shaft centerline.

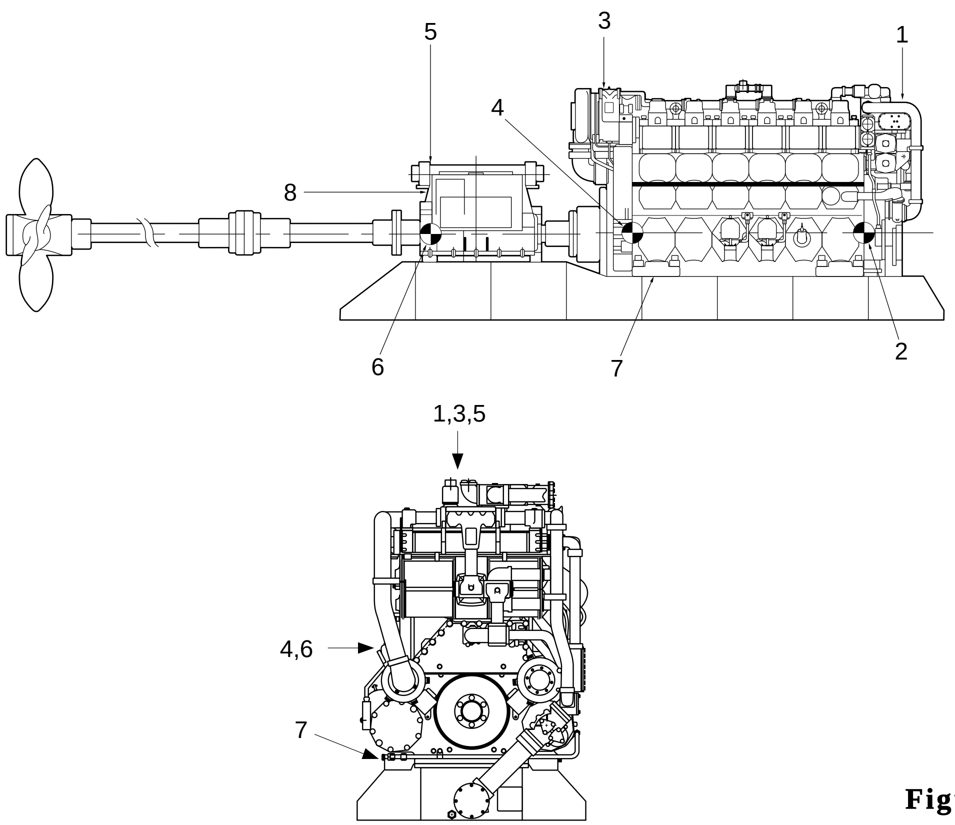


Figure 15

Vibration Measurement Locations

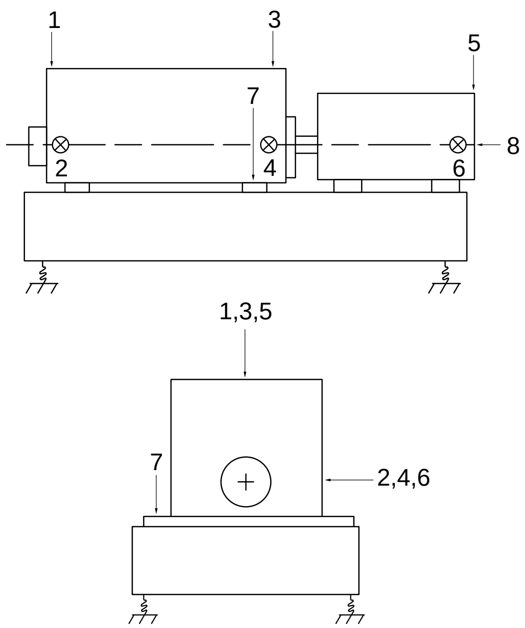


Figure 16

Operating Conditions and Data Format

Vibration measurements must be made at the advertised engine rating (100% load). If additional data is desired, it is recommended that measurements be made at 0% load, 50% load, and 75% load.

Data must be reported in terms of peak-to-peak displacement (mils) at 1/2 order frequency, 1st order frequency, overall velocity level (inches per second) and overall displacement (mils) for each of the eight measuring locations.

Linear Vibration Limits

The vibration levels for any load condition at any of the eight measuring locations cannot exceed the following limits for rigidly mounted engines:

- Peak-to-peak displacement limit at 1/2 order frequency = .13 mm (5.0 mils)
- Peak-to-peak displacement limit at 1st order frequency = .13 mm (5.0 mils)
- Overall displacement = .22 mm (8.5 mils)
- Overall velocity = 34.3 mm/sec (1.35 in./sec)

If the measured vibration levels exceed the limits, contact your Caterpillar dealer representative or Caterpillar factory representative for assistance.

Engines which are mounted on resilient mounts (rubber or spring and rubber isolators) may exhibit first order vibration levels between 6 and 15 mils peak-to-peak depending on the natural frequency of the resilient mounts. A contributing factor to this first order vibration is that the engine is intentionally misaligned to the marine gear at low load conditions to ensure that the torque reaction of the engine under load will result in acceptable alignment. The resilient mount system supplier must perform extensive calculations. This ensures that the natural frequency of the isolators will not be excited at normal operating engine speed and load conditions. Vibrations occuring near low idle are normally not objectionable.

Alignment and Trim Balance

Engine alignment out of specification can result in excessive first order vibration displacement. If excessive first order displacement is found while other limits are met, the alignment must be measured and corrected.

If alignment is found to be acceptable and first order vibration displacement is unacceptable, engine trim balancing can reduce engine first order vibration levels by using weights available from Caterpillar Inc. A vibration balancer (Part No. 4C3020) and the Caterpillar 3600 Engine Trim Balance chart are also available through Caterpillar Inc.

Torsional Vibrations

Torsional vibrations occur as engine components, such as an engine crankshaft, twist and recover. Standard engine components, withstand normal stresses caused by combustion forces and torque reactions. Engine mounting systems and drive arrangements must be designed to prevent the natural frequency of the drive train from approaching the unit's operating speed. Failure of crankshaft, couplings, gears or bearings may result without up front careful attention.

Torsional Analysis

All 3600 engine applications require a torsional vibration analysis. This includes factory packaged ship set generator packages on Caterpillar designed bases. The analysis must be performed by either the customer or by Caterpillar, depending on the customer's preference. Customer performed analyses are subject to Caterpillar review and approval and Caterpillar does not assume responsibility for an analysis performed by others without the approval. For a Caterpillar performed analysis, one complete set of technical data must be submitted to Caterpillar before calculations are undertaken (see the *General Information* section of this guide on Torsional and Vibration Analysis). The report will include a mathematical determination of the natural frequency, critical speeds, relative amplitudes of angular displacement, and approximate nodal locations of the complete elastic system (both engine and driven equipment).

Note: *Consult factory on compound installations. There may be additional charges for analysis of applications where more than one engine drives a single load. A separate torsional analysis is also required for each engine with different driven equipment in multiple engine installations.*

Engine Torsional Pickup

Each 3600 Engine is equipped with a magnetic pickup (7C1897) installed inside the front housing. It generates a signal from the front crankshaft gear (96 teeth) and can be connected to a torsiograph. The electrical characteristics of the pickup are:

Internal impedance ....100 Ohms

Open circuit
voltage at
1000 rpm ....Approx. 80V A.C.

Max. current
output
capability........................10 milliamperes

The pickup output voltage is approximately 50 volts when using a test instrument of approximately 10,000 Ohms impedance.

The pickup should be used when measuring torsionals on all 3600 engine installations, particularly when a high inertia front drive is used. It can also be used to check eventual damper or flexible coupling deterioration.

Reference Material

LEHX1086	EDS 31.1, Linear Vibration Isolators
LEHX9166	EDS 73.1, Linear Vibration
LEKQ2352	EDS 206.1, Torsional Vibration Dampers
SEHS9162	Special Instructions - Spring Isolators

CATERPILLAR®

Engine Performance

Engine Ratings

Distillate Fuel

Marine Propulsion

Available standard ratings for 3600 Engines are shown in Figure 1. Figures 2 through 17 show distillate fuel marine propulsion performance curves. The curves are shown in both English and metric units at the same ratings shown on the technical data sheets in the *Engine Data* section of this guide. *Read this complete guide section for clarification of rating conditions and limits.*

Marine Auxiliary Generator Sets

Available standard ratings and performance data for distillate fuel marine auxiliary generator sets are in the 3600 EPG A&I Guide (LEKX6559).

Heavy Fuel

Marine Propulsion

Available standard ratings for 3600 Engines are shown in Figure 18. Figures 19 through 27 show heavy fuel marine propulsion performance curves. Note that some heavy fuel engine ratings have application restrictions as described in the respective curves. There are two ratings given for the 1000 rpm 3608 and 3616 engines. The higher rating is allowed only with controllable pitch propellers operating near rated speed. It is not applicable for a fixed pitch propeller or water jet.

Heavy fuel engines must be carefully applied for marine propulsion applications. Thorough knowledge of the vessel's operation is necessary. Part speed operation is important as valve temperatures are usually highest at part speed. Limit *zones* of operation are shown on the heavy fuel rating sheet and the performance curves that follow.

The operating zones are:

Zone I — Continuous operation without restriction.

Zone II — For MCR ratings, read the complete section for explanation of MCR and CSR. Operation above the CSR rating is limited to 1 hr/12 hr (8% of time) due to exhaust valve temperature, cylinder pressure and turbocharger speed. Continuous operation (more than 1 hr at a given time) is acceptable if cumulative time at high load is limited. Operation in zone II for cumulative periods more than 8% of the total time will require more frequent overhaul.

Zone III — Operation is limited due to valve temperature. Recommended operation periods limited to transient conditions (such as acceleration). Operation in this zone for 1 hr/12 hr (8% of time) can reduce valve life by approximately 20%.

Zone IV — Operation is limited to 1 hr/12 hr due to combustion deposits. Periodic operation at high load is needed to clear deposits. Valve temperatures are not a consideration.

Controllable pitch propellers allowing the selection of speed and load combinations are very useful in providing long valve life.

Heavy fuel marine propulsion ratings operating in zones II and III must be approved individually by Caterpillar. The custom nature of the applications require individual attention. Submit a special rating request form (LEXQ1183) shown in Figure 28. Information on the vessel, intended duty, ambient conditions, fuel sodium and vanadium, and propeller must be provided. *Applications operating only in Zones I and IV do not need prior approval.*

3600 Distillate Fuel Marine Propulsion Ratings Nominal 32°C (90°F) Coolant Temperature To Aftercooler		Engine Speed Ratings* 750	800	900	1000
3606					
MCR					
POWER	bkW (bhp)	1640 (2200)	1720 (2310)	1900 (2550)	2030 (2720)
BMEP	kPa (psi)	2368 (343)	2328 (338)	2286 (331)	2198 (319)
CSR					
POWER	bkW (bhp)	1490 (2000)	1560 (2090)	1730 (2320)	1850 (2480)
BMEP	kPa (psi)	2151 (312)	2112 (306)	2082 (302)	2003 (290)
3608					
MCR					
POWER	bkW (bhp)	2180 (2920)	2290 (3070)	2530 (3390)	2710 (3630)
BMEP	kPa (psi)	2361 (342)	2325 (337)	2283 (331)	2201 (319)
CSR					
POWER	bkW (bhp)	1980 (2660)	2080 (2790)	2300 (3080)	2460 (3300)
BMEP	kPa (psi)	2144 (311)	2112 (306)	2076 (301)	1998 (290)
3612					
MCR					
POWER	bkW (bhp)	3280 (4400)	3440 (4610)	3800 (5100)	4060 (5440)
BMEP	kPa (psi)	2368 (343)	2328 (338)	2286 (331)	2198 (319)
CSR					
POWER	bkW (bhp)	2980 (4000)	3120 (4180)	3460 (4640)	3700 (4960)
BMEP	kPa (psi)	2151 (312)	2112 (306)	2082 (302)	2003 (290)
3616					
MCR					
POWER	bkW (bhp)	4360 (5850)	4580 (6140)	5060 (6790)	5420 (7270)
BMEP	kPa (psi)	2361 (342)	2325 (337)	2283 (331)	2201 (319)
CSR					
POWER	bkW (bhp)	3960 (5310)	4160 (5580)	4600 (6170)	4920 (6600)
BMEP	kPa (psi)	2144 (311)	2112 (306)	2076 (301)	1998 (290)

* Read this complete section for application restrictions

Figure 1

3600 Heavy Fuel Marine Propulsion Ratings
Nominal 32°C (90°F) Coolant Temperature to Aftercooler

			Engine Speed Ratings					
			750	825	900	1000		Application Restrictions
3606								
MCR								
	POWER	bkW (bhp)	1485 (1995)	1490 (2000)	1730 (2320)	1850 (2485)		*
	BMEP	kPa (psi)	2144 (311)	1955 (283)	2081 (302)	2003 (290)		
CSR								
	POWER	bkW (bhp)	1350 (1810)	1355 (1820)	1570 (2110)	1680 (2260)		*
	BMEP	kPa (psi)	1949 (283)	1778 (258)	1889 (274)	1819 (264)		
3608								
MCR								
	POWER	bkW (bhp)	1980 (2660)**	1980 (2660)*	2300 (3090)*	2320 (3115)*	2460 (3300)***	See Footnotes
	BMEP	kPa (psi)	2144 (311)	1949 (283)	2075 (301)	1884 (273)	1998 (290)	
CSR								
	POWER	bkW (bhp)	1800 (2415)**	1800 (2415)*	2090 (2805)*	2110 (2850)*	2240 (3005)***	See Footnotes
	BMEP	kPa (psi)	1949 (283)	1772 (257)	1886 (273)	1713 (264)	1819 (264)	
3612								
MCR								
	POWER	bkW (bhp)	2970 (3985)	2980 (4000)	3460 (4645)	3700 (4965)		*
	BMEP	kPa (psi)	2144 (311)	1955 (284)	2081 (302)	2003 (290)		
CSR								
	POWER	bkW (bhp)	2700 (3625)	2710 (3640)	3140 (4215)	3360 (4510)		*
	BMEP	kPa (psi)	1949 (283)	1778 (258)	1889 (274)	1819 (264)		
3616								
MCR								
	POWER	bkW (bhp)	3960 (5315)**	3960 (5315)*	4600 (6175)*	4640 (6230)*	4920 (6600)***	See Footnotes
	BMEP	kPa (psi)	2144 (311)	1949 (283)	2076 (301)	1884 (273)	1998 (290)	
CSR								
	POWER	bkW (bhp)	3600 (4830)**	3600 (4830)*	4180 (5610)*	4220 (5665)*	4480 (6015)***	See Footnotes
	BMEP	kPa (psi)	1949 (283)	1772 (257)	1885 (273)	1713 (248)	1819 (264)	

Application Restrictions:

* Limited Time At Part Speed - See Individual Rating Curves For Limit Lines.
** Very Limited Time At Part Speed, Generally Requires CP Propeller.
*** Always Requires CP Propeller.

Figure 18

3600 Engine Rating Request/Rating Information Form

PROJECT/CUSTOMER NAME____________________________________ PROJ. NO.________________
DEALER___________________________________
Requester:____________________________ Phone_____________________Date_____________________
Technical Serv. Rep._____________________________ No. of Engines is this Order____________________
If applicable list Special Request No. assigned to project: (SR)___________

MODEL_________________________Application Description/Duty________________________________
Aftercooler Circuit: Single________ or Separate________ Temperature to AC________ °C (Typically 50°C)
ROT. (ccw/cw) Low Idle Speed_________ High Idle Spd or %Droop_________ Governor Type_________
Is this Engine Certified (Y/N):_________ Society____

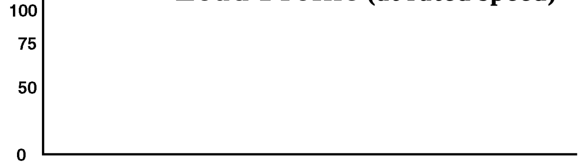
GENERATOR SETS: NOMINAL RATING_________ BKW or EKW @_________**RPM** (advertised)
(optional) Fuel Stop power requested:_____________________ BKW or EKW [with Standard Tolerances]
10% BKW overload capability (±3%bkw & ±5%ekw) is available with Continuous and Prime Power ratings.
Generator Efficiency @ 100% PWR_________________________% (Assumed 96% if not provided)
Is Lafayette packaging the Generator Set? (Y/N)
Are there any Generator Response Requirements? (Y/N) If yes, specify

Regulator Type? (Volts-Hertz or Constant Voltage)

NON GEN SETS: NOMINAL RATING_____________BKW (±3%) @____________RPM (advertised)
Load Demand at the Flywheel by the Propeller, Pump, etc.______________BKW (at rated speed)
Marine - Propeller Type (fixed Pitch/Ctrl Pitch)
(Non-Standard) Fuel Stop (overload) Power requested:__________**%** [With Standard Tolerances]
Lug Requirement? (Y/N)__________ % @__________ RPM

Load Profile (at rated speed)

% Load



(label peaks & valleys in the profile)

Time (specify scale)

Time at Idle _____
Total hrs/yr _____
Load factor (%)_____

SITE CONDITIONS: Max. Altitude___________Meters
Geographical Area:____
Ambient Air (to turbo) Range: Max__________°C to Min____________°C
Engine Room Temperature: Max_____________°C to Min____________°C
BSFC GUARANTEED: (Y/N)_________ If yes, specify test procedure sales code/3L number (s):_________
LHV(kJ/kg) ______ Guaranteed Value: ______ g/bkw*hr @ ______ BKW@ ______ RPM with ______ tolerance

Special Testing Description/Points: (list all engine only tests; inc. sales codes/3L part no.)
(eg. Any special tests to be completed at site/Dealer?)

EMISSION REGULATED (Y/N)_______ If yes, specify:

FUEL TYPE: Distillate (No. 2) _______; Residual Blend _______
For Residual Blend Specify: Fuel Temperature to the Engine (°C) _______
Max Sulfur (%) ________ Max Vanadium (ppm) ________ LHV(kJ/kg) ________ Sodium (ppm) ________
Density (kg/m^3) ________ Viscosity (cst @ 50°C)________ Carbon Residue (%)________ Ash (%)________
Water & Sediment (%)_______ Aluminum (ppm)_______ Silicon (ppm)_______ Asphaltenes (%)_______

Below for Technical Services Rep. Only

Non-Runnable Eng. Ar. ______________ **ESO (s)**______________ **Turbo Selected:** ______________
Head Group Selected: STD or P/N ______________

Below For Performance Engr. Only

Approved Rating: (Advertised) ___________ BKW or EKW @___________ RPM Appl Code ___________
(Fuel Stop) ___________ BKW or EKW @___________ RPM
Boost Relief Valve Required:___________
2T___________ Approved Turbo Prt No. ___________ Perf Engrg Init. ___________ Date ___________

LEXQ1183 (4-91) ________ Need New Spec STD or SPL ________ Append Database

Figure 28

Marine Auxiliary Generator Sets
Available standard ratings and performance data for heavy fuel marine auxiliary generator sets are in the 3600 EPG A&I Guide (LEKX6559).

Performance Criteria

Marine Performance Curves

Caterpillar uses a two level rating system for 3600 Engine marine propulsion applications – *Continuous Service Rating* and *Maximum Continuous Rating*.

The Continuous Service Rating (CSR) corresponds to ISO Continuous and Fuel Stop Power definitions and is similar to the Marine Class A Continuous Ratings used on Caterpillar's other engines. The rating is suitable for continuous duty applications, including dredges, for operation without interruption or load cycling. It is identical to Zone 1 operation as defined by ETDS.

The Maximum Continuous Rating (MCR) corresponds to ISO Overload and Fuel Stop Power definitions and is 10% higher than the CSR rating. It is similar to the Marine Class C Intermittent Ratings used on Caterpillar's other engines. The engine power actually produced under normal operating conditions is limited by application guidelines, leaving a power reserve for vessel fouling, non-continuous normal operation, and/or emergency reserve for unusual operating conditions. This rating is generally used for vessel applications involving varying loads. The establishment of MCR ratings for 3600 Engines is consistent with practices of most worldwide large engine manufacturers.

Some specifications require demonstration of 10% overload capability above the CSR or MCR rating levels. The overload capability can be demonstrated at the factory by specifying a special factory performance test. After completion of the demonstration test, the engine power is reset to the CSR or MCR power setting as applicable.

The performance curves for CSR and MCR ratings are similar in format. Figure 29 is a typical curve on distillate fuel. See Figures 19 through 27 for heavy fuel curves. Both are plotted in terms of engine power versus engine speed, with operating limit line curves identified by the numbers "1" and "3" in the case of distillate fuel, and Zones in the case of heavy fuel. Curves "2" and "4" are the corresponding fixed pitch propeller demand curves based on 85% of MCR output or 90% of CSR output..

Curve 1 defines the MCR limited time operating capability of the engine. Operation in the zone between Curves 1 and 3 is limited to an average of 1 hour in 12 (approximately 8%) over the total engine operating life.

Curve 3 defines the CSR continuous operating limit of the engine. The zone below Curve 3 is for continuous operation without interruption or load cycling while operating at any combination of power and speed on or under Curve 3.

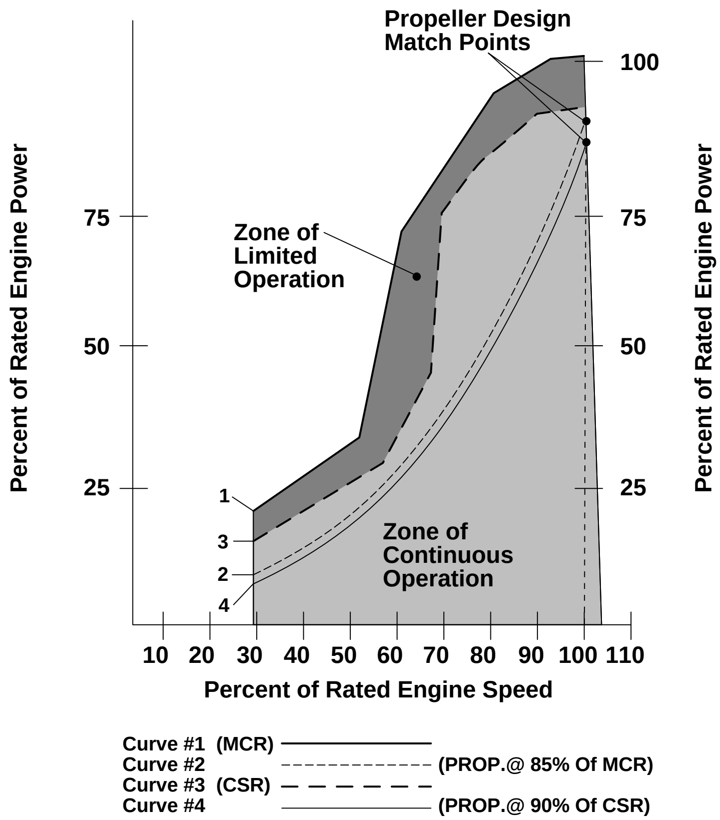


Figure 29 **Typical Performance Ratings**

Curves 2 and 4 define the power demanded by a conventional fixed pitch propeller applied at the recommended propeller design match point. Shaft power may be assumed to be 97% of the engine brake power. Curve 2 is matched to Curve 1 (MCR), and Curve 4 is matched to Curve 3 (CSR).

Note: Additional application considerations are required for heavy fuel. The primary concern is valve temperature limits for vanadium degradation. Because of vanadium level uncertainties found in various bunkering areas, Caterpillar is placing additional restrictions on engine applications. See Figures 19 through 27 for individual rating restrictions. The actual allowed rating will depend on many factors. Contact Caterpillar if the desired rating falls outside the presented guidelines.

Application Guidelines

The power required to develop a given vessel speed will tend to increase over the life of a vessel, particularly due to hull fouling. Adverse maneuvering and weather conditions can result in increased engine power requirements to maintain vessel control. It is essential to provide some engine power reserve when selecting the propeller design match point.

For 3600 marine propulsion applications, the guidelines for propeller design match point at rated engine speed are:

	Fixed Pitch Propeller	Controllable Pitch Propeller
Continuous Service Rating	90% of CSR	100% CSR
Maximum Continuous Rating	85% of MCR	100% MCR*

* Operation above Curve 3 (CSR) is limited to one hour out of 12

Propeller design match points at rating percentages other than specified by the guidelines are satisfactory *provided engine operating limits are not exceeded*.

For controllable pitch propeller applications on distillate fuel, any combination of propeller pitch and engine speed is acceptable for continuous operation at or below Curve 3 or for 1 hour in 12 in the zone between Curves 1 and 3.

Propeller match must always be verified by sea trial. The best measure of propeller match is verification of fuel rate at rated engine speed.

River push boats and dredge pump drive applications are limited to CSR power levels.

3600 application guidelines are comparable to those published by most competitors.

Marine Performance Parameters

Limit Definitions

CSR Continuous operation, including dredge engines, without interruption or load cycling on or under Curve 3.

MCR Operation limited to an average of 1 hour in 12 hours of total engine operating time.

Power Curves 2 and 4 represent the power demand of a typical fixed pitch propeller, applied at the recommended propeller design point. Curve 2 is matched with Curve 1 (MCR), and Curve 4 is matched to Curve 3 (CSR).

See the performance curves in Figures 19 through 27 for additional restrictions for heavy fuel applications.

Conditions

Performance is based upon SAE J1995 and ISO 3046/1 standard conditions of 100 kPa (29.61 in. Hg) barometric pressure, 25°C (77°F) ambient temperature, and 30% relative humidity. For marine engine applications, the nominal aftercooler water temperature is 32°C (90°F) (maximum 38°C (100°F)) instead of the 25°C (77°F) temperature allowed by ISO. Performance and fuel consumption are based on 35 API, 16°C (60°F) fuel having a LHV of 42780 kJ/kg (18,390 Btu/lb) used at 29°C (85°F) with a density of 838.9 g/L (7.001 lb/US gal).

The performance curves show the gross output capability of an engine equipped with fuel, lube oil, and fresh water cooling pumps. The fuel consumption given includes the same engine driven equipment. Power to drive auxiliaries must be deducted from gross output to arrive at the net power available. Auxiliaries may include a marine transmission, an auxiliary generator, and/or an auxiliary water pump.

Lug operation below 85% of rated speed can result in turbocharger surge, depending upon aftercooler water temperature, inlet restriction and ambient conditions.

For standard ratings, engine deration is not required for ambient temperatures up to 45°C (113°F).

Fuel Consumption

3600 brake specific fuel consumption (BSFC) is based on SAE J1995 and ISO 3046 standard ambient conditions of 100 kPa (29.61 in. Hg) barometric pressure, 25°C (77°F) ambient temperature and 30% relative humidity. The BSFC figures are also based on typical production engine configurations, including engine driven fuel, oil and fresh water cooling pumps. BSFC figures are based on 35 API test fuel with LHV of 42,780 kJ/kg (18,390 Btu/lb) and a Caterpillar tolerance of ± 6 g/kW-hr (.010 lb/hp-hr) applies.

A number of 3600 competitors declare fuel consumption according to ISO 3046/1 Standard or the British (BS 5514) and German (DIN 6271) versions of this standard. The latest revision of ISO 3046/1 allows a *maximum* 5% tolerance for published BSFC data. Some competitors do not include engine driven oil and water pumps in their advertised performance data.

The fuel consumption data included in this guide, as well as TMI data, has standard Caterpillar tolerances. When comparing 3600 BSFC to ISO based competitors, it is essential to use identical reference conditions. To do this it is necessary to convert 3600 performance curve BSFC from SAE J1995 to ISO 3046/1 reference conditions using the following modifications:

- Subtract 4 g/kW-hr (.007 lb/hp-hr) from the Caterpillar performance curve SAE J1995 BSFC figures to compensate for the permissible +5% tolerance.
- Subtract approximately 5 g/kW-hr (.008 lb/hp-hr) in cases where the competitive situation dictates a fuel consumption declaration without engine driven pumps.

The results of the fuel consumption calculations derived above provides an ISO 3046/1 BSFC value based on +5% tolerance, 42780 kJ/kg LHV fuel and 32°C (90°F) aftercooler water temperature.

Other considerations where applicable are:

- Compensate for alternate reference fuel heat values by multiplying the 3600 Engine BSFC by the Caterpillar test fuel LHV (42,780), divided by the reference fuel LHV.

Example:

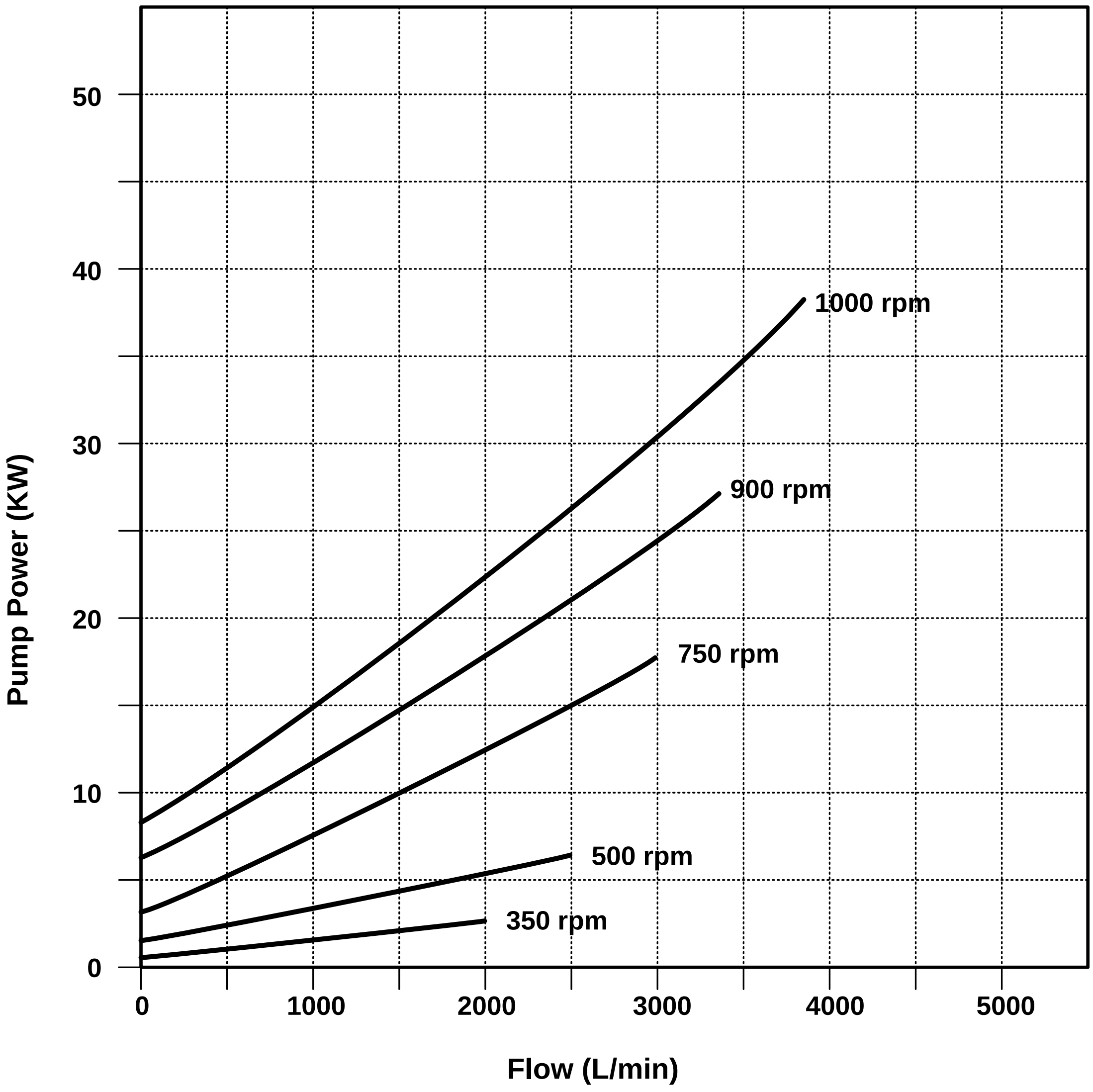
Caterpillar BSFC of 193 g/bkW-hr with 42,780 LHV. Competition declares BSFC with 43,000 LHV fuel. Equivalent Caterpillar BSFC =

$$193 \times \frac{42780}{43000} = 192 \text{ g/bkW-hr}$$

with 43,000 kJ/kg fuel.

- Add 3% to the Caterpillar Performance Curve SAE J1995 BSFC figures to obtain a maximum guaranteed rated fuel consumption.
- Add 5% to the Caterpillar Performance Curve SAE J1995 BSFC figures to obtain maximum guaranteed part load fuel consumption.
- Contact the factory for guaranteed fuel consumption figures with heavy fuels. A complete fuel specification is required.
- The power required to drive the Caterpillar supplied sea water pump is shown in Figure 30. It is sometimes necessary to estimate the *added* fuel consumption needed to drive the pump at the rated speed of the engine. This can be found by multiplying the BSFC for the rated power by the sum of the rated power and the pump power and then dividing by the rated power.

$$BSFC_{SW} = BSFC_R \frac{(Power_R + Power_{SW})}{Power_R}$$



3600 Seawater Pump
Pump Power vs. Flow and Engine Speed **Figure 30**

Note: Some competitors publish fuel consumption figures based on a "fuel optimized engine configuration". This is a fully run-in-test engine, generally without water and oil pumps and with a turbocharger match and fuel injection rates/timing not applicable to production engines. Only guaranteed fuel consumption figures can be compared for specific applications.

3600 Idle Fuel Rates

Figure 31 shows the idle fuel rates of 3600 Engines operating on distillate fuel with a density of 838.9 g/L (7.001 lb/gal).

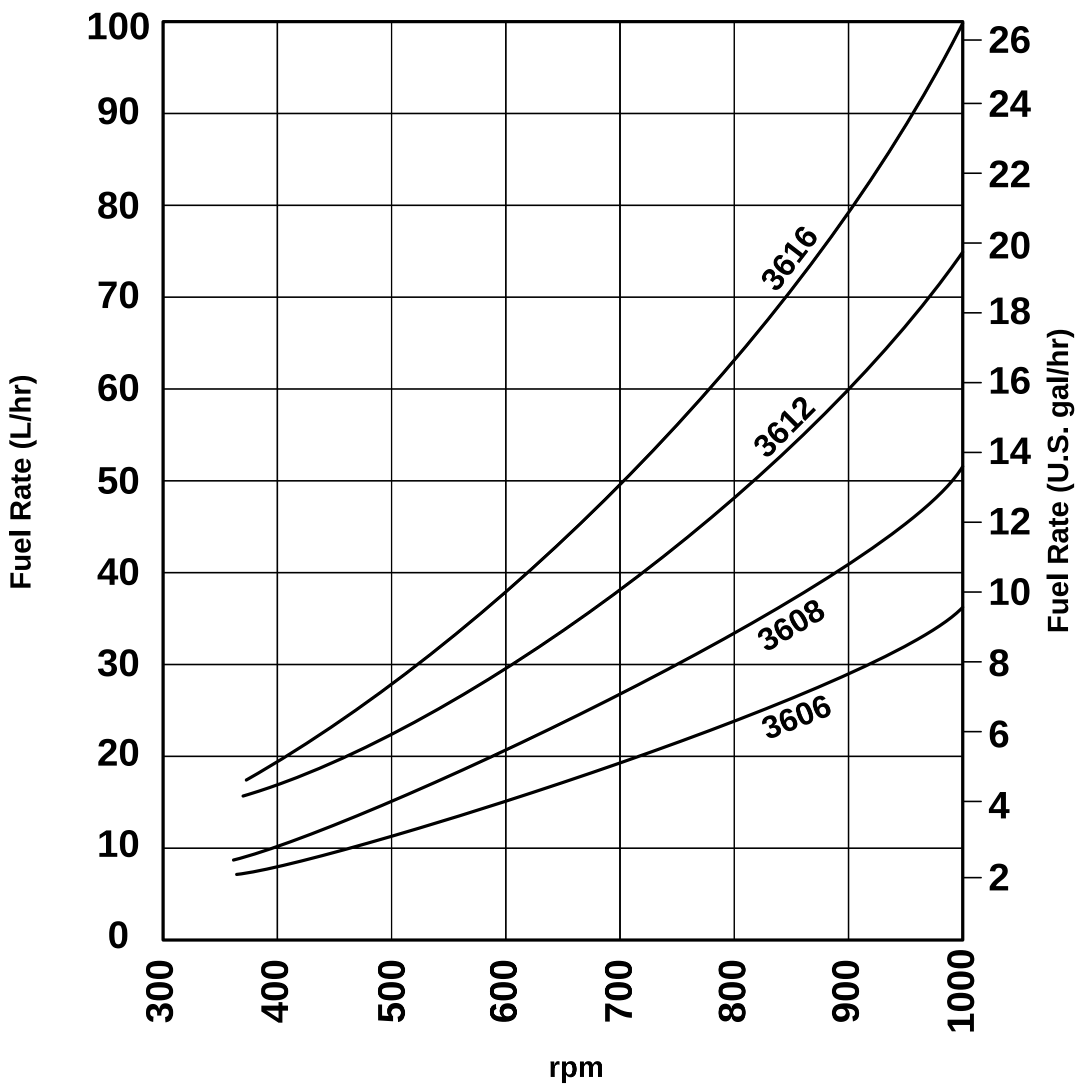
Tolerances

The performance data presented in this section represent typical values under normal operating conditions. Ambient air conditions and fuel will affect these values. Each may vary in accordance with the tolerances shown in Figure 32.

Performance Tolerances

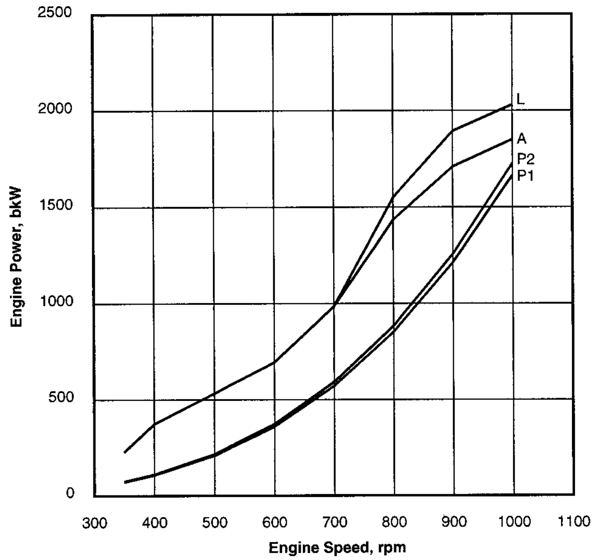
Item	Tolerance
Power	± 3%
Fuel rate	± 5%
Specific fuel consumption	± 3%
Inlet air flow	± 5%
Exhaust flow	± 6%
Heat rejection	± 5%
Exhaust stack temperature	± 8%
Intake manifold pressure	± 10%

Figure 32



3600 Engine Idle Fuel Rates

Figure 31

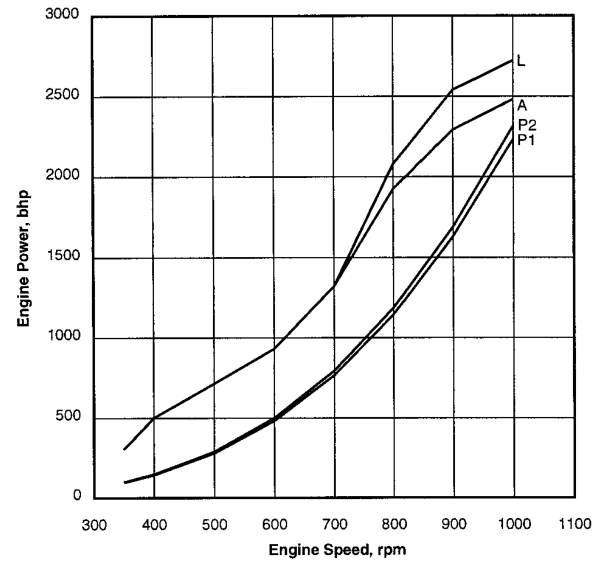


ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8850 Curve A	1000	1850.0	200	440.9	220.6	176.0	407	400.3
	900	1709.2	197	401.5	195.0	148.7	436	353.6
	800	1434.6	198	338.3	147.6	112.9	485	288.1
	700	984.4	208	243.6	78.8	72.8	526	196.3
	600	694.4	234	193.5	46.7	52.0	529	140.0
	500	532.1	237	150.0	29.7	38.2	513	101.9
	400	373.8	252	112.5	17.2	27.7	510	72.6
	350	226.9	258	69.7	6.0	20.7	371	45.1
TM8880 Curve L	1000	2030.0	200	484.7	248.5	190.6	412	436.8
	900	1893.7	196	443.5	227.6	165.4	434	391.6
	800	1549.8	197	363.5	166.7	122.0	485	309.9
	700	984.4	208	243.6	78.8	72.8	526	196.3
	600	694.4	234	193.5	46.7	52.0	529	140.0
	500	532.1	237	150.0	29.7	38.2	513	101.9
	400	373.8	252	112.5	17.2	27.7	510	72.6
	350	226.9	258	69.7	6.0	20.7	371	45.1

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8850 (Curve P1)	1000	1665.0	201	398.4	190.5	159.7	408	363.5
	900	1213.8	203	293.6	113.3	107.9	443	259.1
	800	852.5	209	212.4	59.8	72.5	460	178.9
	700	571.1	219	149.0	28.2	50.2	435	119.6
	600	359.6	229	98.3	11.3	36.5	364	78.1
	500	208.1	245	60.8	2.9	27.3	275	49.8
	400	106.6	304	38.6	-0.3	20.6	220	33.4
	350	71.4	282	24.0	-1.6	17.5	176	25.9
TM8880 (Curve P2)	1000	1726.0	200	412.2	200.4	165.1	407	375.5
	900	1258.3	202	303.1	120.2	111.3	444	267.5
	800	883.7	208	219.1	63.8	74.5	464	184.7
	700	592.0	218	153.9	30.3	51.2	442	123.1
	600	372.8	228	101.5	12.3	37.0	371	80.0
	500	215.8	244	62.7	3.3	27.4	282	50.7
	400	110.5	293	38.6	-0.3	20.6	220	33.4
	350	74.0	281	24.8	-1.5	17.5	178	26.1



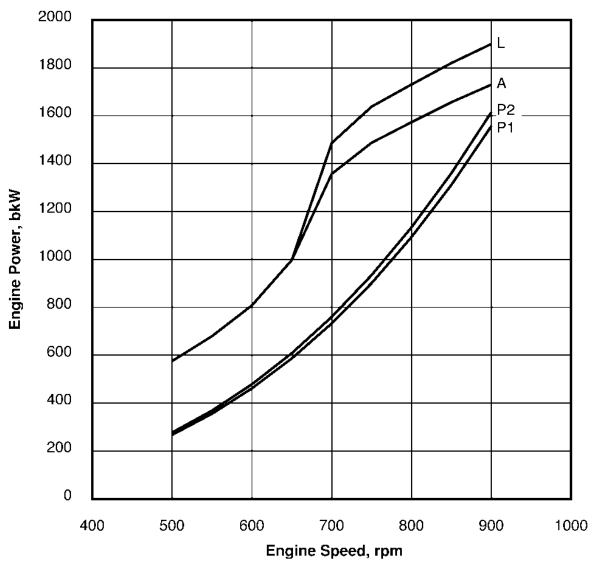
ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8850 Curve A	1000	2481	.329	116.5	65.3	6215	765	14136
	900	2292	.324	106.1	57.7	5251	817	12489
	800	1924	.326	89.4	43.7	3987	905	10173
	700	1320	.342	64.4	23.3	2571	978	6932
	600	931	.385	51.1	13.8	1836	984	4944
	500	714	.390	39.6	8.8	1349	955	3600
	400	501	.414	29.7	5.1	978	950	2565
	350	304	.424	18.4	1.8	731	699	1592
TM8880 Curve L	1000	2722	.329	128.0	73.6	6731	773	15424
	900	2539	.322	117.2	67.4	5841	812	13828
	800	2078	.324	96.0	49.4	4308	905	10944
	700	1320	.342	64.4	23.3	2571	978	6932
	600	931	.385	51.1	13.8	1836	984	4944
	500	714	.390	39.6	8.8	1349	955	3600
	400	501	.414	29.7	5.1	978	950	2565
	350	304	.424	18.4	1.8	731	699	1592

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8850 (Curve P1)	1000	2233	.330	105.2	56.4	5640	766	12836
	900	1628	.334	77.6	33.6	3810	830	9149
	800	1143	.344	56.1	17.7	2560	861	6317
	700	766	.360	39.4	8.4	1773	815	4222
	600	482	.376	26.0	3.3	1289	687	2756
	500	279	.403	16.1	0.9	964	528	1758
	400	143	.500	10.2	-0.1	727	427	1180
	350	96	.464	6.3	-0.5	618	348	915
TM8880 (Curve P2)	1000	2315	.329	108.9	59.3	5830	765	13261
	900	1687	.332	80.1	35.6	3931	830	9445
	800	1185	.342	57.9	18.9	2631	867	6521
	700	794	.358	40.7	9.0	1808	828	4349
	600	500	.375	26.8	3.6	1307	700	2823
	500	289	.401	16.6	1.0	968	539	1791
	400	148	.482	10.2	-0.1	727	427	1180
	350	99	.462	6.6	-0.4	618	353	922

Figure 2

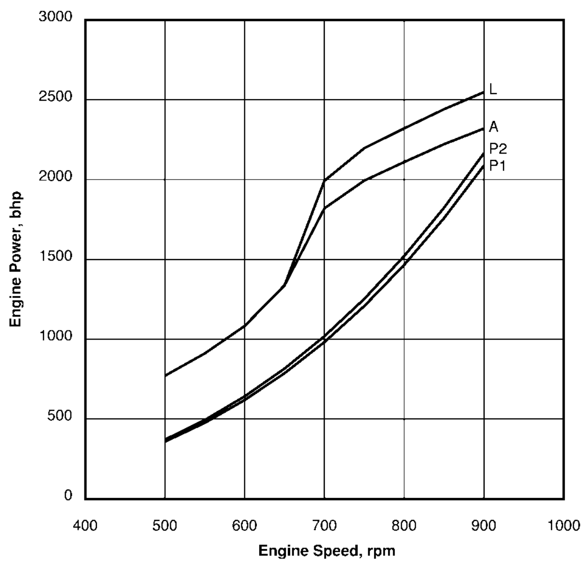


ZONE LIMIT DATA

	Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8883 Curve A	900	1730.0	198	409.3	216.6	159.4	404	361.3
	850	1656.7	198	390.6	203.1	146.0	421	339.4
	800	1573.3	197	370.3	188.1	132.3	439	316.1
	750	1487.3	198	350.3	173.9	119.0	460	293.4
	700	1357.2	199	321.5	151.9	103.2	488	264.5
	650	997.4	206	245.3	92.3	73.4	516	195.7
	600	807.8	212	204.1	66.6	59.2	520	158.8
	550	679.4	219	177.3	52.7	49.6	522	133.7
	500	575.3	226	155.2	42.7	41.9	524	113.4
TM8884 Curve L	900	1900.0	198	449.1	248.7	174.6	404	395.5
	850	1820.3	197	428.4	234.2	160.5	417	370.9
	800	1730.7	197	405.9	219.0	146.1	433	345.9
	750	1638.2	196	383.5	204.2	132.2	456	322.0
	700	1486.1	198	350.3	177.8	113.2	484	288.6
	650	997.4	206	245.3	92.3	73.4	516	195.7
	600	807.8	212	204.1	66.6	59.2	520	158.8
	550	679.4	219	177.3	52.7	49.6	522	133.7
	500	575.3	226	155.2	42.7	41.9	524	113.4

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8883 (Curve P1)	900	1557.0	199	369.9	185.4	144.0	409	328.9
	850	1311.6	201	314.6	139.2	115.7	432	273.5
	800	1093.5	204	266.3	101.2	92.3	453	225.0
	750	901.0	208	223.3	72.6	73.8	462	182.7
	700	732.6	211	184.6	51.2	59.9	456	147.1
	650	586.5	217	151.7	34.7	49.3	435	117.6
	600	461.3	223	122.7	21.6	40.7	400	92.3
	550	355.3	229	96.9	12.7	33.9	358	72.0
	500	267.0	233	74.3	7.1	28.7	312	56.1
TM8884 (Curve P2)	900	1615.0	199	383.0	195.9	149.2	408	339.8
	850	1360.5	200	325.1	148.0	119.9	430	282.8
	800	1134.3	203	275.0	108.0	95.5	453	232.8
	750	934.6	207	230.6	77.5	76.1	464	189.1
	700	759.9	211	190.7	54.8	61.5	461	152.1
	650	608.4	216	156.7	37.2	50.4	442	121.5
	600	478.5	222	126.8	23.4	41.5	408	95.3
	550	368.6	228	100.2	13.8	34.4	366	74.0
	500	276.9	232	76.7	7.8	28.9	320	57.5



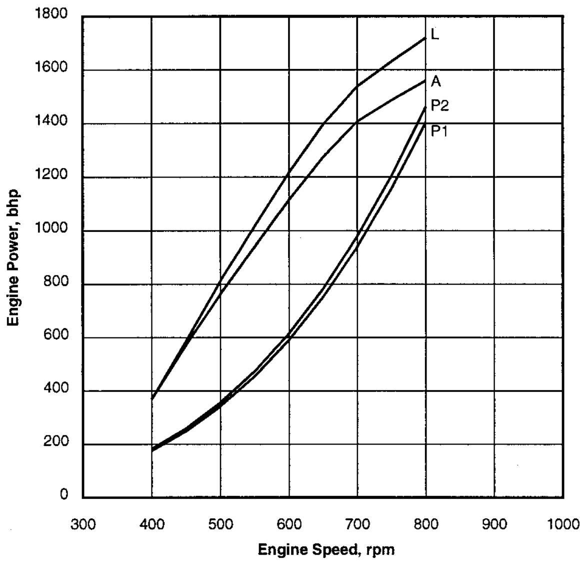
ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8883 Curve A	900	2320	.326	108.1	64.1	5629	760	12761
	850	2222	.326	103.2	60.1	5156	789	11987
	800	2110	.324	97.8	55.7	4672	823	11164
	750	1994	.326	92.5	51.5	4202	859	10362
	700	1820	.327	84.9	45.0	3644	910	9341
	650	1338	.339	64.8	27.3	2592	961	6909
	600	1083	.349	53.9	19.7	2091	968	5609
	550	911	.360	46.8	15.6	1752	971	4721
	500	771	.372	41.0	12.6	1480	976	4004
TM8884 Curve L	900	2548	.326	118.6	73.6	6166	758	13968
	850	2441	.324	113.2	69.4	5668	782	13098
	800	2321	.324	107.2	64.9	5159	811	12215
	750	2197	.322	101.3	60.5	4669	852	11371
	700	1993	.326	92.5	52.7	3998	903	10192
	650	1338	.339	64.8	27.3	2592	961	6909
	600	1083	.349	53.9	19.7	2091	968	5609
	550	911	.360	46.8	15.6	1752	971	4721
	500	771	.372	41.0	12.6	1480	976	4004

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8883 (Curve P1)	900	2088	.327	97.7	54.9	5085	769	11614
	850	1759	.330	83.1	41.2	4086	810	9657
	800	1466	.335	70.3	30.0	3260	847	7947
	750	1208	.342	59.0	21.5	2606	863	6453
	700	982	.347	48.8	15.2	2115	853	5196
	650	787	.357	40.1	10.3	1741	814	4152
	600	619	.367	32.4	6.4	1437	752	3259
	550	476	.376	25.6	3.8	1197	676	2541
	500	358	.383	19.6	2.1	1014	593	1981
TM8884 (Curve P2)	900	2166	.327	101.2	58.0	5269	766	12000
	850	1824	.329	85.9	43.8	4234	807	9987
	800	1521	.334	72.6	32.0	3373	847	8223
	750	1253	.340	60.9	23.0	2687	868	6678
	700	1019	.347	50.4	16.2	2172	862	5370
	650	816	.355	41.4	11.0	1780	827	4290
	600	642	.365	33.5	6.9	1466	767	3364
	550	494	.375	26.5	4.1	1215	690	2613
	500	371	.381	20.3	2.3	1021	608	2032

Figure 3

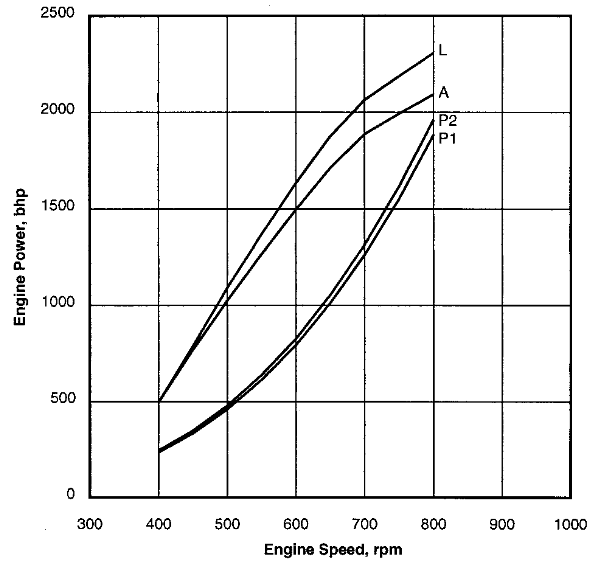


ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9033 Curve A	800	1560.0	191	355.9	245.1	156.1	348	323.0
	750	1486.4	190	336.7	230.1	141.5	361	300.3
	700	1407.5	189	317.7	214.4	127.8	379	278.4
	650	1275.1	190	289.2	184.4	109.6	402	247.8
	600	1115.7	194	257.4	147.3	89.9	438	214.7
	550	942.3	199	223.4	111.1	72.6	478	183.3
	500	763.6	178	162.2	61.4	49.9	478	126.7
	450	574.0	220	150.4	52.6	43.1	513	112.8
	400	369.6	230	101.3	24.9	30.5	431	72.6
TM9034 Curve L	800	1720.0	193	395.3	271.6	166.9	359	352.4
	750	1631.1	191	370.6	258.1	153.8	364	328.2
	700	1538.4	189	346.9	244.6	140.3	375	304.1
	650	1397.1	189	315.1	213.3	120.8	398	271.0
	600	1217.9	192	278.6	171.2	98.5	432	233.1
	550	1018.7	197	239.5	126.7	78.3	482	198.1
	500	813.0	167	162.2	61.4	49.9	478	126.7
	450	589.0	220	154.1	54.9	43.9	521	115.9
	400	369.6	230	101.3	24.9	30.5	431	72.6

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9033 (Curve P1)	800	1404.0	191	320.5	214.5	141.8	347	293.7
	750	1156.9	192	264.9	159.9	112.0	364	238.5
	700	940.6	195	219.1	111.7	86.6	388	191.4
	650	753.1	201	180.5	74.0	66.3	408	151.4
	600	592.3	207	146.3	47.5	51.8	405	118.4
	550	456.2	213	116.0	29.6	41.5	387	92.4
	500	342.8	220	89.8	17.0	33.8	358	71.5
	450	249.9	227	67.6	8.7	27.8	311	54.3
	400	175.5	238	49.7	3.9	23.4	265	41.8
TM9034 (Curve P2)	800	1462.0	191	333.5	226.0	147.1	347	304.6
	750	1204.7	192	275.1	170.1	116.3	363	247.4
	700	979.4	195	227.1	119.6	89.9	387	198.5
	650	784.2	200	187.0	79.6	68.6	410	157.1
	600	616.8	206	151.8	51.1	53.3	411	122.6
	550	475.1	213	120.4	32.0	42.4	395	95.5
	500	356.9	219	93.2	18.6	34.4	366	73.7
	450	260.2	226	70.2	9.6	28.2	318	55.7
	400	182.8	237	51.6	4.3	23.6	269	42.5



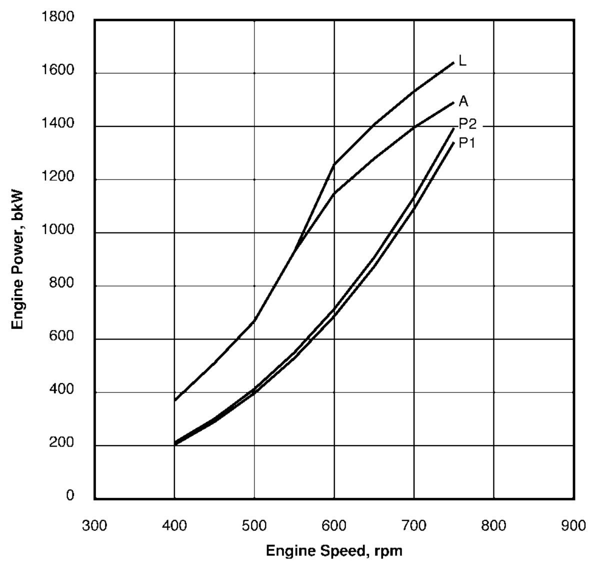
ZONE LIMIT DATA

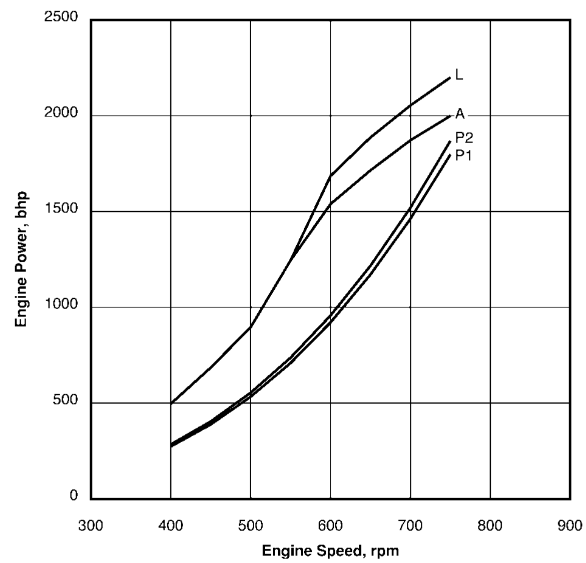
	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9033 Curve A	800	2092	.314	94.0	72.6	5513	658	11408
	750	1993	.312	88.9	68.1	4997	682	10606
	700	1887	.311	83.9	63.5	4513	714	9832
	650	1710	.312	76.4	54.6	3870	756	8749
	600	1496	.319	68.0	43.6	3175	820	7581
	550	1264	.327	59.0	32.9	2564	893	6473
	500	1024	.293	42.8	18.2	1762	893	4473
	450	770	.362	39.7	15.6	1522	956	3983
	400	496	.378	26.8	7.4	1077	807	2564
TM9034 Curve L	800	2307	.317	104.4	80.4	5894	679	12444
	750	2187	.314	97.9	76.4	5431	687	11591
	700	2063	.311	91.6	72.4	4955	708	10739
	650	1874	.311	83.2	63.2	4266	749	9571
	600	1633	.316	73.6	50.7	3478	810	8233
	550	1366	.324	63.3	37.5	2765	899	6994
	500	1090	.275	42.8	18.2	1762	893	4473
	450	790	.362	40.7	16.3	1550	969	4092
	400	496	.378	26.8	7.4	1077	807	2564

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9033 (Curve P1)	800	1883	.314	84.7	63.5	5008	657	10371
	750	1551	.316	70.0	47.4	3955	687	8422
	700	1261	.321	57.9	33.1	3058	730	6757
	650	1010	.330	47.7	21.9	2341	766	5348
	600	794	.340	38.6	14.1	1829	761	4179
	550	612	.350	30.6	8.8	1466	728	3262
	500	460	.362	23.7	5.0	1194	676	2525
	450	335	.373	17.9	2.6	982	592	1918
	400	235	.391	13.1	1.2	826	509	1477
TM9034 (Curve P2)	800	1961	.314	88.1	66.9	5195	657	10757
	750	1616	.316	72.7	50.4	4107	686	8737
	700	1313	.321	60.0	35.4	3175	728	7010
	650	1052	.329	49.4	23.6	2423	769	5547
	600	827	.339	40.1	15.1	1882	772	4331
	550	637	.350	31.8	9.5	1497	742	3373
	500	479	.360	24.6	5.5	1215	692	2604
	450	349	.372	18.5	2.8	996	604	1967
	400	245	.390	13.6	1.3	833	517	1502

Figure 4





ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9015 Curve A	750	1490.5	191	340.2	229.7	140.9	363	299.9
	700	1395.9	191	317.0	210.4	126.0	381	275.5
	650	1278.8	191	291.5	183.4	109.0	407	248.2
	600	1148.0	193	264.7	153.6	91.9	443	220.9
	550	928.5	199	220.5	111.0	70.6	483	179.4
	500	668.5	211	168.0	63.6	49.9	489	128.7
	450	510.5	221	134.4	40.6	38.6	491	98.8
	400	369.7	230	101.4	23.2	29.6	441	71.6
TM9018 Curve L	750	1640.5	191	374.4	262.6	154.9	363	329.8
	700	1531.8	190	347.3	242.0	139.0	377	302.1
	650	1407.0	191	319.8	214.0	120.9	400	272.4
	600	1257.3	192	287.8	179.3	101.6	434	241.2
	550	928.5	199	220.5	111.0	70.6	483	179.4
	500	668.5	211	168.0	63.6	49.9	489	128.7
	450	510.5	221	134.4	40.6	38.6	491	98.8
	400	369.7	230	101.4	23.2	29.6	441	71.6

ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9015 Curve A	750	1999	.314	89.9	68.0	4976	686	10592
	700	1872	.314	83.7	62.3	4450	717	9728
	650	1715	.314	77.0	54.3	3849	765	8765
	600	1539	.317	69.9	45.5	3245	829	7800
	550	1245	.327	58.2	32.9	2493	901	6337
	500	896	.347	44.4	18.8	1762	913	4544
	450	685	.363	35.5	12.0	1363	916	3488
	400	496	.378	26.8	6.9	1045	826	2530
TM9018 Curve L	750	2200	.314	98.9	77.8	5470	686	11646
	700	2054	.312	91.7	71.7	4909	710	10667
	650	1887	.314	84.5	63.4	4270	752	9620
	600	1686	.316	76.0	53.1	3588	812	8517
	550	1245	.327	58.2	32.9	2493	901	6337
	500	896	.347	44.4	18.8	1762	913	4544
	450	685	.363	35.5	12.0	1363	916	3488
	400	496	.378	26.8	6.9	1045	826	2530

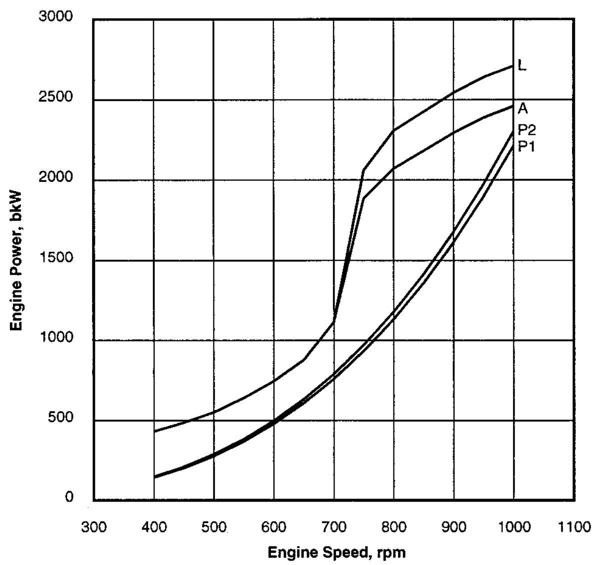
PROPELLER DEMAND DATA

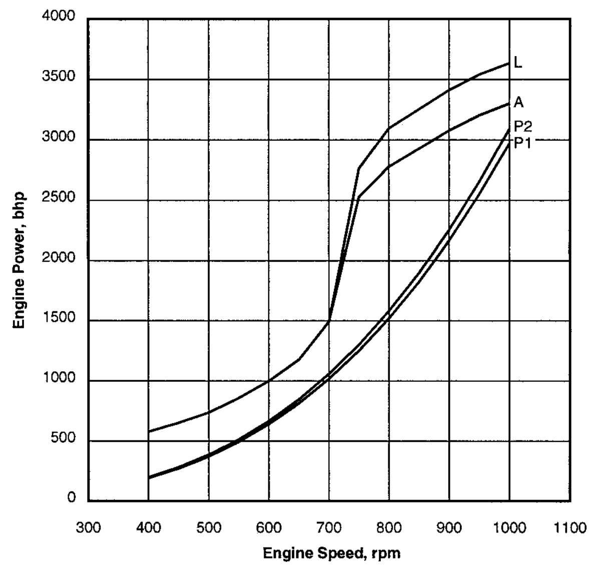
Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9015 (Curve P1)	750	1341.0	192	307.3	195.9	126.8	368	271.8
	700	1090.3	194	252.4	137.9	97.3	397	218.2
	650	872.9	198	206.3	93.0	74.0	426	173.5
	600	686.6	204	166.8	60.9	56.8	438	135.7
	550	528.9	211	132.8	37.7	44.4	422	104.1
	500	397.3	218	103.1	21.3	35.2	386	78.1
	450	289.7	225	77.6	10.5	28.3	333	57.6
	400	203.4	233	56.4	4.1	23	277	42.2
TM9018 (Curve P2)	750	1394.0	192	318.8	208.0	131.8	366	281.7
	700	1133.4	194	261.5	147.5	101.1	395	226.1
	650	907.4	197	213.5	99.8	76.7	426	179.9
	600	713.7	203	172.7	65.6	58.6	441	140.8
	550	549.8	210	137.5	40.8	45.5	429	107.8
	500	413.0	217	106.9	23.2	35.9	395	80.8
	450	301.1	224	80.4	11.7	28.7	342	59.5
	400	211.5	232	58.5	4.6	23.2	281	43.0

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9015 (Curve P1)	750	1798	.316	81.2	58.0	4478	694	9599
	700	1462	.319	66.7	40.8	3436	747	7705
	650	1171	.326	54.5	27.5	2613	798	6125
	600	921	.335	44.1	18.0	2006	820	4791
	550	709	.347	35.1	11.2	1568	791	3675
	500	533	.358	27.2	6.3	1243	727	2758
	450	388	.370	20.5	3.1	999	632	2036
	400	273	.383	14.9	1.2	812	530	1490
TM9018 (Curve P2)	750	1869	.316	84.2	61.6	4654	691	9947
	700	1520	.319	69.1	43.7	3570	744	7986
	650	1217	.324	56.4	29.6	2709	799	6353
	600	957	.334	45.6	19.4	2069	826	4972
	550	737	.345	36.3	12.1	1607	803	3807
	500	554	.357	28.2	6.9	1268	742	2854
	450	404	.368	21.2	3.5	1014	648	2099
	400	284	.381	15.5	1.4	819	538	1518

Figure 5





ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8852 Curve A	1000	2460.0	199	582.4	205.2	218.6	417	505.3
	950	2387.8	197	560.2	200.8	206.9	423	483.4
	900	2293.5	196	534.5	192.6	193.2	433	457.5
	850	2181.6	195	508.1	178.2	175.6	453	429.1
	800	2070.6	196	484.4	162.5	158.3	481	402.0
	750	1883.5	199	446.4	136.6	135.4	521	363.0
	700	1115.1	214	284.4	48.5	78.0	551	218.1
	650	878.2	224	234.1	29.7	61.8	545	172.7
	600	745.5	231	205.1	20.8	52.1	544	144.8
	550	640.5	239	182.1	15.4	44.5	545	124.5
	500	550.1	247	161.9	11.5	38.0	544	106.2
	400	430.8	262	134.6	9.9	29.2	540	81.7
TM8851 Curve L	1000	2710.0	199	643.7	228.6	233.7	431	552.2
	950	2639.7	197	620.3	228.8	224.0	431	530.2
	900	2543.1	195	592.3	223.9	211.8	436	504.1
	850	2425.0	195	563.0	211.2	194.8	449	474.6
	800	2307.1	195	537.0	195.5	177.0	475	445.9
	750	2058.6	197	484.4	159.1	148.4	516	395.1
	700	1115.1	214	284.4	48.5	78.0	551	218.1
	650	878.2	224	234.1	29.7	61.8	545	172.7
	600	745.5	231	205.1	20.8	52.1	544	144.8
	550	640.5	239	182.1	15.4	44.5	545	124.5
	500	550.1	247	161.9	11.5	38.0	544	106.2
	400	430.8	262	134.6	9.9	29.2	540	81.7

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8852 (Curve P1)	1000	2214.0	199	525.9	178.2	201.4	411	461.5
	950	1898.2	199	451.4	142.0	169.1	421	394.0
	900	1614.0	201	387.5	106.7	138.6	442	332.8
	850	1359.7	205	331.5	76.1	112.0	470	279.5
	800	1133.6	209	282.7	52.2	90.7	488	232.3
	750	934.0	216	240.3	34.5	74.3	487	190.7
	700	759.4	223	202.3	21.6	61.2	471	153.8
	650	608.0	230	166.9	12.8	50.9	444	123.5
	600	478.2	237	135.3	7.3	42.8	414	99.3
	550	368.4	251	110.1	3.4	36.0	380	79.0
	500	276.7	249	82.2	0.3	29.9	327	60.3
	400	141.7	289	48.9	-1.5	21.9	256	38.7
TM8851 (Curve P2)	1000	2303.5	199	546.2	188.1	207.8	413	477.5
	950	1975.0	199	468.0	151.3	175.2	421	408.0
	900	1679.3	200	401.3	114.6	143.8	442	344.8
	850	1414.6	204	343.2	82.2	116.1	470	289.6
	800	1179.4	208	292.6	56.4	93.3	491	240.5
	750	971.8	215	248.7	37.4	76.2	494	197.4
	700	790.1	222	209.4	23.5	62.5	480	158.9
	650	632.6	229	173.0	14.0	51.8	454	127.4
	600	497.6	237	140.3	8.0	43.4	423	102.2
	550	383.2	248	113.4	3.9	36.3	388	80.8
	500	287.9	248	85.3	0.6	30.2	336	61.7
	400	147.4	278	48.9	-1.5	21.9	256	38.7

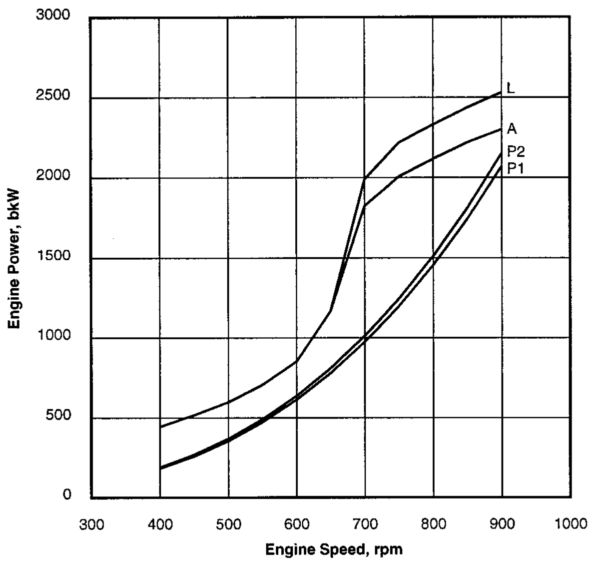
ZONE LIMIT DATA

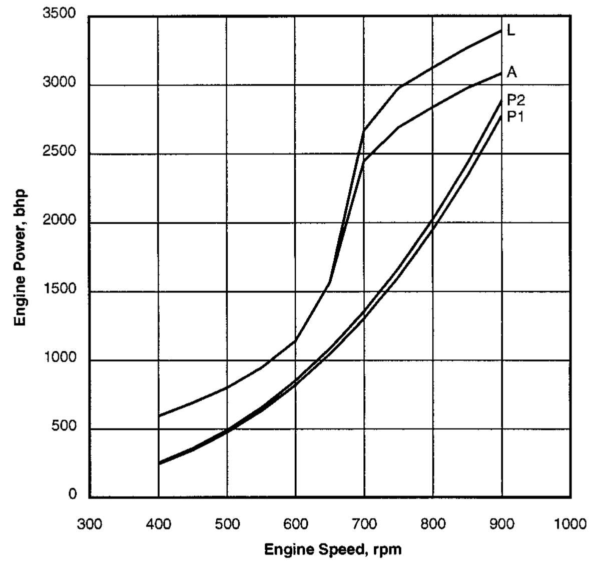
	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8852 Curve A	1000	3299	.327	153.9	60.8	7720	782	17845
	950	3202	.324	148.0	59.5	7307	793	17069
	900	3076	.322	141.2	57.0	6823	811	16155
	850	2926	.321	134.2	52.8	6201	847	15152
	800	2777	.322	128.0	48.1	5590	898	14197
	750	2526	.327	117.9	40.5	4782	969	12817
	700	1495	.352	75.1	14.4	2755	1024	7704
	650	1178	.368	61.8	8.8	2182	1012	6097
	600	1000	.38.0	54.2	6.2	1840	1010	5112
	550	859	.393	48.1	4.6	1572	1013	4398
	500	738	.406	42.8	3.4	1342	1012	3749
	400	578	.431	35.6	2.9	1031	1005	2884
TM8851 Curve L	1000	3634	.327	170.0	67.7	8253	808	19501
	950	3540	.324	163.9	67.8	7910	807	18724
	900	3410	.321	156.5	66.3	7480	817	17802
	850	3252	.321	148.7	62.5	6879	841	16759
	800	3094	.321	141.9	57.9	6251	887	15746
	750	2761	.324	128.0	47.1	5241	960	13951
	700	1495	.352	75.0	14.4	2755	1024	7704
	650	1178	.368	61.8	8.8	2182	1012	6097
	600	1000	.380	54.2	6.2	1840	1010	5112
	550	859	.393	48.1	4.6	1572	1013	4398
	500	738	.406	42.8	3.4	1342	1012	3749
	400	578	.431	35.6	2.9	1031	1005	2884

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8852 (Curve P1)	1000	2969	.327	138.9	52.8	7112	772	16298
	950	2546	.327	119.2	42.1	5972	790	13915
	900	2164	.330	102.4	31.6	4895	828	11752
	850	1823	.337	87.6	22.5	3955	877	9871
	800	1520	.344	74.7	15.5	3203	910	8205
	750	1253	.355	63.5	10.2	2624	908	6734
	700	1018	.367	53.4	6.4	2161	879	5430
	650	815	.378	44.1	3.8	1798	832	4362
	600	641	.390	35.7	2.2	1511	777	3508
	550	494	.413	29.1	1.0	1271	716	2788
	500	371	.409	21.7	0.1	1056	621	2128
	400	190	.475	12.9	-0.4	773	493	1367
TM8851 (Curve P2)	1000	3089	.327	144.3	55.7	7338	775	16861
	950	2649	.327	123.6	44.8	6187	790	14408
	900	2252	.329	106.0	33.9	5078	827	12178
	850	1897	.335	90.7	24.3	4100	878	10228
	800	1582	.342	77.3	16.7	3295	917	8494
	750	1303	.353	65.7	11.1	2691	920	6970
	700	1060	.365	55.3	7.0	2207	895	5612
	650	848	.376	45.7	4.1	1829	849	4498
	600	667	.390	37.1	2.4	1533	794	3610
	550	514	.408	30.0	1.2	1282	730	2853
	500	386	.408	22.5	0.2	1067	636	2179
	400	198	.457	12.9	-0.4	773	493	1367

Figure 6





ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8857 Curve A	900	2300.0	198	543.0	220.6	207.5	402	469.1
	850	2219.4	196	518.6	214.8	197.2	402	446.7
	800	2115.3	195	491.2	203.7	182.8	412	419.8
	750	2005.8	195	466.3	187.5	165.2	433	392.5
	720	1910.1	196	446.3	170.9	151.3	455	370.5
	700	1823.0	198	429.9	155.0	140.0	480	352.6
	650	1167.7	210	292.2	62.6	82.9	536	227.2
	600	852.4	221	224.3	31.7	60.5	539	166.7
	550	706.8	230	193.5	21.3	49.9	537	138.1
	500	597.8	238	169.6	14.1	41.7	535	114.8
	450	516.5	246	151.5	10.6	35.7	532	98.5
	400	443.6	255	134.7	8.7	31.1	525	84.8
TM8856 Curve L	900	2530.0	199	601.3	246.7	224.1	412	514.3
	850	2436.9	197	572.1	244.4	213.7	409	489.7
	800	2329.9	195	542.6	236.0	200.1	416	462.4
	750	2217.4	195	514.5	222.6	184.0	432	434.0
	720	2099.2	192	480.2	197.0	165.3	447	400.1
	700	1988.6	197	466.3	181.5	154.5	475	384.5
	650	1167.7	210	292.2	62.6	82.9	536	227.2
	600	852.4	221	224.3	31.7	60.5	539	166.7
	550	706.8	230	193.5	21.3	49.9	537	138.1
	500	597.9	238	169.5	14.1	41.7	535	114.8
	450	516.5	246	151.5	10.6	35.7	532	98.5
	400	443.6	255	134.7	8.7	31.1	525	84.8

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8857 (Curve P1)	900	2070.0	198	488.5	190.7	190.0	397	426.6
	850	1743.8	198	411.3	146.7	156.9	405	357.0
	800	1453.8	200	347.4	103.7	124.8	430	294.5
	750	1197.9	205	292.7	68.3	97.4	460	239.8
	720	1059.8	209	263.5	51.8	84.0	473	211.2
	700	974.0	211	245.2	43.0	76.6	478	194.1
	650	779.8	219	203.1	25.6	61.4	477	155.6
	600	613.3	226	165.3	13.9	49.8	458	123.0
	550	472.4	233	131.5	6.2	40.4	425	95.3
	500	354.9	240	101.4	1.1	32.9	386	73.0
	450	258.8	261	80.4	-1.3	27.6	349	57.4
	400	181.7	272	58.9	-2.5	23.4	301	45.0
TM8856 (Curve P2)	900	2150.5	198	507.3	201.2	196.2	399	441.5
	850	1811.6	197	426.0	156.6	162.9	403	369.6
	800	1510.4	200	359.4	111.7	129.6	428	305.2
	750	1244.5	204	302.7	74.0	100.8	460	248.5
	720	1101.1	208	272.5	56.2	86.6	476	218.7
	700	1011.8	210	253.6	46.7	78.9	482	200.9
	650	810.1	218	210.2	28.0	62.9	484	161.0
	600	637.2	225	171.2	15.3	50.8	467	127.0
	550	490.8	233	136.3	7.1	41.0	434	98.2
	500	368.7	239	105.2	1.7	33.3	395	75.0
	450	268.8	257	82.5	-1.0	27.8	354	58.3
	400	188.8	262	58.9	-2.5	23.4	301	45.0

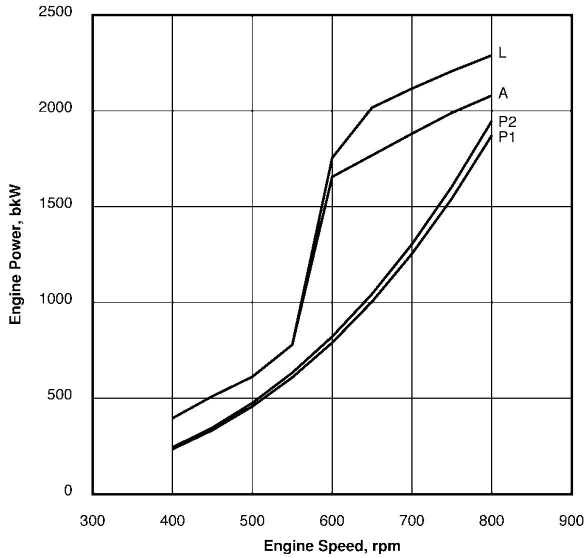
ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8857 Curve A	900	3084	.326	143.4	65.3	7328	756	16566
	850	2976	.322	137.0	63.6	6964	755	15774
	800	2837	.321	129.8	60.3	6456	774	14824
	750	2690	.321	123.2	55.5	5834	812	13862
	720	2561	.322	117.9	50.6	5343	851	13083
	700	2445	.326	113.6	45.9	4944	896	12452
	650	1566	.345	77.2	18.5	2928	996	8025
	600	1143	.363	59.3	9.4	2137	1001	5887
	550	948	.378	51.1	6.3	1762	999	4878
	500	802	.391	44.8	4.2	1473	994	4053
	450	693	.404	40.0	3.1	1261	990	3477
	400	595	.419	35.6	2.6	1098	978	2996
TM8856 Curve L	900	3393	.327	158.8	73.1	7914	773	18162
	850	3268	.324	151.1	72.4	7547	768	17292
	800	3124	.321	143.3	69.9	7066	781	16329
	750	2974	.321	135.9	65.9	6498	810	15328
	720	2815	.316	126.9	58.3	5838	837	14130
	700	2667	.324	123.2	53.7	5456	886	13580
	650	1566	.345	77.2	18.5	2928	996	8025
	600	1143	.363	59.3	9.4	2137	1001	5887
	550	948	.378	51.1	6.3	1762	999	4878
	500	802	.391	44.8	4.2	1473	994	4053
	450	693	.404	40.0	3.1	1261	990	3477
	400	595	.419	35.6	2.6	1098	978	2996

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8857 (Curve P1)	900	2776	.326	129.0	56.5	6710	747	15066
	850	2338	.326	108.7	43.4	5541	760	12606
	800	1950	.329	91.8	30.7	4407	806	10401
	750	1606	.337	77.3	20.2	3440	859	8470
	720	1421	.344	69.6	15.3	2966	884	7458
	700	1306	.347	64.8	12.7	2705	892	6854
	650	1046	.360	53.7	7.6	2168	890	5495
	600	822	.372	43.7	4.1	1759	856	4344
	550	633	.383	34.7	1.8	1427	797	3367
	500	476	.395	26.8	0.3	1162	726	2577
	450	347	.429	21.2	-0.4	975	659	2027
	400	244	.447	15.6	-0.7	826	573	1588
TM8856 (Curve P2)	900	2884	.326	134.0	59.6	6929	749	15591
	850	2429	.324	112.5	46.4	5753	758	13052
	800	2025	.329	94.9	33.1	4577	803	10776
	750	1669	.335	80.0	21.9	3560	860	8775
	720	1477	.342	72.0	16.6	3058	888	7724
	700	1357	.345	67.0	13.8	2786	899	7093
	650	1086	.358	55.5	8.3	2221	903	5686
	600	854	.370	45.2	4.5	1794	872	4486
	550	658	.383	36.0	2.1	1448	813	3466
	500	494	.393	27.8	0.5	1176	743	2647
	450	360	.423	21.8	-0.3	982	670	2060
	400	253	.431	15.6	-0.7	826	573	1588

Figure 7

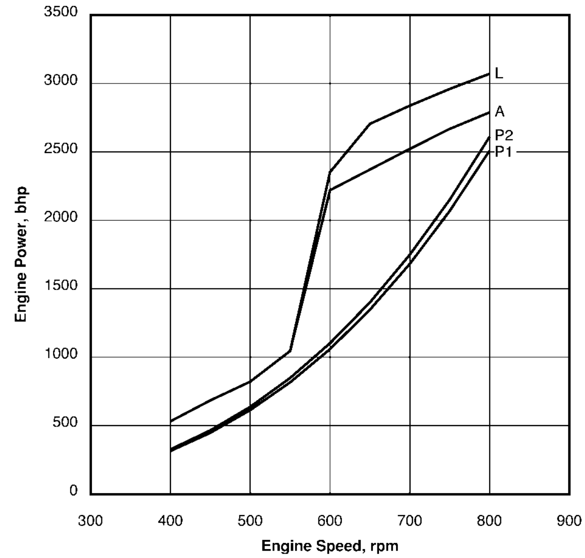


ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM9009 Curve A	800	2080.0	195	483.1	238.1	199.3	364	424.0
	750	1989.8	193	457.9	235.8	188.5	362	400.1
	720	1925.3	192	441.3	220.1	174.9	380	382.0
	700	1880.8	192	430.2	211.2	166.1	390	369.7
	650	1767.9	193	406.5	188.9	145.0	425	341.4
	600	1655.3	197	389.2	165.8	125.4	477	316.7
	550	778.9	223	207.3	35.4	55.8	529	152.2
	500	612.0	234	170.4	19.9	43.4	529	118.4
	450	510.3	245	148.8	12.9	35.6	523	97.0
	400	395.6	255	120.2	6.4	28.3	482	73.0
TM9010 Curve L	800	2290.0	196	535.5	265.1	213.6	375	463.0
	750	2207.0	194	510.5	268.4	205.1	370	441.3
	720	2153.5	193	494.2	260.0	195.2	380	426.4
	700	2116.2	192	483.7	253.6	187.2	385	416.2
	650	2017.0	192	460.6	237.3	168.5	411	391.1
	600	1754.2	196	410.4	185.1	134.7	467	335.5
	550	778.9	223	207.3	35.4	55.8	529	152.2
	500	612.0	234	170.4	19.9	43.4	529	118.4
	450	510.3	245	148.8	12.9	35.6	523	97.0
	400	395.6	255	120.2	6.4	28.3	482	73.0

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM9009 (Curve P1)	800	1872.0	195	434.5	206.3	182.0	360	384.6
	750	1542.5	195	357.9	157.9	146.1	374	315.6
	720	1364.7	197	320.9	120.7	121.4	407	276.7
	700	1254.1	200	298.5	99.9	107.1	428	252.5
	650	1004.1	208	249.0	59.7	78.9	467	198.8
	600	789.8	218	205.2	34.6	59.9	478	152.6
	550	608.3	227	164.6	19.1	46.7	466	118.1
	500	457.0	236	128.5	8.4	36.4	439	88.0
	450	333.2	245	97.1	2.5	29.2	388	65.3
	400	234.0	244	68.0	-0.2	24.2	332	49.1
TM9010 (Curve P2)	800	1947.0	195	451.8	218.1	188.5	360	398.7
	750	1604.3	194	371.2	168.7	152.1	371	327.3
	720	1419.4	196	332.3	129.9	126.5	404	287.0
	700	1304.3	199	308.9	108.1	111.7	425	261.8
	650	1044.3	207	257.5	64.9	81.7	469	206.2
	600	821.4	217	212.6	37.8	61.7	485	158.5
	550	632.7	226	170.8	21.2	47.9	476	122.7
	500	475.3	236	133.6	9.5	37.1	452	91.4
	450	346.5	244	100.8	3.1	29.5	397	67.1
	400	243.4	243	70.4	0.1	24.3	339	50.0



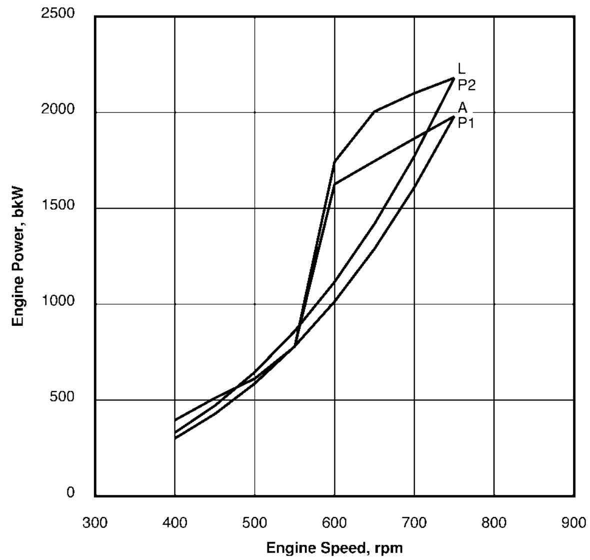
ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9009 Curve A	800	2789	.321	127.6	70.5	7038	687	14974
	750	2668	.317	121.0	69.8	6657	684	14130
	720	2582	.316	116.6	65.2	6177	715	13491
	700	2522	.316	113.6	62.5	5866	734	13055
	650	2371	.317	107.4	55.9	5121	797	12056
	600	2220	.324	102.8	49.1	4428	890	11183
	550	1045	.367	54.8	10.5	1971	984	5376
	500	821	.385	45.0	5.9	1533	984	4180
	450	684	.403	39.3	3.8	1257	974	3426
	400	531	.419	31.8	1.9	999	899	2578
TM9010 Curve L	800	3071	.322	141.5	78.5	7543	707	16349
	750	2960	.319	134.9	79.5	7243	699	15583
	720	2888	.317	130.6	77.0	6893	716	15057
	700	2838	.316	127.8	75.1	6611	724	14697
	650	2705	.316	121.7	70.3	5951	771	13813
	600	2352	.322	108.4	54.8	4757	872	11847
	550	1045	.367	54.8	10.5	1971	984	5376
	500	821	.385	45.0	5.9	1533	984	4180
	450	684	.403	39.3	3.8	1257	974	3426
	400	531	.419	31.8	1.9	999	899	2578

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9009 (Curve P1)	800	2510	.321	114.8	61.1	6427	679	13581
	750	2069	.321	94.5	46.8	5159	704	11147
	720	1830	.324	84.8	35.7	4287	765	9772
	700	1682	.329	78.9	29.6	3782	803	8916
	650	1347	.342	65.8	17.7	2786	873	7019
	600	1059	.358	54.2	10.2	2115	892	5389
	550	816	.373	43.5	5.7	1649	871	4169
	500	613	.388	33.9	2.5	1285	822	3109
	450	447	.403	25.7	0.7	1031	730	2305
	400	314	.401	18.0	-0.1	855	629	1732
TM9010 (Curve P2)	800	2611	.321	119.4	64.6	6657	680	14081
	750	2151	.319	98.1	50.0	5371	700	11559
	720	1903	.322	87.8	38.5	4467	760	10134
	700	1749	.327	81.6	32.0	3945	798	9246
	650	1400	.340	68.0	19.2	2885	877	7283
	600	1102	.357	56.2	11.2	2179	904	5596
	550	848	.372	45.1	6.3	1692	889	4333
	500	637	.388	35.3	2.8	1310	846	3229
	450	465	.401	26.6	0.9	1042	747	2370
	400	326	.399	18.6	0.0	858	641	1766

Figure 8



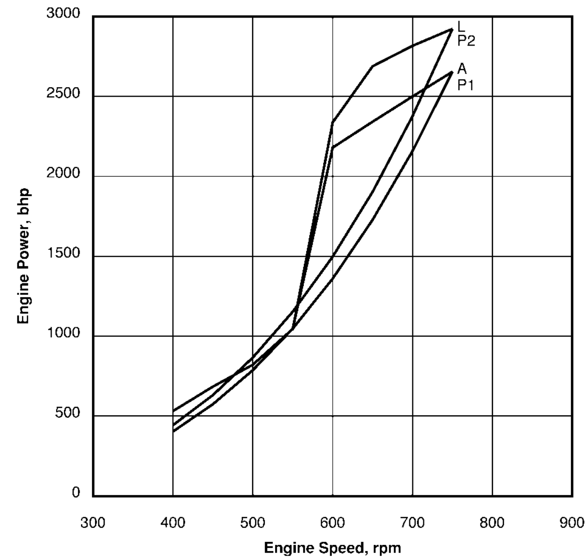
ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9013 Curve A	750	1980.0	193	455.6	234.2	187.6	362	398.3
	720	1910.8	192	438.1	217.5	173.6	380	379.3
	700	1864.3	192	426.6	208.2	164.5	391	366.4
	650	1746.3	193	401.9	184.7	143.0	427	337.1
	600	1625.9	198	383.0	160.2	122.7	479	311.1
	550	778.9	223	207.3	35.4	55.8	529	152.2
	500	612.0	234	170.4	19.9	43.4	529	118.4
	450	510.3	245	148.8	12.9	35.6	523	97.0
	400	395.6	255	120.2	6.4	28.3	482	73.0
TM9014 Curve L	750	2180.0	194	503.9	264.4	203.1	369	436.2
	720	2135.4	192	489.8	257.1	193.7	379	422.9
	700	2100.3	192	480.0	250.8	185.9	385	413.1
	650	2005.0	192	457.9	235.0	167.4	411	388.7
	600	1742.5	196	407.9	182.8	133.6	468	333.3
	550	778.9	223	207.3	35.4	55.8	529	152.2
	500	612.0	234	170.4	19.9	43.4	529	118.4
	450	510.3	245	148.8	12.9	35.6	523	97.0
	400	395.6	255	120.2	6.4	28.3	482	73.0

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9013 (Curve P1)	750	1980.0	193	455.6	234.2	187.6	362	398.3
	720	1751.8	193	403.1	188.9	158.6	385	349.4
	700	1609.8	194	372.5	161.2	140.2	407	318.8
	650	1288.9	201	308.3	101.1	101.0	466	251.7
	600	1013.8	212	255.6	60.0	73.4	511	195.1
	550	780.9	223	207.8	35.6	55.9	529	152.6
	500	586.8	234	163.6	17.7	42.1	516	113.1
	450	427.7	243	124.0	7.3	32.2	458	80.5
	400	300.4	246	88.2	1.7	25.3	382	56.0
TM9014 (Curve P2)	750	2180.0	194	503.9	264.4	203.1	369	436.2
	720	1928.7	192	442.1	220.7	175.2	380	382.7
	700	1772.4	193	406.9	191.2	155.7	396	349.2
	650	1419.1	198	334.9	123.1	112.4	457	275.9
	600	1116.2	209	277.6	73.7	80.5	515	214.7
	550	859.7	221	226.9	44.3	60.6	551	169.2
	500	645.9	233	179.6	23.1	45.1	545	125.8
	450	470.9	244	136.9	10.2	33.9	492	89.0
	400	330.7	248	98.0	3.0	26.1	411	60.6

Note: These ratings are for CPP applications only.



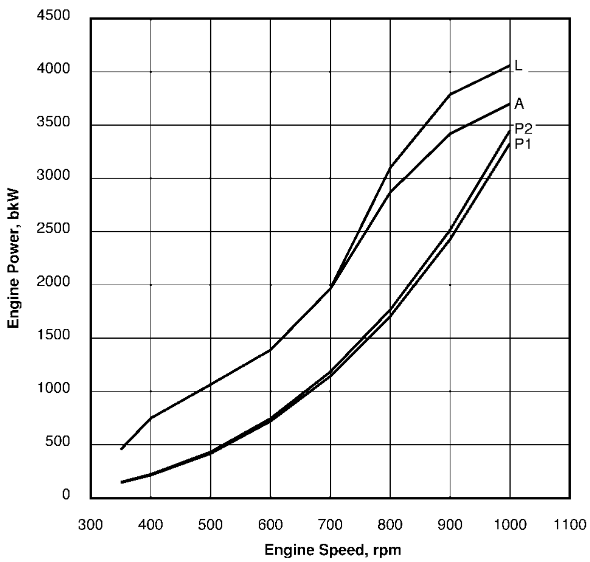
ZONE LIMIT DATA

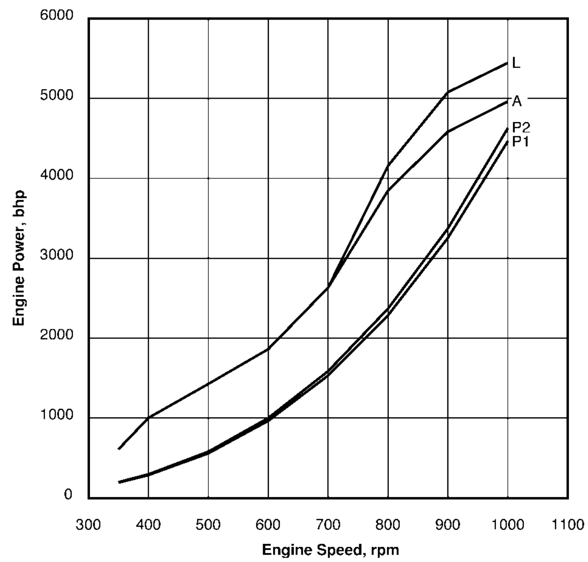
	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9013 Curve A	750	2655	.317	120.4	69.4	6625	684	14065
	720	2562	.316	115.7	64.4	6131	716	13394
	700	2500	.316	112.7	61.7	5809	735	12940
	650	2342	.317	106.2	54.7	5050	800	11903
	600	2180	.326	101.2	47.4	4333	895	10986
	550	1045	.367	54.8	10.5	1971	984	5376
	500	821	.385	45.0	5.9	1533	984	4180
	450	684	.403	39.3	3.8	1257	974	3426
	400	531	.419	31.8	1.9	999	899	2578
TM9014 Curve L	750	2923	.319	133.1	78.3	7172	697	15403
	720	2864	.316	129.4	76.1	6840	715	14933
	700	2817	.316	126.8	74.3	6565	724	14587
	650	2689	.316	121.0	69.6	5912	772	13728
	600	2337	.322	107.8	54.1	4718	874	11769
	550	1045	.367	54.8	10.5	1971	984	5376
	500	821	.385	45.0	5.9	1533	984	4180
	450	684	.403	39.3	3.8	1257	974	3426
	400	531	.419	31.8	1.9	999	899	2578

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9013 (Curve P1)	750	2655	.317	120.4	69.4	6625	684	14065
	720	2349	.317	106.5	55.9	5601	726	12338
	700	2159	.319	98.4	47.7	4951	764	11258
	650	1728	.330	81.4	29.9	3567	870	8887
	600	1360	.349	67.5	17.8	2592	951	6890
	550	1047	.367	54.9	10.5	1974	985	5390
	500	787	.385	43.2	5.2	1487	961	3995
	450	574	.399	32.8	2.2	1137	856	2842
	400	403	.404	23.3	0.5	893	719	1978
TM9014 (Curve P2)	750	2923	.319	133.1	78.3	7172	697	15403
	720	2586	.316	116.8	65.4	6187	715	13514
	700	2377	.317	107.5	56.6	5498	746	12332
	650	1903	.326	88.5	36.5	3969	855	9742
	600	1497	.344	73.3	21.8	2843	959	7583
	550	1153	.363	59.9	13.1	2140	1023	5975
	500	866	.383	47.4	6.8	1593	1013	4442
	450	631	.401	36.2	3.0	1197	918	3142
	400	443	.408	25.9	0.9	922	771	2141

Figure 9





ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8881 Curve A	1000	3700.0	200	881.9	220.6	352.0	407	800.6
	900	3418.4	197	803.1	195.0	297.5	436	707.3
	800	2869.2	198	676.7	147.6	223.3	485	569.6
	700	1963.4	208	485.9	78.4	145.2	525	391.5
	600	1388.7	234	387.1	46.7	984.1	529	2523.0
	500	1064.2	237	300.1	29.7	764.0	513	1956.0
	400	747.5	252	225.0	17.2	114.9	510	296.6
	350	453.8	258	139.4	6.0	41.4	371	90.1
TM8882 Curve L	1000	4060.0	200	969.4	248.5	381.3	412	873.5
	900	3787.3	196	886.9	227.6	330.7	434	783.1
	800	3099.6	197	726.9	166.7	242.5	485	613.2
	700	1963.4	208	485.9	78.4	145.2	525	391.5
	600	1388.7	234	387.1	46.7	984.1	529	2523.0
	500	1064.2	237	300.1	29.7	764.0	513	1956.0
	400	747.5	252	225.0	17.2	114.9	510	296.6
	350	453.8	258	139.4	6.0	41.4	371	90.1

ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8881 Curve A	1000	4962	.329	233.0	65.3	12431	765	28273
	900	4584	.324	212.2	57.7	10506	817	24978
	800	3848	.326	178.8	43.7	7886	905	20115
	700	2633	.342	128.4	23.2	5128	977	13826
	600	1862	.385	102.3	13.8	34753	984	89099
	500	1427	.390	79.3	8.8	26980	955	69086
	400	1002	.414	59.4	5.1	4058	950	10474
	350	609	.424	36.8	1.8	1462	699	3182
TM8882 Curve L	1000	5445	.329	256.1	73.6	13465	773	30847
	900	5079	.322	234.3	67.4	11679	812	27655
	800	4157	.324	192.0	49.4	8564	905	21655
	700	2633	.342	128.4	23.2	5128	977	13826
	600	1862	.385	102.3	13.8	34753	984	89099
	500	1427	.390	79.3	8.8	26980	955	69086
	400	1002	.414	59.4	5.1	4058	950	10474
	350	609	.424	36.8	1.8	1462	699	3182

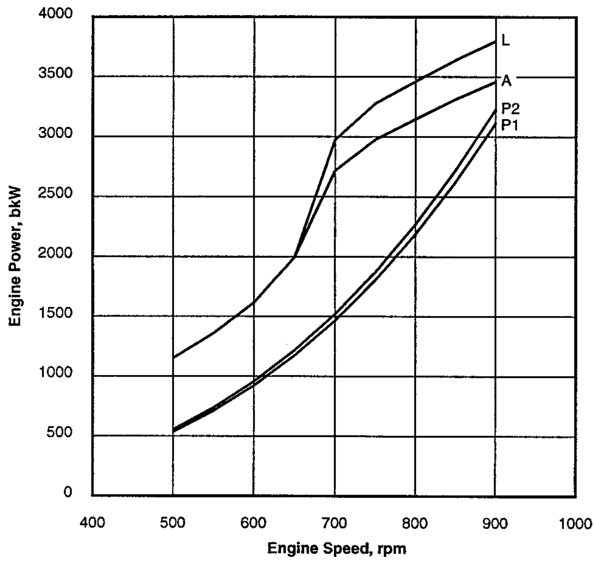
PROPELLER DEMAND DATA

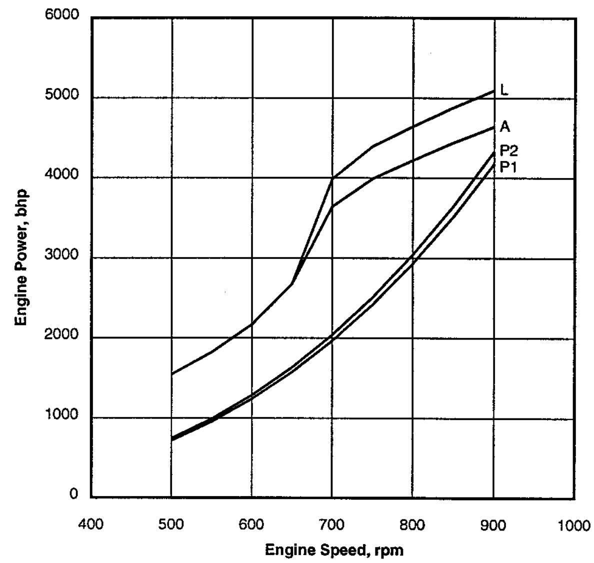
Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8881 (Curve P1)	1000	3330.0	201	796.7	190.5	319.4	408	726.9
	900	2427.6	203	587.2	113.3	215.7	443	518.1
	800	1705.0	209	424.8	59.8	142.3	460	352.3
	700	1142.2	219	298.0	28.2	100.4	435	239.1
	600	719.3	229	196.7	11.3	70.5	364	149.5
	500	416.3	245	121.6	2.9	54.5	275	99.5
	400	213.1	304	77.3	-0.3	41.2	220	66.8
	350	142.8	282	48.0	-1.6	35.0	176	51.8
TM8882 (Curve P2)	1000	3451.0	200	824.3	200.4	330.1	407	750.8
	900	2515.8	202	606.0	120.2	222.6	444	534.8
	800	1766.9	208	438.1	63.7	146.0	464	363.5
	700	1183.7	218	307.6	30.3	102.3	442	246.2
	600	745.4	228	202.9	12.3	73.3	371	158.2
	500	431.4	244	125.4	3.3	54.9	282	101.4
	400	220.9	294	77.3	-0.3	41.2	220	66.8
	350	148.0	281	49.5	-1.5	35.1	178	52.2

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8881 (Curve P1)	1000	4466	.330	210.5	56.4	11280	766	25671
	900	3255	.334	155.1	33.6	7617	830	18297
	800	2286	.344	112.2	17.7	5025	861	12442
	700	1532	.360	78.7	8.4	3546	815	8444
	600	965	.376	52.0	3.3	2490	687	5280
	500	558	.403	32.1	0.9	1925	528	3515
	400	286	.500	20.4	-0.1	1455	427	2360
	350	191	.464	12.7	-0.5	1236	348	1829
TM8882 (Curve P2)	1000	4628	.329	217.8	59.3	11657	765	26516
	900	3374	.332	160.1	35.6	7861	830	18885
	800	2369	.342	115.7	18.9	5156	867	12836
	700	1587	.358	81.3	9.0	3613	828	8695
	600	1000	.375	53.6	3.6	2589	700	5586
	500	579	.401	33.1	1.0	1939	539	3582
	400	296	.483	20.4	-0.1	1455	427	2360
	350	198	.462	13.1	-0.4	1240	353	1843

Figure 10





ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8885 Curve A	900	3460.0	198	818.6	216.6	318.8	404	722.7
	850	3313.3	198	781.2	203.1	292.0	421	678.9
	800	3146.5	197	740.6	188.0	264.5	439	632.3
	750	2974.6	198	700.7	173.9	238.1	460	586.8
	700	2714.3	199	643.0	151.9	206.3	488	529.0
	650	1994.6	206	490.5	92.3	146.7	516	391.3
	600	1615.6	212	408.2	66.6	118.3	520	317.6
	550	1358.7	219	354.6	52.7	99.1	522	267.4
	500	1150.6	226	310.4	42.7	83.8	524	226.8
TM8886 Curve L	900	3800.0	198	898.2	248.7	349.3	404	791.0
	850	3640.6	197	856.7	234.2	321.0	417	741.8
	800	3461.5	197	811.8	219.0	292.2	433	691.8
	750	3276.4	196	767.1	204.2	264.3	456	644.0
	700	2972.2	198	700.6	177.7	226.4	484	577.2
	650	1994.6	206	490.5	92.3	146.7	516	391.3
	600	1615.6	212	408.2	66.6	118.3	520	317.6
	550	1358.7	219	354.6	52.7	99.1	522	267.4
	500	1150.6	226	310.4	42.7	83.8	524	226.8

ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8885 Curve A	900	4640	.326	216.3	64.1	11258	760	25521
	850	4443	.326	206.4	60.1	10312	789	23974
	800	4220	.324	195.6	55.7	9341	823	22328
	750	3989	.326	185.1	51.5	8408	859	20724
	700	3640	.327	169.9	45.0	7285	910	18683
	650	2675	.339	129.6	27.3	5181	961	13818
	600	2167	.349	107.8	19.7	4178	968	11217
	550	1822	.360	93.7	15.6	3500	971	9443
	500	1543	.372	82.0	12.6	2959	976	8008
TM8886 Curve L	900	5096	.326	237.3	73.6	12335	758	27935
	850	4882	.324	226.3	69.4	11336	782	26196
	800	4642	.324	214.5	64.9	10319	811	24430
	750	4394	.322	202.6	60.5	9334	852	22743
	700	3986	.326	185.1	52.6	7995	903	20383
	650	2675	.339	129.6	27.3	5181	961	13818
	600	2167	.349	107.8	19.7	4178	968	11217
	550	1822	.360	93.7	15.6	3500	971	9443
	500	1543	.372	82.0	12.6	2959	976	8008

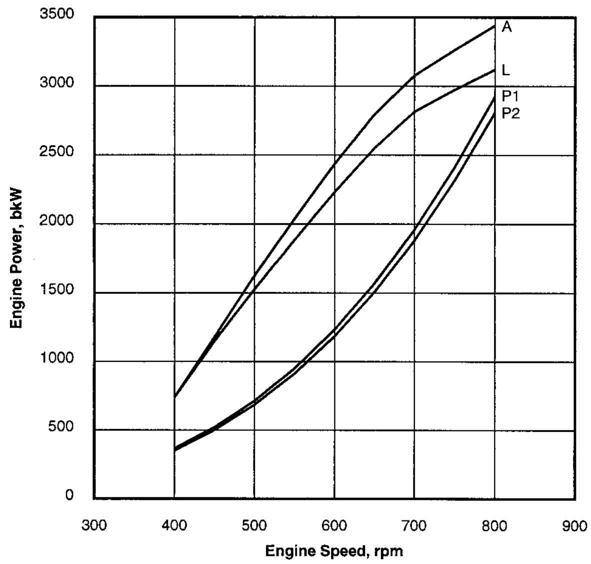
PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8885 (Curve P1)	900	3114.0	199	739.9	185.4	288.1	409	657.8
	850	2623.3	201	629.1	139.2	231.4	432	546.9
	800	2187.1	204	532.6	101.2	184.5	453	450.1
	750	1802.1	208	446.6	72.6	147.6	462	365.4
	700	1465.2	211	369.1	51.2	119.8	456	294.3
	650	1173.1	217	303.4	34.7	98.6	435	235.1
	600	922.7	223	245.3	21.6	81.5	400	184.6
	550	710.7	229	193.8	12.7	67.8	358	143.9
	500	534.0	233	148.6	7.1	57.3	312	112.2
TM8886 (Curve P2)	900	3230.0	199	766.0	195.9	298.4	408	679.6
	850	2721.0	200	650.3	148.0	239.8	430	565.6
	800	2268.5	203	550.0	108.0	190.9	453	465.7
	750	1869.2	207	461.2	77.5	152.2	464	378.2
	700	1519.7	211	381.4	54.8	122.9	461	304.1
	650	1216.8	216	313.4	37.2	100.8	442	243.0
	600	957.0	222	253.6	23.4	83.0	408	190.5
	550	737.2	228	200.4	13.8	68.8	366	148.0
	500	553.8	232	153.4	7.8	57.9	320	115.1

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8885 (Curve P1)	900	4176	.327	195.5	54.9	10174	769	23228
	850	3518	.330	166.2	41.2	8172	810	19314
	800	2933	.335	140.7	30.0	6516	847	15894
	750	2417	.342	118.0	21.5	5212	863	12905
	700	1965	.347	97.5	15.2	4231	853	10392
	650	1573	.357	80.1	10.3	3482	814	8304
	600	1237	.367	64.8	6.4	2878	752	6518
	550	953	.376	51.2	3.8	2394	676	5082
	500	716	.383	39.3	2.1	2024	593	3962
TM8886 (Curve P2)	900	4331	.327	202.4	58.0	10538	766	24001
	850	3649	.329	171.8	43.8	8468	807	19974
	800	3042	.334	145.3	32.0	6742	847	16445
	750	2507	.340	121.8	23.0	5375	868	13357
	700	2038	.347	100.8	16.2	4340	862	10740
	650	1632	.355	82.8	11.0	3560	827	8581
	600	1283	.365	67.0	6.9	2931	767	6728
	550	989	.375	52.9	4.1	2430	690	5227
	500	743	.381	40.5	2.3	2045	608	4063

Figure 11

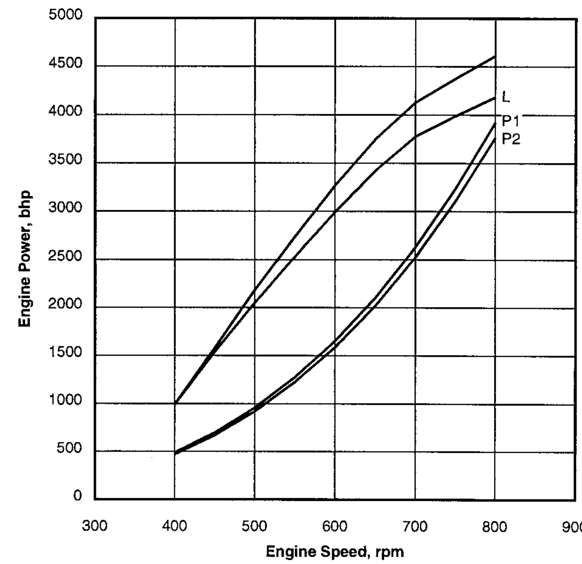


ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM9012 Curve A	800	3120.0	191	711.8	245.1	312.1	348	646.1
	750	2973.1	190	673.6	230.1	283.0	361	600.7
	700	2815.0	189	635.4	214.4	255.5	379	556.9
	650	2550.0	190	578.4	184.4	219.2	402	495.5
	600	2231.3	194	514.7	147.3	179.8	438	429.3
	550	1884.5	199	446.8	111.1	145.3	478	366.6
	500	1527.3	178	324.3	61.4	99.9	478	253.3
	450	1148.1	220	300.7	52.6	86.2	513	225.6
	400	739.1	230	202.7	24.9	61.1	431	145.2
TM9011 Curve L	800	3440.2	193	790.6	271.6	333.7	359	704.8
	750	3262.1	191	741.1	258.1	307.6	364	656.4
	700	3076.8	189	693.7	244.6	280.5	375	608.2
	650	2794.3	189	630.3	213.3	241.6	398	542.1
	600	2435.8	192	557.2	171.2	197.0	432	466.3
	550	2037.4	197	479.1	126.7	156.5	482	396.1
	500	1626.1	167	324.3	61.4	99.9	478	253.3
	450	1178.1	220	308.3	54.9	87.9	521	231.7
	400	739.1	230	202.7	24.9	61.1	431	145.2

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM9012 (Curve P1)	800	2808.0	191	641.0	214.5	283.7	347	587.4
	750	2313.7	192	529.9	159.9	224.0	364	477.0
	700	1881.1	195	438.2	111.7	173.1	388	382.7
	650	1506.1	201	361.0	74.0	132.5	408	302.9
	600	1184.6	207	292.7	47.5	103.7	405	236.7
	550	912.5	213	232.0	29.6	83.0	387	184.7
	500	685.5	220	179.6	17.0	67.6	358	143.0
	450	499.8	227	135.2	8.7	55.7	311	108.6
	400	351.0	238	99.5	3.9	46.7	265	83.7
TM9011 (Curve P2)	800	2924.0	191	667.0	226.0	294.3	347	609.2
	750	2409.3	192	550.2	170.1	232.6	363	494.8
	700	1958.9	195	454.3	119.6	179.9	387	397.0
	650	1568.4	200	374.1	79.6	137.2	410	314.2
	600	1233.6	206	303.6	51.1	106.5	411	245.3
	550	950.2	213	240.8	32.0	84.9	395	191.0
	500	713.9	219	186.4	18.6	68.8	366	147.5
	450	520.4	226	140.5	9.6	56.4	318	111.4
	400	365.5	237	103.3	4.3	47.1	269	85.1



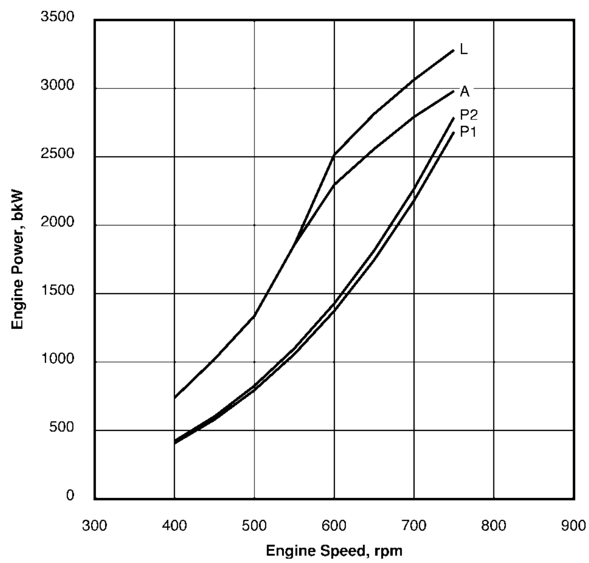
ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9012 Curve A	800	4184	.314	188.0	72.6	11022	658	22816
	750	3987	.312	177.9	68.1	9994	682	21214
	700	3775	.311	167.9	63.5	9023	714	19665
	650	3420	.312	152.8	54.6	7741	756	17497
	600	2992	.319	136.0	43.6	6350	820	15162
	550	2527	.327	118.0	32.9	5131	893	12946
	500	2048	.293	85.7	18.2	3528	893	8946
	450	1540	.362	79.4	15.6	3044	956	7967
	400	991	.378	53.5	7.4	2158	807	5128
TM9011 Curve L	800	4613	.317	208.9	80.4	11785	679	24890
	750	4375	.314	195.8	76.4	10863	687	23180
	700	4126	.311	183.3	72.4	9906	708	21479
	650	3747	.311	166.5	63.2	8532	749	19142
	600	3266	.316	147.2	50.7	6957	810	16467
	550	2732	.324	126.6	37.5	5527	899	13989
	500	2181	.275	85.7	18.2	3528	893	8946
	450	1580	.362	81.4	16.3	3104	969	8183
	400	991	.378	53.5	7.4	2158	807	5128

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9012 (Curve P1)	800	3766	.314	169.3	63.5	10019	657	20743
	750	3103	.316	140.0	47.4	7910	687	16845
	700	2523	.321	115.8	33.1	6113	730	13515
	650	2020	.330	95.4	21.9	4679	766	10696
	600	1589	.340	77.3	14.1	3662	761	8359
	550	1224	.350	61.3	8.8	2931	728	6524
	500	919	.362	47.4	5.0	2387	676	5049
	450	670	.373	35.7	2.6	1967	592	3836
	400	471	.391	26.3	1.2	1649	509	2954
TM9011 (Curve P2)	800	3921	.314	176.2	66.9	10393	657	21514
	750	3231	.316	145.3	50.4	8214	686	17473
	700	2627	.321	120.0	35.4	6353	728	14021
	650	2103	.329	98.8	23.6	4845	769	11094
	600	1654	.339	80.2	15.1	3761	772	8661
	550	1274	.350	63.6	9.5	2998	742	6747
	500	957	.360	49.2	5.5	2430	692	5208
	450	698	.372	37.1	2.8	1992	604	3935
	400	490	.390	27.3	1.3	1663	517	3005

Figure 12

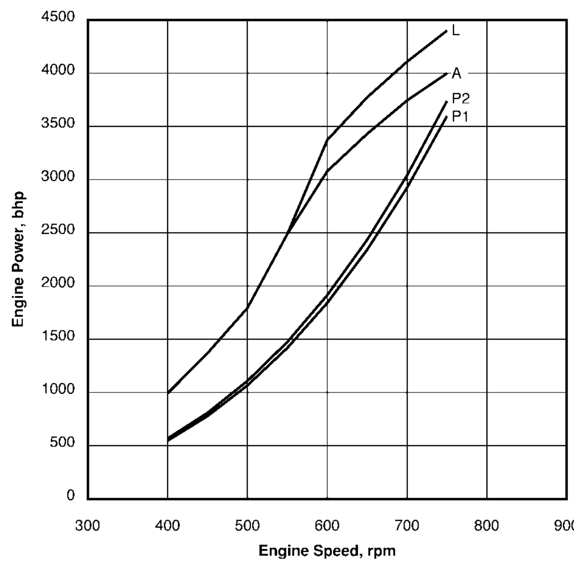


ZONE LIMIT DATA

	Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM9021 Curve A	750	2981.0	191	680.3	229.8	281.8	363	599.9
	700	2791.8	191	634.0	210.4	251.9	381	551.0
	650	2557.5	191	583.0	183.4	218.0	407	496.4
	600	2296.1	193	529.4	153.6	183.8	443	441.7
	550	1856.2	199	440.8	110.9	141.2	483	358.7
	500	1337.1	211	336.1	63.6	99.8	489	257.3
	450	1021.0	221	268.8	40.6	77.1	491	197.5
	400	739.3	230	202.8	23.2	59.3	441	143.3
TM9022 Curve L	750	3281.0	191	748.8	262.6	309.9	363	659.6
	700	3063.5	190	694.7	242.0	277.9	377	604.1
	650	2813.9	191	639.6	214.0	241.9	400	544.8
	600	2514.7	192	575.6	179.3	203.3	434	482.3
	550	1856.2	199	440.8	110.9	141.2	483	358.7
	500	1337.1	211	336.1	63.6	99.8	489	257.3
	450	1021.0	221	268.8	40.6	77.1	491	197.5
	400	739.3	230	202.8	23.2	59.3	441	143.3

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM9021 (Curve P1)	750	2682.0	192	614.6	195.9	253.7	368	543.6
	700	2180.6	194	504.8	137.9	194.5	397	436.4
	650	1745.9	198	412.6	93.0	147.9	426	346.9
	600	1373.2	204	333.6	60.9	113.5	438	271.4
	550	1057.7	211	265.5	37.7	88.8	422	208.1
	500	794.7	218	206.2	21.3	70.3	386	156.2
	450	579.3	225	155.1	10.5	56.6	333	115.3
	400	406.9	233	112.8	4.1	45.9	277	84.4
TM9022 (Curve P2)	750	2788.0	192	637.7	208.0	263.6	366	563.4
	700	2266.7	194	522.9	147.5	202.2	395	452.3
	650	1814.9	197	427.1	99.8	153.4	426	359.8
	600	1427.5	203	345.3	65.6	117.2	441	281.6
	550	1099.5	210	275.1	40.8	91.1	429	215.6
	500	826.1	217	213.8	23.2	71.8	395	161.7
	450	602.2	224	160.9	11.7	57.4	342	118.9
	400	423.0	232	117.0	4.6	46.4	281	86



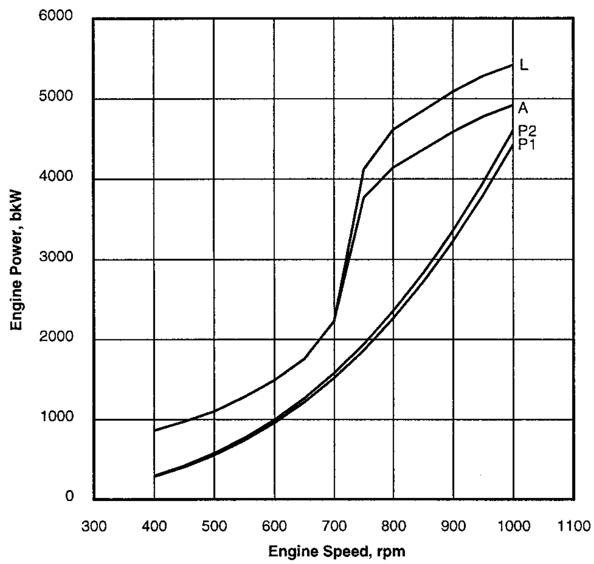
ZONE LIMIT DATA

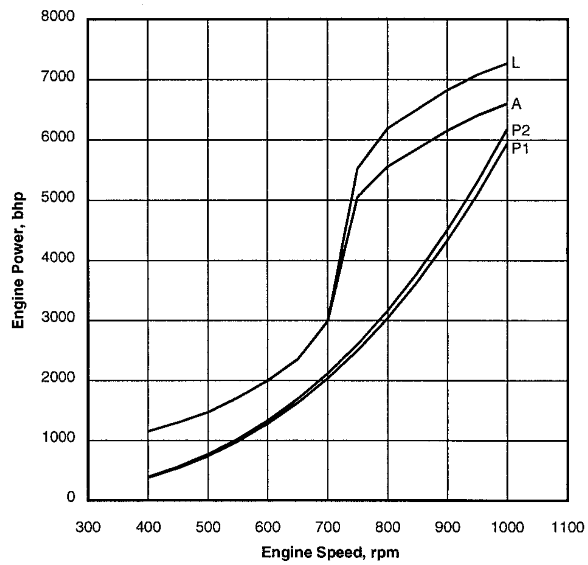
	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9021 Curve A	750	3998	.314	179.7	68.1	9952	686	21184
	700	3744	.314	167.5	62.3	8896	717	19457
	650	3430	.314	154.0	54.3	7699	765	17531
	600	3079	.317	139.9	45.5	6491	829	15599
	550	2489	.327	116.4	32.8	4986	901	12668
	500	1793	.347	88.8	18.8	3524	913	9087
	450	1369	.363	71.0	12.0	2723	916	6975
	400	991	.378	53.6	6.9	2094	826	5060
TM9022 Curve L	750	4400	.314	197.8	77.8	10944	686	23293
	700	4108	.312	183.5	71.7	9814	710	21333
	650	3773	.314	169.0	63.4	8543	752	19239
	600	3372	.316	152.1	53.1	7179	812	17034
	550	2489	.327	116.4	32.8	4986	901	12668
	500	1793	.347	88.8	18.8	3524	913	9087
	450	1369	.363	71.0	12.0	2723	916	6975
	400	991	.378	53.6	6.9	2094	826	5060

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9021 (Curve P1)	750	3597	.316	162.4	58.0	8959	694	19197
	700	2924	.319	133.4	40.8	6869	747	15411
	650	2341	.326	109.0	27.5	5223	798	12250
	600	1841	.335	88.1	18.0	4008	820	9583
	550	1418	.347	70.1	11.2	3136	791	7350
	500	1066	.358	54.5	6.3	2483	727	5515
	450	777	.370	41.0	3.1	1999	632	4071
	400	546	.383	29.8	1.2	1621	530	2980
TM9022 (Curve P2)	750	3739	.316	168.5	61.6	9309	691	19895
	700	3040	.319	138.1	43.7	7141	744	15971
	650	2434	.324	112.8	29.6	5417	799	12706
	600	1914	.334	91.2	19.4	4139	826	9943
	550	1474	.345	72.7	12.1	3217	803	7615
	500	1108	.357	56.5	6.9	2536	742	5709
	450	808	.368	42.5	3.5	2027	648	4199
	400	567	.381	30.9	1.4	1639	538	3036

Figure 13





ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8889 Curve A	1000	4920.0	199	1165.0	205.2	437.1	417	1011.0
	950	4775.4	197	1120.0	200.8	413.7	423	966.7
	900	4587.0	196	1069.0	192.6	386.4	433	914.9
	850	4363.4	195	1016.0	178.2	351.2	453	858.2
	800	4141.1	196	968.9	162.5	316.5	481	804.0
	750	3767.0	199	892.9	136.6	270.8	521	725.9
	700	2230.2	214	568.7	48.5	156.0	551	436.3
	650	1756.5	224	468.2	29.7	123.7	545	345.3
	600	1490.9	231	410.3	20.8	104.1	544	289.5
	550	1281.0	239	364.2	15.4	88.9	545	249.1
	500	1100.1	247	323.8	11.5	76.0	544	212.3
	400	861.7	262	269.2	9.9	58.5	540	163.4
TM8890 Curve L	1000	5420.0	199	1288.0	228.6	467.4	431	1104.0
	950	5279.4	197	1241.0	228.8	448.1	431	1060.0
	900	5086.5	195	1185.0	223.9	423.6	436	1008.0
	850	4850.2	195	1126.0	211.2	389.7	449	949.1
	800	4614.2	195	1074.0	195.5	354.1	475	891.7
	750	4117.1	197	968.7	159.0	296.8	516	790.1
	700	2230.2	214	568.7	48.5	156.0	551	436.3
	650	1756.5	224	468.2	29.7	123.7	545	345.3
	600	1490.9	231	410.3	20.8	104.1	544	289.5
	550	1281.0	239	364.2	15.4	88.9	545	249.1
	500	1100.1	247	323.8	11.5	76.0	544	212.3
	400	861.7	262	269.2	9.9	58.5	540	163.4

ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8889 Curve A	1000	6598	.327	307.7	60.8	15436	782	35689
	950	6404	.324	296.0	59.5	14610	793	34139
	900	6151	.322	282.4	57.0	13646	811	32309
	850	5851	.321	268.5	52.8	12403	847	30307
	800	5553	.322	256.0	48.1	11177	898	28393
	750	5052	.327	235.9	40.5	9563	969	25635
	700	2991	.352	150.2	14.4	5509	1024	15408
	650	2356	.368	123.7	8.8	4368	1012	12194
	600	1999	.38	108.4	6.2	3676	1010	10224
	550	1718	.393	96.2	4.6	3139	1013	8797
	500	1475	.406	85.5	3.4	2684	1012	7497
	400	1156	.431	71.1	2.9	2066	1005	5770
TM8890 Curve L	1000	7268	.327	340.1	67.7	16506	808	39002
	950	7080	.324	327.7	67.8	15825	807	37448
	900	6821	.321	312.9	66.3	14959	817	35604
	850	6504	.321	297.5	62.5	13762	841	33517
	800	6188	.321	283.7	57.9	12505	887	31490
	750	5521	.324	255.9	47.1	10481	960	27902
	700	2991	.352	150.2	14.4	5509	1024	15408
	650	2356	.368	123.7	8.8	4368	1012	12194
	600	1999	.38	108.4	6.2	3676	1010	10224
	550	1718	.393	96.2	4.6	3139	1013	8797
	500	1475	.406	85.5	3.4	2684	1012	7497
	400	1156	.431	71.1	2.9	2066	1005	5770

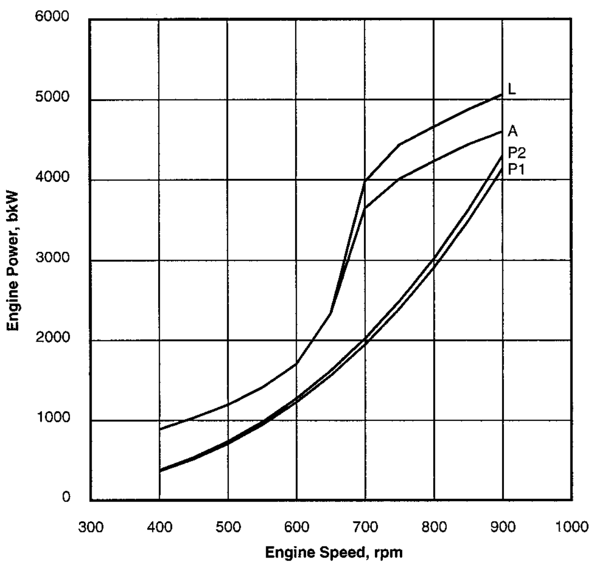
PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/min	Exh Temp °C	Exh Flow cu m/min
TM8889 (Curve P1)	1000	4428.0	199	1052.0	178.2	402.8	411	923.0
	950	3796.5	199	902.8	142.0	338.3	421	788.1
	900	3228.0	201	774.9	106.7	277.2	442	665.6
	850	2719.3	205	663.0	76.1	224.0	470	559.0
	800	2267.1	209	565.3	52.2	181.4	488	464.7
	750	1868.1	216	480.7	34.5	148.7	487	381.4
	700	1518.8	223	404.6	21.6	122.4	471	307.5
	650	1216.0	230	333.9	12.8	101.8	444	247.0
	600	956.4	237	270.6	7.3	85.6	414	198.7
	550	736.7	251	220.2	3.4	71.9	380	157.9
	500	553.5	249	164.5	0.3	59.9	327	120.6
	400	283.4	289	97.7	-1.5	43.9	256	77.4
TM8890 (Curve P2)	1000	4607.0	199	1093.0	188.1	415.6	413	954.9
	950	3949.9	199	936.0	151.3	350.5	421	816.0
	900	3358.5	200	802.7	114.6	287.5	442	689.7
	850	2829.3	204	686.5	82.2	232.1	470	579.3
	800	2358.8	208	585.1	56.4	186.7	491	481.1
	750	1943.6	215	497.4	37.4	152.4	494	394.8
	700	1580.2	222	418.9	23.5	125.0	480	317.8
	650	1265.2	229	346.0	14.0	103.5	454	254.8
	600	995.1	237	280.6	8.0	86.8	423	204.4
	550	766.5	248	226.8	3.9	72.6	388	161.6
	500	575.9	248	170.6	0.6	60.4	336	123.4
	400	294.8	278	97.7	-1.5	43.9	256	77.4

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/hp-hr	Fuel Rate gal/hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8889 (Curve P1)	1000	5938	.327	277.9	52.8	14225	772	32597
	950	5091	.327	238.5	42.1	11947	790	27830
	900	4329	.330	204.7	31.6	9789	828	23504
	850	3647	.337	175.1	22.5	7910	877	19741
	800	3040	.344	149.3	15.5	6406	910	16410
	750	2505	.355	127.0	10.2	5251	908	13469
	700	2037	.367	106.9	6.4	4323	879	10859
	650	1631	.378	88.2	3.8	3595	832	8723
	600	1283	.390	71.5	2.2	3023	777	7016
	550	988	.413	58.2	1.0	2539	716	5577
	500	742	.409	43.5	0.1	2115	621	4257
	400	380	.475	25.8	-0.4	1550	493	2733
TM8890 (Curve P2)	1000	6178	.327	288.6	55.7	14677	775	33723
	950	5297	.327	247.3	44.8	12378	790	28816
	900	4504	.329	212.1	33.9	10153	827	24356
	850	3794	.335	181.4	24.3	8197	878	20456
	800	3163	.342	154.6	16.7	6593	917	16988
	750	2606	.353	131.4	11.1	5382	920	13940
	700	2119	.365	110.7	7.0	4414	895	11224
	650	1697	.376	91.4	4.1	3655	849	8996
	600	1334	.390	74.1	2.4	3065	794	7219
	550	1028	.408	59.9	1.2	2564	730	5706
	500	772	.408	45.1	0.2	2133	636	4358
	400	395	.457	25.8	-0.4	1550	493	2733

Figure 14

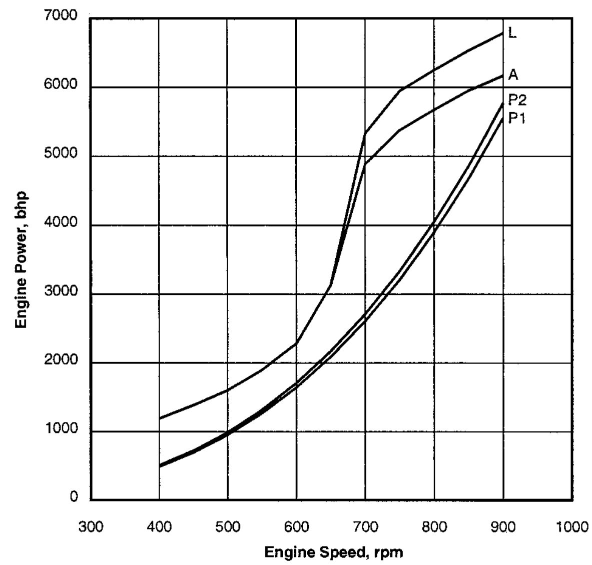


ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8887 Curve A	900	4600.0	198	1086.0	220.6	415.0	402	938.2
	850	4438.8	196	1037.0	214.8	394.3	402	893.3
	800	4230.3	195	982.4	203.7	365.6	412	839.5
	750	4011.5	195	932.6	187.5	330.3	433	785.0
	720	3819.9	196	892.6	170.9	302.6	455	740.9
	700	3645.7	198	859.7	154.9	280.0	480	705.1
	650	2335.5	210	584.3	62.6	165.8	536	454.5
	600	1704.7	221	448.6	31.7	120.9	539	333.4
	550	1413.6	230	386.9	21.3	99.8	537	276.2
	500	1195.7	238	339.3	14.1	83.3	535	229.5
	450	1033.0	246	302.9	10.6	71.5	532	196.9
	400	887.2	255	269.4	8.7	62.1	525	169.7
TM8888 Curve L	900	5060.0	199	1203.0	246.7	448.1	412	1029.0
	850	4873.8	197	1144.0	244.4	427.3	409	979.3
	800	4659.7	595	1085.0	236.0	400.3	416	924.8
	750	4434.8	195	1029.0	222.6	367.9	432	868.0
	720	4198.9	192	960.3	197.0	330.6	447	800.3
	700	3977.4	197	932.7	181.6	309.1	475	769.1
	650	2335.5	210	584.3	62.6	165.8	536	454.5
	600	1704.7	221	448.6	31.7	120.9	539	333.4
	550	1413.6	230	386.9	21.3	99.8	537	276.2
	500	1195.7	238	339.3	14.1	83.3	535	229.5
	450	1033.0	246	302.9	10.6	71.5	532	196.9
	400	887.2	255	269.4	8.7	62.1	525	169.7

PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM8887 (Curve P1)	900	4140.0	198	977.0	190.7	379.9	397	853.3
	850	3487.6	198	822.6	146.7	313.9	405	713.9
	800	2907.7	200	694.8	103.7	249.6	430	589.1
	750	2395.8	205	585.5	68.3	194.7	460	479.7
	720	2119.7	209	527.0	51.8	167.9	473	422.4
	700	1947.9	211	490.5	43.0	153.3	478	388.2
	650	1559.6	219	406.3	25.6	122.9	477	311.2
	600	1226.7	226	330.5	13.9	99.7	458	246.0
	550	944.8	233	263.0	6.2	80.9	425	190.7
	500	709.9	240	202.7	1.1	65.8	386	146.0
	450	517.5	261	160.7	-1.3	55.2	349	114.8
	400	363.5	272	117.8	-2.5	46.9	301	90.0
TM8888 (Curve P2)	900	4301.0	198	1015.0	201.2	392.4	399	883.0
	850	3623.3	197	852.1	156.6	325.7	403	739.2
	800	3020.7	200	718.8	111.7	259.3	428	610.3
	750	2489.0	204	605.4	74.0	201.7	460	497.0
	720	2202.1	208	544.9	56.2	173.3	476	437.4
	700	2023.7	210	507.2	46.7	157.7	482	401.7
	650	1620.2	218	420.4	28.0	125.8	484	322.0
	600	1274.4	225	342.3	15.3	101.6	467	254.1
	550	981.6	233	272.6	7.1	82.1	434	196.3
	500	737.5	239	210.4	1.7	66.6	395	149.9
	450	537.6	257	165.0	-1.0	55.6	354	116.7
	400	377.6	262	117.8	-2.5	46.9	301	90.0



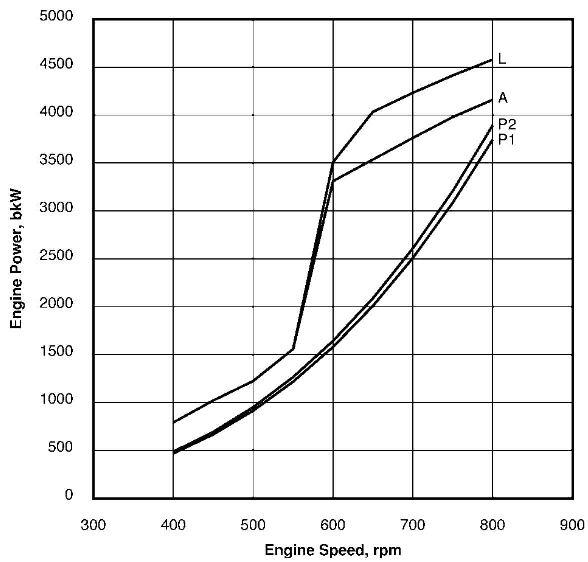
ZONE LIMIT DATA

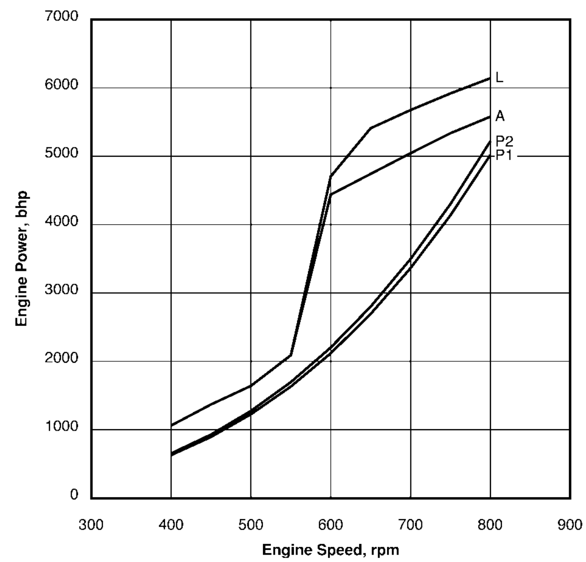
	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8887 Curve A	900	6169	.326	286.9	65.3	14656	756	33132
	850	5953	.322	274.0	63.6	13925	755	31547
	800	5673	.321	259.5	60.3	12911	774	29646
	750	5380	.321	246.4	55.5	11664	812	27723
	720	5123	.322	235.8	50.6	10686	851	26163
	700	4889	.326	227.1	45.9	9888	896	24901
	650	3132	.345	154.4	18.5	5855	996	16051
	600	2286	.363	118.5	9.4	4270	1001	11774
	550	1896	.378	102.2	6.3	3524	999	9755
	500	1603	.391	89.6	4.2	2942	994	8106
	450	1385	.404	80.0	3.1	2525	990	6955
	400	1190	.419	71.2	2.6	2193	978	5993
TM8888 Curve L	900	6786	.327	317.7	73.1	15825	773	36325
	850	6536	.324	302.2	72.4	15090	768	34584
	800	6249	.321	286.7	69.9	14136	781	32659
	750	5947	.321	271.8	65.9	12992	810	30653
	720	5631	.316	253.7	58.3	11675	837	28262
	700	5334	.324	246.4	53.8	10916	886	27161
	650	3132	.345	154.4	18.5	5855	996	16051
	600	2286	.363	118.5	9.4	4270	1001	11774
	550	1896	.378	102.2	6.3	3524	999	9754
	500	1603	.391	89.6	4.2	2942	994	8105
	450	1385	.404	80.0	3.1	2525	990	6953
	400	1190	.419	71.2	2.6	2193	978	5993

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM8887 (Curve P1)	900	5552	.326	258.1	56.5	13416	747	30133
	850	4677	.326	217.3	43.4	11085	760	25211
	800	3899	.329	183.5	30.7	8815	806	20802
	750	3213	.337	154.7	20.2	6876	859	16940
	720	2843	.344	139.2	15.3	5929	884	14917
	700	2612	.347	129.6	12.7	5414	892	13707
	650	2091	.36	107.3	7.6	4340	890	10991
	600	1645	.372	87.3	4.1	3521	856	8688
	550	1267	.383	69.5	1.8	2857	797	6733
	500	952	.395	53.5	0.3	2324	726	5154
	450	694	.429	42.5	-0.4	1949	659	4054
	400	487	.447	31.1	-0.7	1656	573	3177
TM8888 (Curve P2)	900	5768	.326	268.0	59.6	13857	749	31183
	850	4859	.324	225.1	46.4	11502	758	26104
	800	4051	.329	189.9	33.1	9157	803	21553
	750	3338	.335	159.9	21.9	7123	860	17550
	720	2953	.342	143.9	16.6	6120	888	15448
	700	2714	.345	134.0	13.8	5569	899	14186
	650	2173	.358	111.1	8.3	4443	903	11372
	600	1709	.370	90.4	4.5	3588	872	8972
	550	1316	.383	72.0	2.1	2899	813	6932
	500	989	.393	55.6	0.5	2352	743	5294
	450	721	.423	43.6	-0.3	1963	670	4121
	400	506	.431	31.1	-0.7	1656	573	3177

Figure 15





ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9025 Curve A	800	4160.0	195	966.2	238.1	398.6	364	848.0
	750	3979.5	193	915.7	235.8	376.9	362	800.2
	720	3850.5	192	882.6	220.1	349.8	380	764.0
	700	3761.5	192	860.5	211.2	332.1	390	739.3
	650	3535.8	193	812.9	188.9	290.0	425	682.7
	600	3310.5	197	778.4	165.8	250.8	477	633.3
	550	1557.8	223	414.6	35.4	111.6	529	304.5
	500	1223.9	234	340.9	19.9	86.7	529	236.7
	450	1020.5	245	297.7	12.9	71.2	523	194.1
	400	791.2	255	240.5	6.4	56.6	482	146.0
TM9026 Curve L	800	4580.0	196	1071.0	265.1	427.2	375	925.9
	750	4414.0	194	1021.0	268.4	410.1	370	882.5
	720	4306.8	193	988.3	260.0	390.4	380	852.7
	700	4232.3	192	967.4	253.6	374.5	385	832.3
	650	4034.1	192	921.2	237.3	337.0	411	782.3
	600	3508.4	196	820.7	185.1	269.5	467	671.0
	550	1557.8	223	414.6	35.4	111.6	529	304.5
	500	1223.9	234	340.9	19.9	86.7	529	236.7
	450	1020.5	245	297.7	12.9	71.2	523	194.1
	400	791.2	255	240.5	6.4	56.6	482	146.0

ZONE LIMIT DATA

	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9025 Curve A	800	5579	.321	255.2	70.5	14076	687	29948
	750	5337	.317	241.9	69.8	13310	684	28260
	720	5164	.316	233.2	65.2	12353	715	26980
	700	5044	.316	227.3	62.5	11728	734	26110
	650	4742	.317	214.7	55.9	10241	797	24111
	600	4439	.324	205.6	49.1	8857	890	22366
	550	2089	.367	109.5	10.5	3941	984	10752
	500	1641	.385	90.1	5.9	3062	984	8360
	450	1369	.403	78.6	3.8	2514	974	6853
	400	1061	.419	63.5	1.9	1999	899	5156
TM9026 Curve L	800	6142	.322	282.9	78.5	15086	707	32698
	750	5919	.319	269.7	79.5	14483	699	31165
	720	5776	.317	261.1	77.0	13787	716	30112
	700	5676	.316	255.6	75.1	13225	724	29393
	650	5410	.316	243.4	70.3	11901	771	27626
	600	4705	.322	216.8	54.8	9517	872	23694
	550	2089	.367	109.5	10.5	3941	984	10752
	500	1641	.385	90.1	5.9	3062	984	8360
	450	1369	.403	78.6	3.8	2514	974	6853
	400	1061	.419	63.5	1.9	1999	899	5156

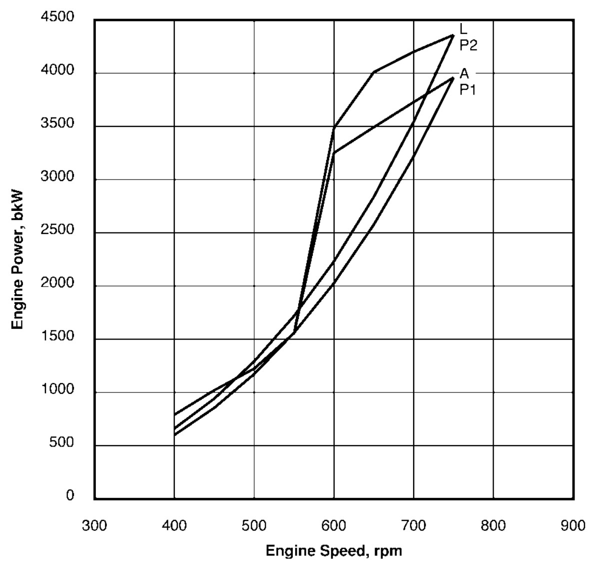
PROPELLER DEMAND DATA

Optimum Load	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9025 (Curve P1)	800	3744.0	195	869.0	206.3	364.0	360	769.2
	750	3085.0	195	715.8	157.9	292.1	374	631.3
	720	2729.4	197	641.8	120.7	242.7	407	553.4
	700	2508.2	200	597.0	99.9	214.2	428	505.0
	650	2008.2	208	498.0	59.7	157.8	467	397.5
	600	1579.5	218	410.5	34.6	119.8	478	305.2
	550	1216.6	227	329.3	19.1	93.4	466	236.1
	500	914.1	236	257.1	8.4	72.8	439	176.1
	450	666.4	245	194.3	2.5	58.4	388	130.6
	400	468.0	244	136.0	-0.2	48.3	332	98.1
TM9026 (Curve P2)	800	3893.0	195	903.3	218.0	377.0	360	797.3
	750	3207.7	194	742.3	168.7	304.0	371	654.5
	720	2838.0	196	664.5	129.9	252.9	404	573.8
	700	2608.0	199	617.8	108.0	223.2	425	523.5
	650	2088.1	207	515.0	64.8	163.4	469	412.3
	600	1642.4	217	425.1	37.7	123.3	485	316.8
	550	1265.0	226	341.5	21.2	95.8	476	245.3
	500	950.4	236	267.0	9.5	74.3	452	182.8
	450	692.9	244	201.5	3.1	59.0	397	134.2
	400	486.6	243	140.8	0.1	48.7	339	100.0

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg- Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9025 (Curve P1)	800	5021	.321	229.6	61.1	12855	679	27163
	750	4137	.321	189.1	46.8	10315	704	22293
	720	3660	.324	169.5	35.7	8571	765	19543
	700	3364	.329	157.7	29.6	7564	803	17832
	650	2693	.342	131.6	17.7	5573	873	14038
	600	2118	.358	108.4	10.2	4231	892	10777
	550	1631	.373	87.0	5.7	3298	871	8339
	500	1226	.388	67.9	2.5	2571	822	6218
	450	894	.403	51.3	0.7	2062	730	4610
	400	628	.401	35.9	-0.1	1706	629	3464
TM9026 (Curve P2)	800	5221	.321	238.6	64.6	13314	680	28155
	750	4302	.319	196.1	50.0	10736	700	23112
	720	3806	.322	175.5	38.5	8931	760	20263
	700	3497	.327	163.2	32.0	7882	798	18489
	650	2800	.340	136.0	19.2	5770	877	14562
	600	2202	.357	112.3	11.2	4354	904	11189
	550	1696	.372	90.2	6.3	3383	889	8664
	500	1275	.388	70.5	2.8	2624	846	6457
	450	929	.401	53.2	0.9	2084	747	4739
	400	653	.399	37.2	0.0	1720	641	3531

Figure 16

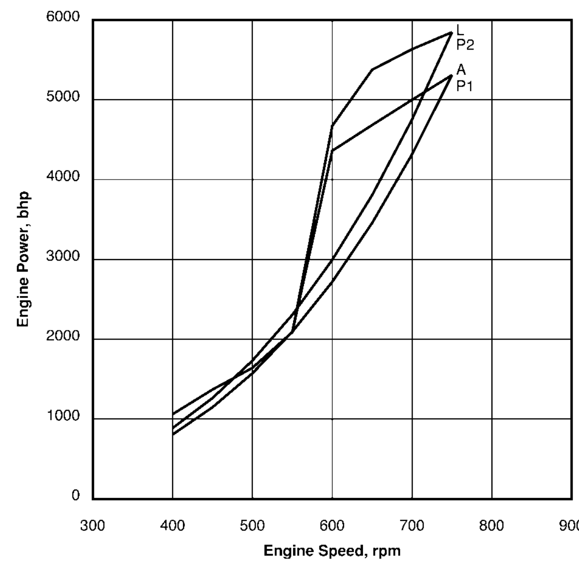


ZONE LIMIT DATA

	Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9019 Curve A	750	3960.0	193	911.1	234.2	375.2	362	796.5
	720	3821.8	192	876.2	217.5	347.2	380	758.6
	700	3728.7	192	853.3	208.2	329.0	391	732.9
	650	3492.7	193	803.8	184.7	285.9	427	674.1
	600	3251.9	198	766.0	160.2	245.4	479	622.2
	550	1557.8	223	414.6	35.4	111.6	529	304.5
	500	1223.9	234	340.9	19.9	86.7	529	236.7
	450	1020.5	245	297.7	12.9	71.2	523	194.1
	400	791.2	255	240.5	6.4	56.6	482	146.0
TM9020 Curve L	750	4360.0	194	1008.0	264.4	406.2	369	872.3
	720	4270.9	192	979.7	257.1	387.5	379	845.8
	700	4201.1	192	960.1	250.8	371.8	385	826.2
	650	4010.0	192	915.9	235.0	334.7	411	777.5
	600	3485.0	196	815.7	182.8	267.2	468	666.5
	550	1557.8	223	414.6	35.4	111.6	529	304.5
	500	1223.9	234	340.9	19.9	86.7	529	236.7
	450	1020.5	245	297.7	12.9	71.2	523	194.1
	400	791.2	255	240.5	6.4	56.6	482	146.0

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp °C	Exh Flow cu m/ min
TM9019 (Curve P1)	750	3960.0	193	911.1	234.2	375.2	362	796.5
	720	3503.6	193	806.2	188.9	317.2	385	698.7
	700	3219.6	194	745.1	161.2	280.4	407	637.6
	650	2577.8	201	616.6	101.1	202.1	466	503.3
	600	2027.5	212	511.3	60.0	146.9	511	390.2
	550	1561.7	223	415.6	35.6	111.8	529	305.3
	500	1173.3	234	327.3	17.7	84.2	516	226.2
	450	855.4	243	247.9	7.3	64.4	458	161.0
	400	600.7	246	176.3	1.7	50.6	382	112.0
TM9020 (Curve P2)	750	4360.0	194	1008	264.4	406.2	369	872.3
	720	3857.4	192	884.1	220.7	350.5	380	765.3
	700	3544.8	193	813.9	191.2	311.5	396	698.4
	650	2838.2	198	669.9	123.1	224.8	457	551.7
	600	2232.3	209	555.2	73.7	161.0	515	429.5
	550	1719.5	221	453.8	44.3	121.1	551	338.4
	500	1291.9	233	359.2	23.1	90.3	545	251.6
	450	941.8	244	273.9	10.2	67.8	492	178.0
	400	661.4	248	195.9	3.0	52.2	411	121.2



ZONE LIMIT DATA

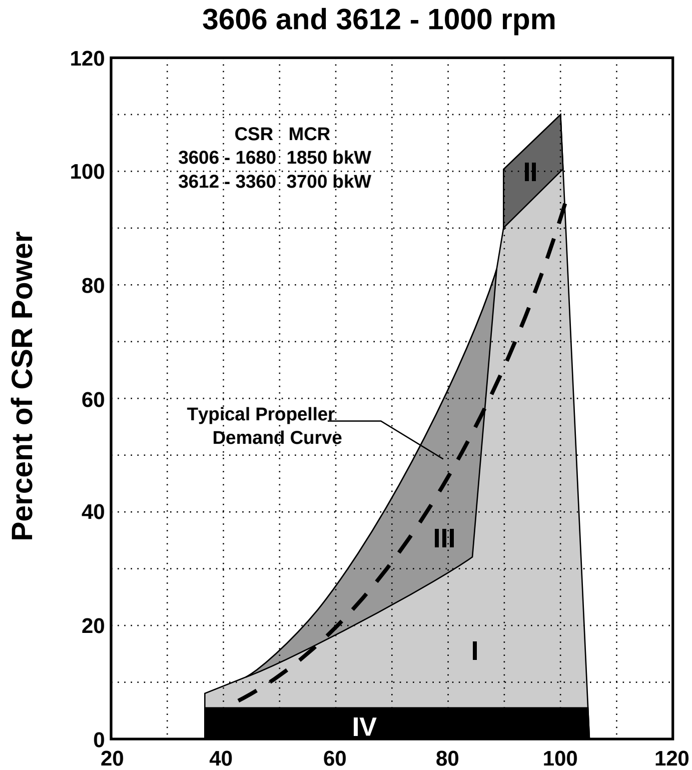
	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9019 Curve A	750	5310	.317	240.7	69.4	13250	684	28129
	720	5125	.316	231.5	64.4	12261	716	26788
	700	5000	.316	225.4	61.7	11619	735	25881
	650	4684	.317	212.3	54.7	10096	800	23807
	600	4361	.326	202.4	47.4	8666	895	21972
	550	2089	.367	109.5	10.5	3941	984	10752
	500	1641	.385	90.1	5.9	3062	984	8360
	450	1369	.403	78.6	3.8	2514	974	6853
	400	1061	.419	63.5	1.9	1999	899	5156
TM9020 Curve L	750	5847	.319	266.2	78.3	14345	697	30805
	720	5727	.316	258.8	76.1	13684	715	29867
	700	5634	.316	253.6	74.3	13130	724	29176
	650	5377	.316	242.0	69.0	11820	772	27455
	600	4673	.322	215.5	54.1	9436	874	23537
	550	2089	.367	109.5	10.5	3941	984	10752
	500	1641	.385	90.1	5.9	3062	984	8360
	450	1369	.403	78.6	3.8	2514	974	6853
	400	1061	.419	63.5	1.9	1999	899	5156

PROPELLER DEMAND DATA

Optimum Load	Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in Hg-Gauge	Air Flow cfm	Exh Temp °F	Exh Flow cfm
TM9019 (Curve P1)	750	5310	.317	240.7	69.4	13250	684	28129
	720	4698	.317	213.0	55.9	11202	726	24675
	700	4318	.319	196.8	47.7	9902	764	22517
	650	3457	.330	162.9	29.9	7137	870	17774
	600	2719	.349	135.1	17.8	5188	951	13780
	550	2094	.367	109.8	10.5	3948	985	10781
	500	1573	.385	86.5	5.2	2973	961	7989
	450	1147	.399	65.5	2.2	2274	856	5685
	400	806	.404	46.6	0.5	1787	719	3956
TM9020 (Curve P2)	750	5847	.319	266.2	78.3	14345	697	30805
	720	5173	.316	233.6	65.4	12378	715	27027
	700	4754	.317	215.0	56.6	11001	746	24663
	650	3806	.326	177.0	36.5	7939	855	19483
	600	2994	.344	146.7	21.8	5686	959	15166
	550	2306	.363	119.9	13.1	4277	1023	11949
	500	1732	.383	94.9	6.8	3189	1013	8884
	450	1263	.401	72.4	3.0	2394	918	6284
	400	887	.408	51.8	0.9	1843	771	4282

Note: These ratings are for CPP applications only.

Figure 17



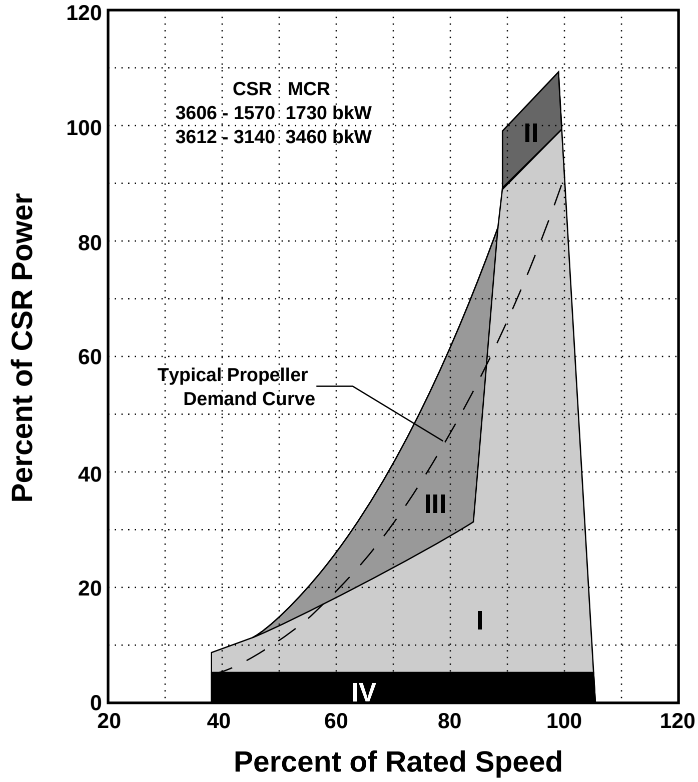
Zone I - Continuous Duty
Zone II, III and IV - Limited Operation

Figure 19

Marine Propulsion Applications
Heavy Fuel

3606/3612 1000 rpm Figure 19						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3606 Power**	**3612 Power**	**3606 Power**	**3612 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	1000	100.0%	1680	3360	2253	4506
90.0%	900	90.0%	1512	3024	2028	4055
85.0%	850	32.7%	550	1100	738	1475
80.0%	800	28.6%	480	960	644	1287
78.0%	780	26.6%	447	894	599	1199
70.0%	700	23.1%	388	776	520	1041
60.0%	600	16.5%	277	554	371	743
50.0%	500	12.4%	208	416	279	558
35.0%	350	8.6%	145	290	194	389
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3606 Power**	**3612 Power**	**3606 Power**	**3612 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	1000	110.0%	1850	3700	2481	4962
90.0%	900	99.1%	1665	3330	2233	4466
85.0%	850	73.7%	1238	2476	1660	3320
80.0%	800	60.1%	1010	2020	1354	2709
78.0%	780	57.0%	957	1914	1283	2567
70.0%	700	41.2%	692	1384	928	1856
60.0%	600	26.0%	436	872	585	1169
50.0%	500	15.0%	252	504	338	676
35.0%	350	8.6%	145	290	194	389

3606 and 3612 - 900 rpm



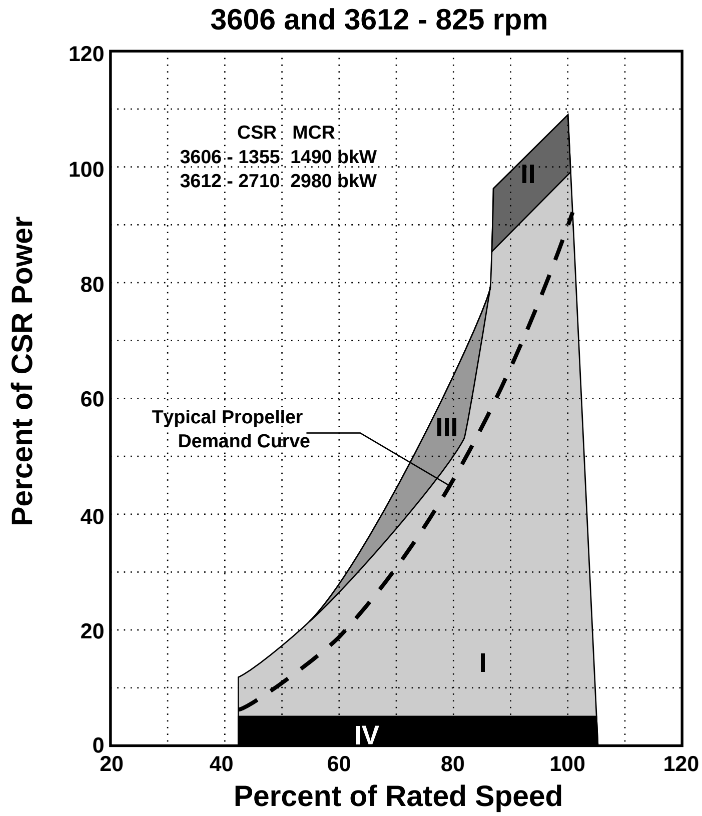
Zone I - Continuous Duty
Zone II, III and IV - Limited Operation

Marine Propulsion Applications
Heavy Fuel

Figure 20

3606/3612
900 rpm
Figure 20

% Rated Speed	speed	% CSR Power	3606 Power	3612 Power	3606 Power	3612 Power
CONTINUOUS DUTY						
% Rated Speed	speed	% CSR Power	3606 Power	3612 Power	3606 Power	3612 Power
	rpm		bkw	bkw	bhp	bhp
100.0%	900	100.0%	1570	3140	2105	4211
88.9%	800	88.9%	1396	2792	1872	3744
83.3%	750	30.9%	485	970	650	1301
80.0%	720	27.5%	432	864	579	1159
77.8%	700	25.5%	401	802	538	1075
66.7%	600	21.2%	333	666	447	893
55.6%	500	14.7%	231	462	310	620
44.4%	400	10.6%	166	332	223	445
38.9%	350	9.2%	145	290	194	389
INTERMITTENT DUTY						
% Rated Speed	speed	% CSR Power	3606 Power	3612 Power	3606 Power	3612 Power
	rpm		bkw	bkw	bhp	bhp
100.0%	900	110.0%	1730	3460	2320	4640
88.9%	800	98.0%	1538	3076	2062	4125
83.3%	750	69.4%	1090	2180	1462	2923
80.0%	720	61.4%	964	1928	1293	2585
77.8%	700	56.4%	886	1772	1188	2376
66.7%	600	35.5%	558	1116	748	1497
55.6%	500	20.6%	323	646	433	866
44.4%	400	10.6%	166	332	223	445
38.9%	350	9.2%	145	290	194	389

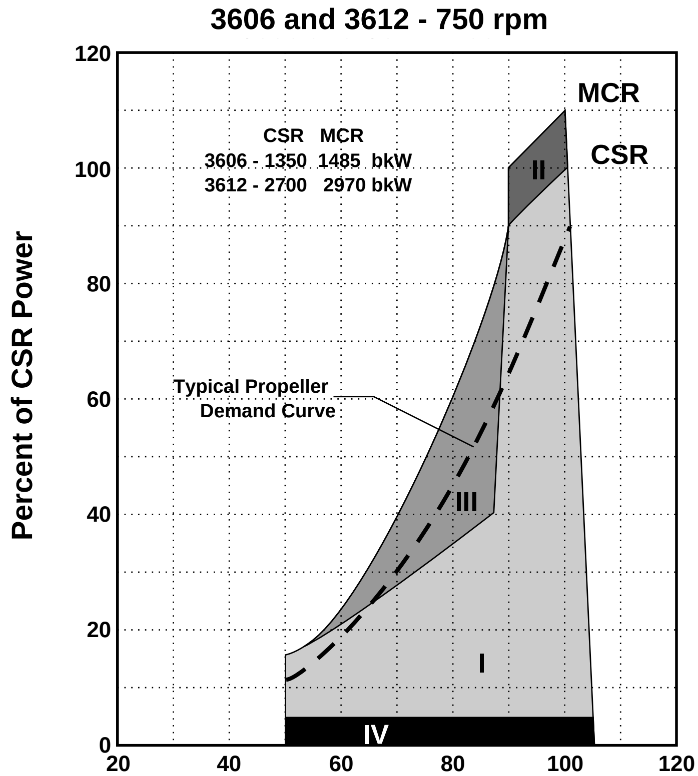


Zone I - Continuous Duty
Zone II, III and IV - Limited Operation

Marine Propulsion Applications
Heavy Fuel

Figure 21

3606/3612 825 rpm Figure 21						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3606 Power**	**3612 Power**	**3606 Power**	**3612 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	825	100.0%	1355	2710	1817	3634
90.9%	750	90.9%	1232	2464	1652	3304
87.3%	720	87.2%	1182	2364	1585	3170
78.8%	650	44.3%	600	1200	805	1609
72.7%	600	32.7%	443	886	594	1188
60.6%	500	23.8%	323	646	433	866
48.5%	400	16.4%	222	444	298	595
42.4%	350	12.0%	162	324	217	434
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3606 Power**	**3612 Power**	**3606 Power**	**3612 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	825	110.0%	1490	2980	1998	3996
90.9%	750	99.9%	1354	2708	1816	3631
87.3%	720	95.9%	1300	2600	1743	3487
78.8%	650	58.6%	794	1588	1065	2130
72.7%	600	46.2%	626	1252	839	1679
60.6%	500	26.7%	362	724	485	971
48.5%	400	16.4%	222	444	298	595
42.4%	350	12.0%	162	324	217	434

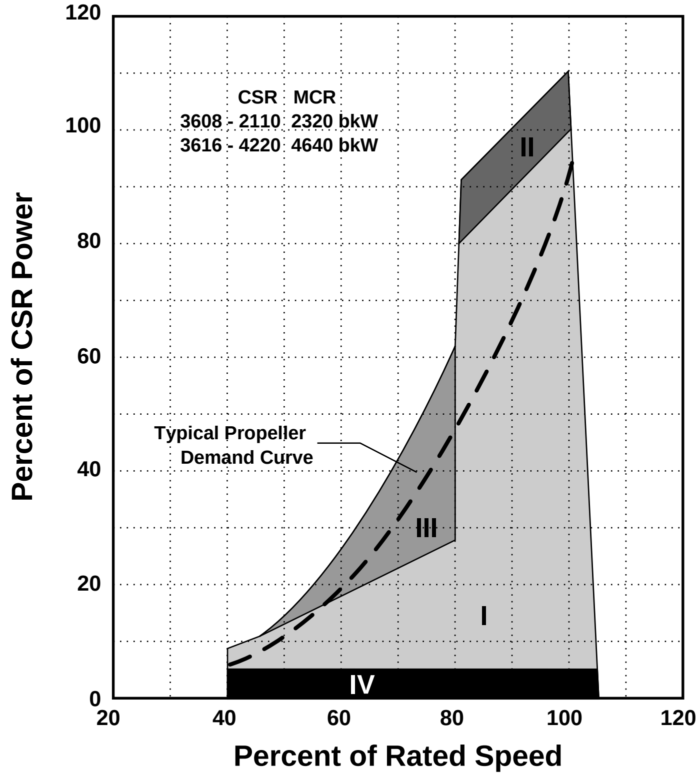


Zone I - Continuous Duty
Zone II, III and IV - Limited Operation
Marine Propulsion Applications
Heavy Fuel

Figure 22

3606/3612 750 rpm Figure 22						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3606 Power**	**3612 Power**	**3606 Power**	**3612 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	750	100.0%	1350	2700	1810	3621
96.0%	720	96.0%	1296	2592	1738	3476
86.7%	650	44.4%	600	1200	805	1609
80.0%	600	32.8%	443	886	594	1188
66.7%	500	23.9%	323	646	433	866
53.3%	400	16.4%	222	444	298	595
46.7%	350	12.0%	162	324	217	434
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3606 Power**	**3612 Power**	**3606 Power**	**3612 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	750	110%	1485	2970	1991	3983
96.0%	720	106.0%	1431	2862	1919	3838
86.7%	650	78.1%	1055	2110	1415	2830
80.0%	600	61.4%	829	1658	1112	2223
66.7%	500	35.6%	480	960	644	1287
53.3%	400	16.4%	222	444	298	595
46.7%	350	12.0%	162	324	217	434

3608 and 3616 - 1000 rpm

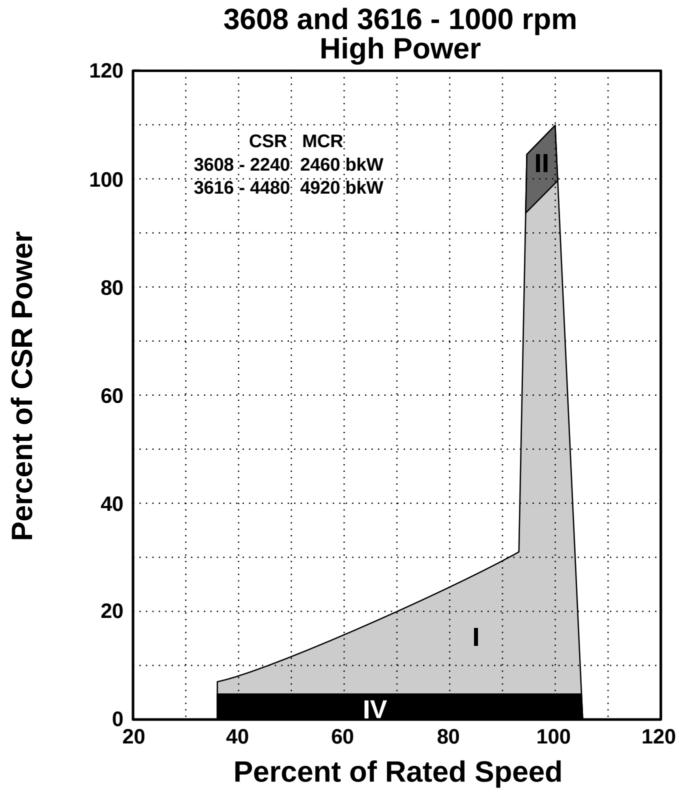


Zone I - Continuous Duty
Zone II, III and IV - Limited Operation

Marine Propulsion Applications
Heavy Fuel

Figure 23

3608/3616 1000 rpm Figure 23						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	1000	100.0%	2110	4220	2830	5659
90.0%	900	90.0%	1899	3798	2547	5093
85.0%	850	85.0%	1793	3586	2404	4809
80.0%	800	30.3%	640	1280	858	1716
70.0%	700	24.5%	517	1034	693	1387
60.0%	600	19.2%	406	812	544	1089
50.0%	500	14.6%	308	616	413	826
40.0%	400	9.6%	202	404	271	542
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	1000	110.0%	2320	4640	3111	6222
90.0%	900	99.0%	2088	4176	2800	5600
85.0%	850	93.5%	1972	3944	2644	5289
80.0%	800	61.4%	1296	2592	1738	3476
70.0%	700	41.1%	868	1736	1164	2328
60.0%	600	25.9%	547	1094	734	1467
50.0%	500	15.0%	317	634	425	850
40.0%	400	9.6%	202	404	271	542



Zone I - Continuous Duty
Zone II, III and IV - Limited Operation
Controllable Pitch Prop Only
Marine Propulsion Applications
Heavy Fuel

Figure 24

3608/3616 1000 rpm High Power Figure 24						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	1000	100.0%	2240	4480	3004	6008
95.0%	950	94.9%	2126	4252	2851	5702
80.0%	800	23.9%	535	1070	717	1435
70.0%	700	19.2%	430	860	577	1153
60.0%	600	16.7%	374	748	502	1003
50.0%	500	12.1%	271	542	363	727
40.0%	400	8.8%	197	394	264	528
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	1000	110.0%	2460	4920	3299	6598
95.0%	950	105.0%	2352	4704	3154	6308

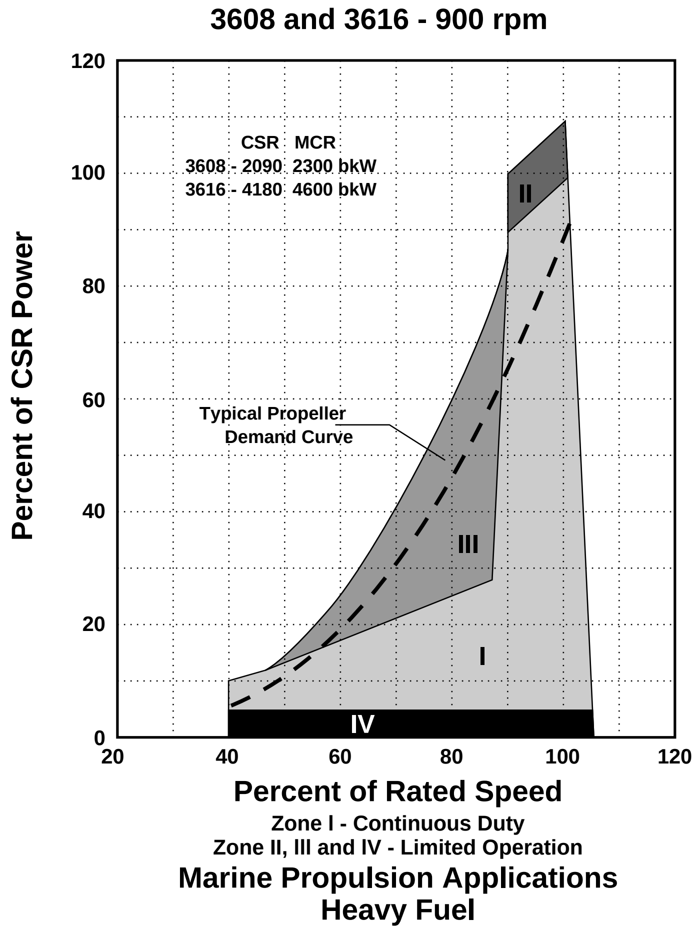
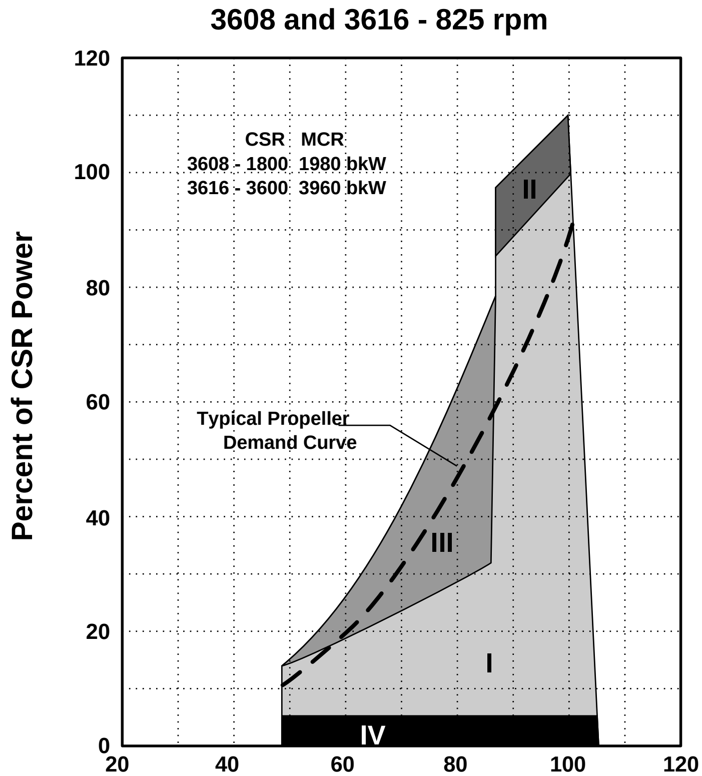


Figure 25

3608/3616 900 rpm Figure 25						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	900	100.0%	2090	4180	2803	5605
90.0%	810	90.0%	1881	3762	2522	5045
83.3%	750	26.9%	562	1124	754	1507
80.0%	720	25.4%	531	1062	712	1424
77.8%	700	24.7%	517	1034	693	1387
66.7%	600	19.4%	406	812	544	1089
55.6%	500	14.7%	308	616	413	826
44.4%	400	9.7%	202	404	271	542
38.9%	350	8.2%	172	344	231	461
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	900	110.0%	2300	4600	3084	6169
90.0%	810	99.0%	2070	4140	2776	5552
83.3%	750	69.0%	1442	2884	1934	3867
80.0%	720	61.3%	1281	2562	1718	3436
77.8%	700	51.8%	1082	2164	1451	2902
66.7%	600	32.6%	681	1362	913	1826
55.6%	500	18.9%	394	788	528	1057
44.4%	400	9.7%	202	404	271	542
38.9%	350	8.2%	172	344	231	461



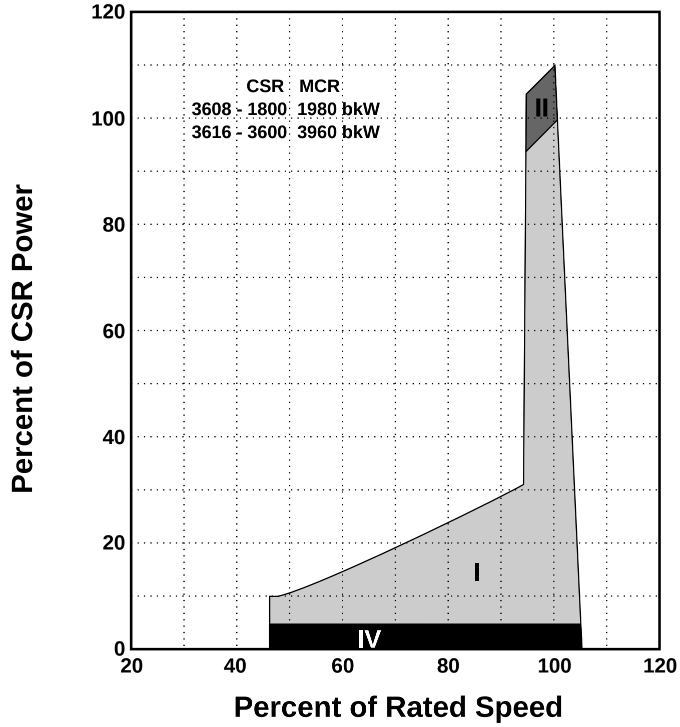
Zone I - Continuous Duty
Zone II, III and IV - Limited Operation

Figure 26

Marine Propulsion Applications
Heavy Fuel

3608/3616 825 rpm Figure 26						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	825	100.0%	1800	3600	2414	4828
90.9%	750	90.9%	1637	3274	2195	4390
87.3%	720	87.3%	1571	3142	2107	4213
78.8%	650	27.8%	501	1002	672	1344
72.7%	600	24.6%	443	886	594	1188
60.6%	500	17.3%	312	624	418	837
48.5%	400	13.7%	246	492	330	660
42.4%	350	10.8%	194	388	260	520
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	825	110.0%	1980	3960	2655	5310
90.9%	750	100.0%	1800	3600	2414	4828
87.3%	720	96.0%	1728	3456	2317	4634
78.8%	650	58.2%	1048	2096	1405	2811
72.7%	600	46.2%	831	1662	1114	2229
60.6%	500	26.7%	481	962	645	1290
48.5%	400	13.7%	246	492	330	660
42.4%	350	10.8%	194	388	260	520

3608 and 3616 - 750 rpm



Zone I - Continuous Duty
Zone II, III and IV - Limited Operation

Generally Requires Controllable Pitch Prop
Consult Caterpillar For Fixed Pitch Applications

Figure 27

Marine Propulsion Applications
Heavy Fuel

3608/3616 750 rpm Figure 27						
CONTINUOUS DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	750	100.0%	1800	3600	2414	4828
95.1%	713	90.0%	1620	3240	2172	4345
90.0%	675	27.9%	503	1006	675	1349
85.1%	638	26.6%	479	958	642	1285
80.0%	600	24.6%	443	886	594	1188
66.7%	500	17.3%	312	624	418	837
53.3%	400	14.1%	253	506	339	679
46.7%	350	10.3%	185	370	248	496
INTERMITTENT DUTY						
% Rated Speed	**speed**	**% CSR Power**	**3608 Power**	**3616 Power**	**3608 Power**	**3616 Power**
	rpm		**bkw**	**bkw**	**bhp**	**bhp**
100.0%	750	110.0%	1980	3960	2655	5310
95.1%	713	105.9%	1906	3812	2556	5112

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- **Piping**

LEKM8462 8-98

Diesel Engine Systems - Piping

General Requirements

The requirements included for diesel main propulsion and generator set installations are not intended to replace applicable regulatory agency requirements. Their requirements should be reviewed prior to initiating system design or evaluation.

Piping should be direct with minimum bends and sufficient joints for ready accessibility and removal. It must not interfere with walkways, doors or hatches, and permit unrestricted access in walk areas and designated work spaces. Piping should clear areas required for operation and machinery control, and should be routed around machinery or tank access openings, and access openings used for shipping or receiving machinery and equipment.

Expansion joints must be used at bulkheads and decks to prevent piping damage from structure movement due to ship flexing. Use removable piping when it obstructs equipment requiring dismantling for periodic overhaul. Provide isolating valves to minimize system disruption.

Keep piping close to bulkheads, behind framing, and along the underside of decks. Leave sufficient space between pipes and spool all pipes from decks or bulkheads to permit easy maintenance and painting. Galvanizing of ferrous piping should be done only after fabrication.

Minimize piping in control rooms or over electrical equipment. When this is not possible, fix the pipe in one length with all flanges or screwed connections kept away from electrical switch gear or cabinets.

Support piping to prevent vibration damage. If subject to mechanical damage it should be adequately protected by removable metal guards. The guards must allow for inspection and painting. When subject to movement from expansion or other causes, specially designed hangers or supports must be provided. Spring type hangers should be provided when required for main engine exhaust gas pipes. Heavy items such as valves and fittings must be supported to prevent overloading the attached piping. Revise the number of supports provided, the type selected, and the location to eliminate excessive vibration of piping under all normal operating conditions.

Use flexible connections for all piping connected to the engine or other reciprocating machinery. The length and weight of piping mounted on the engine must be kept to a minimum, and the flexible connection should be placed right at the engine connection flange whenever possible. Provide pipe support on the hull side of the system piping to minimize pipe movement and flex connection loading. Flexible connections installed in piping systems for fuel oil, flammable liquids, and high pressure containment may require approval by the classification society and/or other applicable regulatory bodies.

Avoid piping arrangements with excessive turbulence, such as tee connections. High and low points should not occur. Use plugs or valves for draining in unavoidable low points. Fit high points with vent valves.

The integrity of water and oil tight areas in the ship’s structure must not be disrupted by piping design. Use flange type welded connections on either side of bulkheads to permit pipe dismantling for service. Vent connections to the weather deck should have a flanged joint just above the deck to facilitate service of the vent terminal. Do not use heat sensitive material, such as PVC piping in piping systems penetrating water or oil tight division bulkheads, or for systems transporting flammable materials such as fuel oil, diesel oil and lube oil. PVC or other such piping material must also meet all applicable classification society approval.

Valves should normally be gate or globe type, except for throttling purposes where globe type valves should be used. Pay special attention to the selection of seat, stem and trim materials. Improper material application may result in the accelerated corrosion and failure of salt water service valves, and deterioration of seat materials in ball and butterfly valves used in fuel oil and lube oil transfer systems. The substitution of butterfly or ball valves can be made where permitted by classification societies. Do not use butterfly or ball valves where close, controllable throttling is mandatory. Hand wheels or operating levers of valves should be easily operated from a walkway or deck. Unless obvious, provide valves with nameplates clearly stating their purpose. Valves attached to the ships hull or oil tanks should be selected and arranged based on classification society requirements.

Safety or relief valve inlet piping should be as short as possible. Where discharging to atmosphere, direct the open end of pipes away from machinery, electrical equipment, or operating personnel. Discharge oil system relief valves to the low pressure side of the system.

System monitoring gauges, thermometers, etc. should be visible from operating areas. Thermometers should have separate wells. Pressure gauges should have test tees. Locate isolating valves close to the main piping run. Pressure gauges, pressure switches, or similar instrumentation used in heated fuel oil piping systems, should be the filled or electric transmitter type.

Vent tanks containing flammable fluids and the engine crankcase to atmosphere with a gooseneck ventilator and flame screens and closures. Air vent discharges must not enter ventilation air inlets, openings to accommodations or work spaces, discharge on machinery, electrical equipment, or personnel. Thoroughly clean all piping and equipment after fabrication and prior to ship installation. After installation, each system must be cleaned and flushed with the applicable system's medium, or an approved substitute. The process should be reviewed by the owner, regulatory body's inspector and the engine builder. Conduct each flushing at the system's maximum operating pressure and temperature, and above normal line velocity. Remove, bypass, or blank-off heat exchangers, control valves, and other in-line components which could trap debris during the flushing process. Refer to Caterpillar procedure 3L0492 for further details on pipe flushing and pickling.

Visually inspect combustion air and exhaust gas piping systems to ensure weld slag and debris is removed prior to installation.

Piping Sizes

The following table is a pipe selection guide for suggested fluid velocities. To avoid erosion, water hammer, or the possibility of noise, the upper velocity limits should not be exceeded. The final pipe sizes should be selected based on considerations of piping layout, number of fittings, valves, viscosity of fluid passing through the pipe, and pressure drop. Head loss on the suction side of pumps should be carefully analyzed. Compare the losses in the suction piping to the net positive suction head available with the specific pump selected.

Fluid Design Velocities

Service	Nominal[a] m/sec (ft/sec)		Limit m/sec (ft/sec)	
Hot water suctions	0.06√d	(√d)	.9	(3)
Hot-water discharge	0.18√d	(3√d)	2.4	(8)
Cold fresh water suction	0.18√d	(3√d)	4.6	(15)
Cold fresh water discharge	0.30√d	(5√d)	6.1	(20)
Lube oil service pump suction	0.06√d	(√d)	1.2	(4)
Lube oil discharge	0.12√d	(2√d)	1.8	(6)
Fuel oil service suction	0.06√d	(√d)	1.2	(4)
Fuel oil service discharge	0.09√d	(1.5√d)	1.8	(6)
Fuel oil transfer suction	0.06√d	(√d)	1.8	(6)
Fuel oil transfer discharge	0.12√d	(2√d)	4.6	(15)
Diesel oil suction	0.12√d	(2√d)	2.1	(7)
Diesel oil discharge	0.30√d	(5√d)	3.7	(12)
Hydraulic oil suction	0.09√d	(1.5√d)	2.4	(8)
Hydraulic oil discharge	0.48√d	(8√d)	6.1	(20)
Seawater suctions[b]	0.18√d	(3√d)	4.6	(15)
Seawater discharge[b]	0.30√d	(5√d)	4.6	(15)
Steam	3.00√d	(50√d)	61.0	(200)
Steam exhaust, 14 800 kPag (215 psig)	4.54√d	(75√d)	76.2	(250)
Steam exhaust, high vacuum	4.54√d	(75√d)	100.6	(300)

[a] d is the pipe internal diameter in mm (inches)
[b] 2.7 m/sec (8.8 ft/sec) nominal velocity for galvanized steel pipe

Schedule of Piping

Figure 1 is a guide for preparing piping schedules. It is not intended to replace specific requirements of applicable classification societies or regulatory bodies.

Abbreviations

ASTM	American Society of Testing and Materials	CuNi	copper-nickel
		Galv.	galvanized
Brz.	bronze	Sch	schedule
Cu.	copper	Std.	standard
		Wt.	weight

Piping Symbol

Symbol	Description	Symbol	Description	Symbol	Description
	Gate Valve		Un-Insulated Pipe		Tank Heating Coil
R	Gate Valve with Remote Operating Gear Attached		Insulated Pipe		Gauge Glass (Automatic Closure)
LO	Locked "Open" Valve		Air Vent with Flame Screen		Plate Heat Exchange
LC	Locked "Closed" Valve		Air Vent w/Flame Screen & Closure		Shell and Tube Heat Exchanger
	Globe Valve		Air Vent w/Flame Screen, Check Valve & Closure		Centrifugal Pump
T	Screw Down Non-Return Valve		Drip Pan		Positive Displacement Pump
LS	Lock Shut Valve	T	Thermometer		Manhole in Tank
	Swing Check Valve		Thermometer	FM	Flow Meter
	Three -way Cock	HTA	High Temperature Alarm		Pipe Return to Tank
	Air Operated Three-Way Cock (or Valve)	LTA	Low Temperature Alarm		Pump Suction Bell
	Relief Valve	HLA	High Level Alarm	F	Filter
	Angle Valve	LLA	Low Level Alarm	ΔP	Differential Pressure Indicator
	Pressure Control Valve	PSH	Pump Start	PS	Pressure Switch
	Self-Contained Temperature Control Valve w/ Manual Override	PSL	Pump Stop	A	Alarm
	Butterfly Valve		Pressure Switch	M	Motor
	Ball Valve		Steam Blow-Out		
	In-Line Relief Valve		Sounding Valve with Lever		
	Diverting Valve with Manual Lever	S	Simplex Strainer		
	Temperature Control Valve	S S	Duplex Strainer		
	Air Operated Butterfly Valve		Orifice Plate		
	Flexible Connector	P	Pressure Gauge		
	Flexible Connector	L	Level Indicator		

Schedule of Piping

##	SYSTEM: SERVICE	PIPING: SIZE	PIPING: TYPE	TAKE DOWN JOINTS: SIZE	TAKE DOWN JOINTS: TYPE	BOLTS	NUTS	GASKETS	VALVES: SIZE	VALVES: PRESS	VALVES: MATERIAL	VALVES: TRIM	FITTINGS: SIZE	FITTINGS: TYPE	GENERAL NOTES
1	Cooling Fresh Water	Above 10mm (.5 in.)	Seamless, ASTM A106, Sch. 40 Grade A or B	Above 10mm (.5 in.)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Grade B	ASTM A307 Grade B	Inserted Rubber Sheet	50mm (2 in.) and above	125#	Cast Iron or Forged Steel Flanged	Brass	50mm (2 in.) and Above	Forged Steel Std. Wt.,Butt Welded ends, ASTM A-234	
		10mm (.5 in.) and Below	Seamless Copper, ASTM B88, Type K or L	Below 10mm (.5 in.)	Brass Unions, Bite Joint or Sleeve				40mm (1-.5 in.) and below	200#	Bronze	Brass	40mm (1.5 in.) and Below	Ductile Iron, Forged Steel, or Brz., Screwed	
2	Cooling Sea Water	Above 10mm (.5 in.)	90 / 10 CuNi Pipe	Above 10mm (.5 in.)	Bronze Flanges, Brazed.	ASTM A307 Galv.	ASTM A307 Galv.	Inserted Rubber Sheet	50mm (2 in.) and above	125# 150#	Cast Iron, Flanged Cast Steel, Flanged	Brass or Monel	Above 10mm (.5 in.)	Bronze, Brazed; or Built-up Cu, Flanged	Or use ## 3 which is acceptable substitute
		10mm (.5 in.) and Below	Seamless Copper, ASTM B88, Type K or L	Below 10mm (.5 in.)	Brass Unions, Bite Joint or Sleeve				40mm (1-1/2 in.) and below	200#	Bronze, Flanged or Screwed	Brass or Monel	10mm (.5 in.) and Below	Brass Joints	
3	Sea Chest, Overboard, Air Vent, and Blow-Out Conn.	All	Seamless, ASTM A106, Sch. 80 Grade A or B, Galvanized	Above 10mm (.5 ft.)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Galv.	ASTM A307 Galv.	Inserted Rubber Sheet	50mm (2 in.) and above	150#	Cast Steel, Flanged	Brass or Monel	50mm (2 in.) and Above	Butt Welded Galvanized	
				Below 10mm (.5 ft.)	Brass Unions, Bite Joint or Sleeve				40mm (1-.5 in.) and below	200#	Bronze, Flanged	Brass or Monel	40mm (1.5 in.) and Below	Ductile Iron or Forged Steel, Galv. Screwed	
4	Oil & Fuel-Filling,Transfer, and Service	Above 10mm (.5 in.)	Seamless, ASTM A106, Sch. 40 Grade A or B	Above 10mm (.5 in.)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Galv.	ASTM A307 Galv.	Nitrile	50mm (2 in.) and above	125# 150# *	Cast Iron or Forged Steel, Flanged Cast Steel, Flanged	Brass	50mm (2 in.) and Above	Forged Steel Std. Wt.,Butt Welded ends, ASTM A-234	*Valves on Oil & Fuel tanks will be Cast Steel Flanged
		10mm (.5 in.) and Below	Seamless Copper, ASTM B88, Type K or L	Below 10mm (.5 in.)	Brass Unions, Bite Joint or Sleeve				40mm (1.5 in.) and below	200#	Bronze, Flanged or Screwed	Brass	40mm (1.5 in.) and Below	Ductile Iron or Forged Steel Screwed or Socket Weld	
5	Exhaust Gas	All	Steel Resistance Welded, ASTM A53*	All	Steel Plate Flanges	ASTM A307 Galv.	ASTM A307 Galv.	Hi-Temp., Asbestos Free					All	Forged Steel, Butt Welded Flngd. (Flex conns. to be Stainless Steel)	*Pipe to be at least 7mm (.25 in.) thick
6	Exhaust Gas - Open Drains	All	Steel Resistance Welded, ASTM A53 Sch.40						50mm (2 in.) and above	200#	Bronze, Flanged or Screwed	Brass	All	Forged Steel, Butt Welded	
									40mm (1.5 in.) and below	200#	Bronze, Flanged or Screwed	Brass	All	Forged Steel, Butt Welded	
7	Starting Air and Control Air	Above 10mm (.5 in.)	Seamless, ASTM A106, Sch. 40 Grade A or B	Above 10mm (.5 in.)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Galv.	ASTM A307 Galv.	Nitrile	50mm (2 in.) and above	150#	Cast Iron or Forged Steel, Flanged	Brass	50mm (2 in.) and Above	Forged Steel, Flanged or Butt Welded	
		10mm (.5 in.) and Below	Seamless Copper, ASTM B88, Type K or L	Below 10mm (.5 in.)	Brass Unions, Bite Joint or Sleeve				40mm (1.5 in.) and below	200#	Bronze, Flanged or Screwed	Brass	40mm (1.5 in.) and Below	Forged Steel, Screwed or socket weld	

Figure 1

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- Distillate Fuel
- Heavy Fuel

LEKM8463 8-98

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Engine Systems - Distillate Fuel Oil

Engine Fuel System Description

Refer to Figures 1, 2, and 3 on pages 24, 25 and 26 for schematics of the engine fuel system.

The standard primary fuel system components include an engine driven fuel transfer pump, duplex media type filters (secondary), unit fuel injectors and a fuel pressure regulator. Optional Caterpillar supplied fuel system components include flexible hoses, a manual fuel priming pump, and a duplex primary fuel strainer.

If used, the primary duplex fuel strainer is installed remote from the engine in the transfer pump suction line. The strainer has 178 micron (0.007 in.) cleanable elements. The manual priming pump is installed on the engine in parallel to the engine driven pump. The manual pump helps to bleed air from the fuel piping before initial engine operation and following engine maintenance (filter element changes, injector replacement, etc.). It has a suction lift of 2.6 m (8.5 ft) and a flow of 38 L (10 gal) per 115 revolutions. The manual priming pump has a lift of 7.8 m (25.5 ft) if the fuel lines between the fuel tank and the pump are full, as after a filter element change.

To avoid air suction into the fuel transfer pump at low suction pressures and seal leakage at high suction pressures, the fuel pressure at the engine driven transfer pump at rated speed must be greater than -39 kPa (-5.7 psi) or less than 100 kPa (14.5 psi). If the manual priming pump is used the suction pressure must be less than 50 kPa (7.25 psi). The engine driven transfer pump may be used for fuel with a viscosity up to 40 cSt at 50°C. Higher viscosity fuels require a fuel booster module to circulate and heat the fuel prior to engine operation (see the *Heavy Fuel Oil* section of this guide).

The engine driven transfer pump delivers fuel to the unit injectors via the secondary fuel filters. The 5 micron (0.0002 in.) duplex filters are usually both in service for normal operation, although one housing may be isolated at a time during operation for filter replacement if required. The recommended fuel delivery pressure to the injectors is 414-690 kPa (60-100 psi) at rated speed.

The unit injector combines the functions of pumping, metering and injecting into a single unit. It is mounted in the cylinder head at the centerline of each cylinder. External manifolds supply fuel from the transfer pump to the drilled passages in the cylinder head, eliminating the need for high pressure fuel lines. A 100 micron (0.004 in.) edge type filter within each injector prevents contaminants from entering the injector during maintenance. Fuel circulates through the injectors and the portion that is not used for combustion cools the injectors and is returned to the fuel tank via the pressure regulating valve. For heavy fuel oil applications a special cooling circuit is designed in the unit injector to supply and circulate the coolant through the injector tip (see the *Heavy Fuel Oil* section of this guide).

The fuel delivery pressure to the injectors is controlled by adjusting the pressure regulating valve on site. The valve is a spring loaded variable orifice type mounted on the front right side of the engine, and it maintains adequate injector supply pressure for all engine speed and load ranges. The pressure regulator must be adjusted at the installation site. To provide 414-690 kPa (60-100 psi) fuel to the injectors, the fuel return line restriction must not exceed 350 kPa (51 psi) at rated engine speed.

Engine Fuel Flow Rates

Refer to the table on page 6 for 3600 engine fuel flow rates and heat rejections at various engine speeds.

Bulk Storage and Delivery Systems

Shipboard fuel systems must insure a continuous supply of clean fuel to the engines. Bulk fuel is usually stored in a large tank(s) and transferred to a smaller tank(s) (day or service tank) near the engine room by one of three methods:

- Fuel flows by gravity from the ship's main tank(s) to the service tanks. The engine driven transfer pump takes fuel directly from the service tank. Fuel is normally returned from the engine through a deaeration tank back to the transfer pump inlet or directly back to the service tank.
- An electric driven transfer pump delivers fuel from the ship's main tank to a settling tank. After allowing time for settling of water and solids the fuel is transferred to the service tank.
- A fuel oil separator may be used to transfer fuel from the ship's main or settling tank to the service tank.

Install vents on each tank to relieve air pressure created by filling and to prevent vacuum formation as fuel is consumed. Water and sediment should be periodically drained from each fuel tank.

Seal piping and fittings to prevent air or dirt contamination. Air in the system causes hard starting, erratic engine operation, and can also erode injectors.

Fuel lines can be black iron pipe, steel pipe or copper tubing. Galvanized, aluminum, or zinc-bearing alloy pipe must not be used.

3600 Engine Fuel Flow

	Rated Speed rpm	Fuel Flow-L/min (gal/min) to Engine	Fuel Flow-L/min (gal/min) from Engine	Fuel Heat Rejection Without Injector Tip Cooling, kW (Btu/min)
3606	1000	41.5 (11.0)	32.4 (8.6)	12.5 (712)
	900	38.0 (10.0)	30.0 (7.9)	11.0 (626)
	750	31.5 (8.3)	24.5 (6.5)	10.5 (598)
	720	30.0 (7.9)	23.6 (6.2)	10.0 (567)
3608	1000	41.5 (11.0)	30.0 (7.9)	16.7 (951)
	900	38.0 (10.0)	27.6 (7.3)	14.6 (831)
	750	31.5 (8.3)	22.6 (6.0)	14.0 (797)
	720	30.0 (7.9)	21.4 (5.6)	13.3 (757)
3612	1000	78.5 (20.7)	60.1 (15.9)	25.0 (1423)
	900	72.0 (19.0)	55.4 (14.6)	22.0 (1252)
	750	61.2 (16.2)	47.3 (12.5)	20.2 (1150)
	720	58.1 (15.3)	45.2 (11.9)	19.1 (1087)
3616	1000	78.5 (20.7)	55.2 (14.6)	33.3 (1895)
	900	72.0 (19.0)	51.1 (13.5)	29.3 (1668)
	750	61.2 (16.2)	43.2 (11.4)	26.9 (1531)
	720	58.1 (15.3)	41.2 (10.9)	25.4 (1446)

Maximum inlet restriction on pump = -39 kPa (-5.7 psi).
Maximum return line restriction = 350 kPa (51 psi) at rated speed.

Day Tank (Distillate Fuel Service Tank)

Day tanks are used in almost all marine applications. The installation design must consider engine mounted transfer pump limitations. *Total suction head must not exceed 2.6 m (8.5 ft).*

Locate tanks to avoid fuel levels higher than the engine fuel injectors to prevent fuel leakage into the cylinders due to static head when the engine is shut down. If overhead mounting is unavoidable, include an open/close solenoid valve in the supply line and a 3.45 kPa (0.5 psi) check valve in the return line.

The delivery line carrying fuel to the fuel transfer pump and the return line carrying excess fuel to the service tank should be no smaller than the engine fittings. Larger fuel supply and return lines ensure adequate flow if the fuel tank feeds multiple engines over 9.14 m (30 ft) from the tank or temperatures are low. *The maximum inlet flow restriction is -39 kPa (-5.7 psi) at rated speed.* Caterpillar fuel pumps prime up to 2.6 m (8.5 ft) of suction lift, but pipe size, bends, and cold ambients modify this capability. Position fuel suction lines to remove fuel about 76 mm (3 in.) above the tank bottom and near the tank end opposite the return line. Do not use joint cement affected by fuel or gasketed connections. *Flexible fuel lines must be installed at the engine fuel inlet and outlet to accommodate engine motion.*

The return line should enter the top of the tank without shutoff valves. Avoid dips so air passes freely and prevents vacuum in the fuel system. All return fuel from the engine must be allowed to deaerate before being returned to the engine. The maximum return flow restriction is 350 kPa (51 psi) at rated speed.

All engines add heat to the fuel as the engine operates. The day tank can be sized to dissipate the added heat. If this is not possible fuel coolers may be required (see the section on *Fuel Temperature*).

Figure 4 on page 27 shows a typical delivery system from the day tank to a main propulsion engine.

See Figure 5 for a recommended tank design. The rules and regulations for fuel tanks of the applicable marine society must be observed.

Typical Arrangement of Service Tank

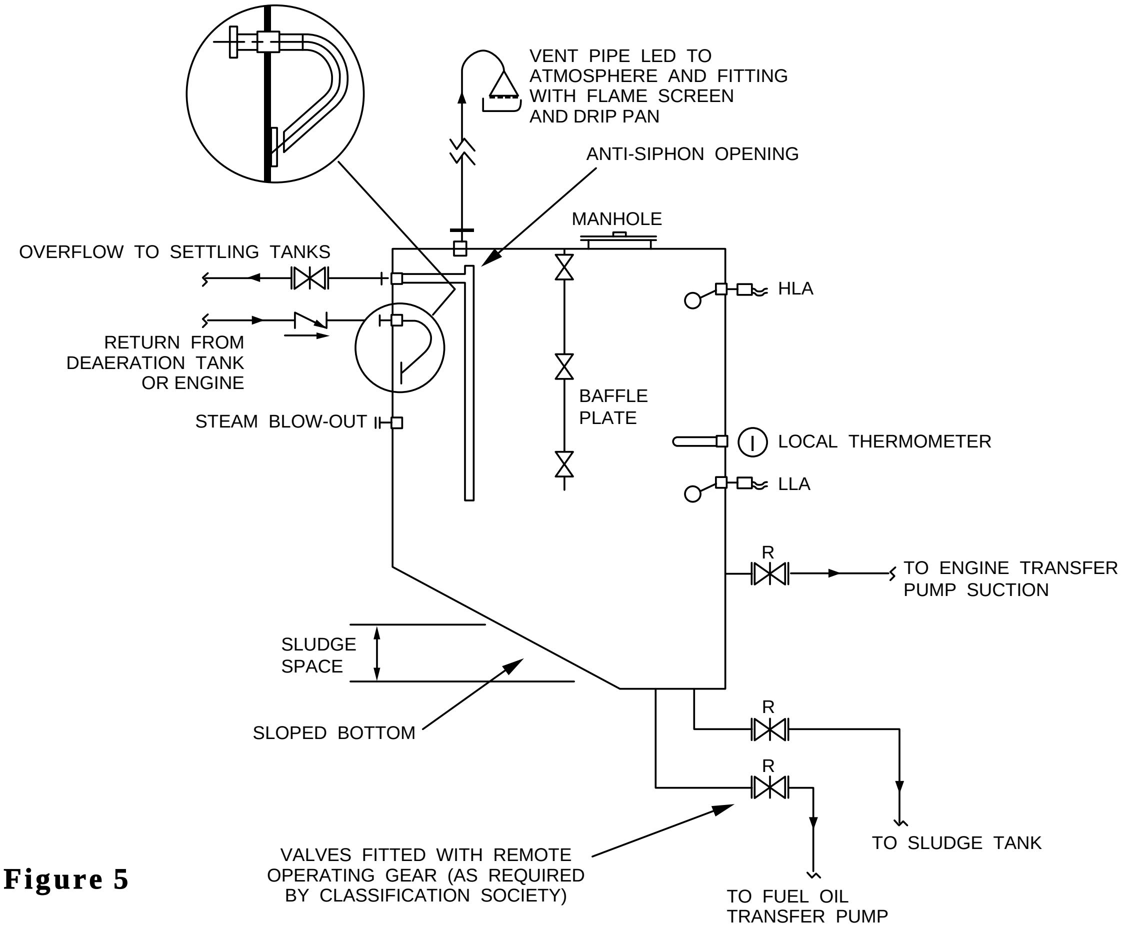


Figure 5

Emergency Pump

An electric motor driven emergency pump may be required in some engine applications for use as backup to the engine driven pump. This is generally a marine society requirement for single engine propulsion applications. Recommended flow rates are shown in the following table and will fulfill the minimum engine requirements at all rated speeds between 700 and 1000 rpm.

Flow Rate L/min (gal/min)				
Engine	3606	3608	3612	3616
Fuel Pump	42 (11)	42 (11)	79 (21)	79 (21)

The emergency pump must deliver the stated flow of diesel fuel at 65°C (149°F) against a head of 500 kPa (73 psi) pressure. Adjust the fuel pressure regulator to 414-690 kPa (60-100 psi).

Fuel treatment systems should be capable of being maintained without interruption in engine operation.

Settling Tank

The settling tank should hold a 24 hour minimum supply of distillate fuel for the propulsion engine, plus the normal expected kilowatt load from the diesel generator sets. Refer to the typical settling tank design (Figure 14) in the *Heavy Fuel Oil* section of this guide.

A heating coil can be installed in the tank. It can be used as a standby heater to bring the fuel to the proper centrifuge temperature. The coil should keep the distillate fuel temperature approximately 20°C (11°F) above the pour point. Fit the heating steam supply with an automatic temperature regulating valve to control fuel tank temperature.

Use screw type pumps to transfer fuel from the bunker tanks to the settling tank. They minimize the possibility of emulsifying water entrained in the distillate fuel. The transfer pump should operate automatically and fill the settling tank in less than two hours.

The following pump characteristics are provided for guidance:

- Operating pressure — to suit conditions of piping system
- Operating fluid temperature — 38°C (100°F)
- Viscosity for sizing the pump motor — 500 cSt

Fuel Cleanliness

Clean fuel is essential. The final filters are engine mounted and tested at the factory and are never bypassed on an operating engine. Optional factory supplied duplex primary filters with 178 micron (.007 in.) cleanable mesh screens collect large debris prior to the engine transfer pump.

Water Separation

With modern high output engines using high injection pressure fuel pumps, it is extremely important to maintain water and sediment levels at or below 0.1%. Depending on how the engines are applied, water and sediment can collect in fuel tanks. Therefore, fuel meeting the required specifications when delivered to the site can exceed limits when used in the engine. Several methods can be used to remove excess water and sediment:

- A water and sediment separator can be installed in the supply line ahead of the transfer pump. The separator must be sized to the handle the fuel being consumed by the engines as well as fuel being returned to the tank.
- Coalescing filter systems work effectively to remove sediment and water. If the level in the day tank is not maintained at a consistent level, install them between the main tank and the day tank. If proper day tank operation is maintained, a smaller system can be used between the main tank and the day tank to clean only the fuel being burned. The filters can plug and careful attention must be given to fuel pressure levels at the injectors to guard against misfiring.
- A centrifuge system can be used, particularly if the fuel quality consistently exceeds the defined limits specified herein.

Centrifuges

Clean distillate fuel with a separate centrifuge system from those dedicated for heavy fuel on the same ship (see Figure 6 on page 28 of this section). Even though the main propulsion engines may be arranged for heavy fuel, size the distillate fuel treatment plant to suit both the main engines and the ship service generator sets. Two transfer pumps, two centrifuges and heaters are normally used.

Use an automatic self cleaning centrifuge. Consult the centrifuge manufacturer to size the flow.

The fuel centrifuge piping system must allow one of the centrifuges to act as a standby. The required flow rate can be approximated as follows:

$$Q = \left\{\frac{P \times b \times 24 \times 1.15}{R \times t}\right\}$$

Where:

Q = Flow required, L/hr
P = Total Engine Output, kW
b = Fuel Consumption, g/kW-hr
R = Density of fuel, kg/m^3
t = Daily separating time in automatic operation: 23 hr

or:

$$Q = \left\{\frac{P \times be \times 24 \times 1.15}{R \times t}\right\}$$

Where:

Q = Flow required, gal/hr
P = Total engine output, bhp
be = Specific fuel consumption, lb/bhp-hr
R = Density of fuel, lb/gal
t = Daily separating time in automatic operation: 23 hr

Note:

- *The centrifuge manufacturer should assist in the final centrifuge selection.*
- *The centrifuge flow has been increased by 15% as a safety factor for operational tolerances.*

Centrifuge seal water and control air requirements must be specified by the centrifuge manufacturer.

Sample Points

The centrifuge operating efficiency is checked by drawing samples from both sides of the centrifuge. Arrange the points as shown in Figure 15 on page 48 of the *Heavy Fuel Oil* section.

Suction Strainer

Install a simplex strainer ahead of the centrifuge supply pump and use a stainless steel basket with perforations sized to protect the pump (0.8 mm (1/32 in.)). The strainer body is normally manufactured from cast iron or bronze.

Centrifuge Supply Pump

Mount an electric motor driven supply pump separately from the centrifuge and size for the centrifuge flow. The following pump characteristics are provided for guidance:

- Operating pressure - to suit conditions of piping system
- Operating fluid temperature - 38°C (100°F)
- Viscosity for sizing pump motor - 500 cSt

Fuel Heater

The heater is sized using the pump capacity and the temperature rise required between the settling tank and the final centrifuge. The heater should be thermostatically controlled and selected to maintain fuel temperature to the centrifuge within ± 2°C (± 4°F). The maximum preheating temperature for distillate fuel is 40° to 50°C (104° to 122°F).

Customer Connections

Engine Fuel Piping (Inside Diameter)		
	3606/3608	3612/3616
Fuel Supply	22 mm (7/8 in.)	28 mm (1-1/8 in.)
Fuel Return	22 mm (7/8 in.)	22 mm (7/8 in.)

Flex Connections

Connections to the engine must be flexible hose located at the engine inlet and outlet. Do not attach rigid fuel lines. The factory provided flex connections can be oriented to take maximum advantage of multiple direction flexing.

Fuel Lines

Bypass (return) fuel leaving the engine pressure regulator should be returned to the engine day tank. Any fuel returned directly to the transfer pump inlet must be routed through a deaerator.

The final installation must be hydrostatically tested to at least 1.5 times normal working pressure or to applicable marine society requirements, whichever is greater.

After fabrication and testing, steel piping must be removed and chemically cleaned (pickled) to remove mill scale, dirt, etc. Wash piping with suitable solvent and dry thoroughly. Coat the inside of piping with oil prior to final assembly.

Pressure and Flow Monitoring

Engine fuel lines have pressure variations due to injector spill pulses. Monitoring devices must include dampers or orifices in the lines to minimize pulse effects and obtain accurate readings. Caterpillar supplied gauges have proper damping incorporated in the hardware.

Fuel Recommendations

Caterpillar 3600 engines are capable of burning a wide range of distillate fuels. Also see the *Heavy Fuel Oil* section of this guide.

Distillate Fuel Recommendations

Specifications	Requirements*
Aromantics (ASTM D1319)	35% Maximum
Ash (ASTM D482)	0.02% Weight Maximum
Cetane Number (ASTM D613)	40 Minimum
Cloud Point (ASTM D97)	Not above lowest expected ambient temperature
Gravity API (ASTM D287)	30 Minimum and 45 Maximum
Pour Point (ASTM D97)	6°C (10°F) below ambient temperature
Sulfur (ASTM D2788, D3605, or D1552)	0.5% Maximum (See Sulfur Topic)
Viscosity, Kinematic @ 38°C (100°F) (ASTM D445)	20.0 cSt Maximum 1.4 cSt Minimum
Water & Sediment (ASTM D1796)	0.1% Maximum

*As delivered to fuel system.

The fuels recommended for 3600 engines are normally No. 2-D diesel fuel and No. 2 fuel oil. No. 1 grades and ISO-F-DMB fuels are also acceptable. Other fuel types may be used when economics or fuel availability dictate.

Consider the following fuel characteristics when procuring fuel:

Cetane Number
The minimum cetane number required for average starting conditions is 40. A higher cetane value may be required for high altitude operation or cold weather starting.

Filtering
Fuels should have no more than 0.1% sediment and water. Storage of fuel for extended periods of time can cause fuel oxidation and formation of solids, leading to filtration problems.

Pour Point
The pour point of the fuel should be at least 6°C (10°F) below the lowest expected starting and operating temperatures. The lower pour point of No. 1 or No. 1-D fuel may be necessary in cold weather.

Cloud Point
The cloud point should be below the lowest expected ambient operating temperature. This prevents fuel filter elements plugging with wax crystals.

Sulfur
Fuels containing 0.5% or less sulfur may be used with normal crankcase oil drain intervals using API CF performance oils. With sulfur above the 0.5% level, use API CF oil with an ASTM D-2896 minimum total base number (TBN) of 10 times the fuel sulfur for normal oil drain intervals. See the guide section on *Lubricating Oil* for further details.

Viscosity
Fuel viscosity is important for lubrication of fuel system components and fuel atomization. The *minimum* allowable viscosity at the injectors is 1.4 cSt.

Additives
Fuel additives are generally not recommended. Cetane improvers can be used as necessary. Biocides may be needed to eliminate microorganism growth in storage tanks. Treatment for entrained water may also be necessary in cold conditions. *Consult the fuel supplier about the use of additives to prevent incompatibility with additives already in the fuel.*

Fuel Sulfur Content
The percentage of sulfur in fuel will affect engine oil recommendations. Fuel sulfur is chemically changed during combustion to form both sulfurous and sulfuric acid. The acids chemically attack metal surfaces and cause corrosive wear.

Certain additives used in lubricating oils contain alkaline compounds formulated to neutralize acids. The measure of reserve alkalinity is total base number (TBN). Required TBN values are essential to neutralize acids and minimize corrosive wear.

The TBN recommendation for an oil is dependent on the amount of sulfur in the fuel used. For 3600 engines running on distillate fuel oil, the minimum new oil TBN (by ASTM D 2896) must be 10 times the sulfur percent by weight in the fuel, with a minimum TBN of 5 regardless of the sulfur content (see Figure 7).

In most oil formulations the TBN is a function of the ash bearing additives in the oil. Excessive amounts of ash bearing additives can lead to excessive piston deposits and loss of oil control. Therefore, excessively high TBN or high ash oils should not be used with 3600 engines running on distillate fuel. Successful operation of 3600 engines on distillate fuel has generally been obtained with new oil TBN levels between 10 and 15. See the guide section on *Lubricating Oil* for more information.

Periodically request fuel sulfur information from the fuel supplier. Fuel sulfur content can change with each delivery.

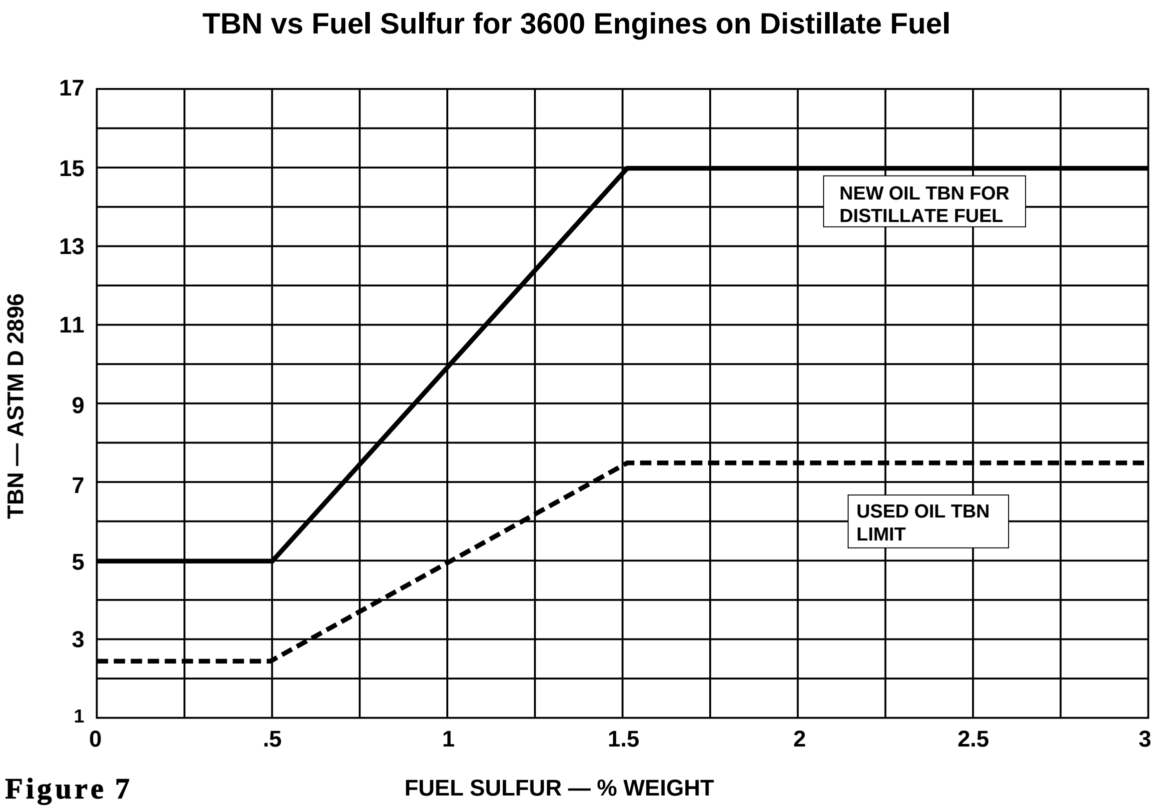


Figure 7

NOTE:
OPERATION AT FUEL SULFUR LEVELS OVER 1.5% MAY REQUIRE SHORTENED OIL CHANGE PERIODS TO MAINTAIN ADEQUATE WEAR PROTECTION.

Specific Gravity
Fuel rack settings are based on 35° API (specific gravity) fuel. Fuel oil with a higher API (lower specific gravity) number reduces power output unless the rack setting is corrected. When using heavier fuels (lower API number), a corrected rack setting prevents power output above the approved rating. The Caterpillar dealer will correct the rack setting for non-standard fuels.

Fuel Temperature

The fuel temperature supplied to the engine can affect unit injector life and maximum power capability. Reduced lubrication capability as a result of high temperature/low viscosity fuel may result in plunger scuffing. The *minimum* allowable viscosity at the injectors is 1.4 cSt. *A maximum fuel temperature limit of 72°C (162°F) to the unit injectors, regardless of fuel viscosity, prevents coking or gumming of the injectors.* The maximum fuel viscosity to the unit injectors of 20 cSt prevents overpressure damage to the injectors.

The engines are power set at the factory with 30 ± 3°C (86 ± 5°F) fuel to the engine transfer pump. Higher fuel temperatures reduce *maximum* power capability. *The **fuel stop** power reduction is 1% for each 5.6°C (10°F) fuel supply temperature increase above 30°C.* If the engine is operating below the *fuel stop* limit, the governor will add fuel as required to maintain the required engine speed and power.

Day tank sizing is critical to maintain the desired fuel supply temperature. Fuel coolers may be required.

Fuel Coolers

Fuel coolers are site specific and sized to handle fuel heat not dissipated by the day tank. The cooler must be located on the return circuit with a three way temperature regulating valve to control fuel return temperature to the service tank (see Figure 4). Submit the cooler design and materials to the appropriate classification society for approval.

The suggested material for a shell and tube type heat exchanger is:

- Shell — Red brass
- Heads — Cast iron
- Tubes — Copper
- Tube sheets — Brass
- Baffles — Brass

A plate type heat exchanger may also be used with titanium plates for sea water cooling or stainless steel plates for fresh water cooling.

Day Tank Sizing as a Heat Sink
Day tank sizing is critical when fuel to the engine is from a day tank without a fuel cooler. The supply temperature must be within specified limits for injector life and maximum power capability.

Day tank temperatures are impacted by:

- Day tank wetted surface area (including tank bottom)
- Engine(s) fuel consumption rate
- Day tank replenishing level
- Storage tank fuel temperature
- Ambient temperature
- Spaces contiguous to the day tank (void tanks, cofferdams, vessel shell plating, etc.)
- Return fuel temperature

Tank temperature calculation are performed in five [5] steps. The first determines the fuel mass in the tank at each time interval. The second step is based on a fuel mix temperature resulting from the engine driven transfer pump flow rate to the engine and the return flow rate to the day tank. The third step determines the day tank fuel height for each incremental time element. Typically, the calculations will be based upon a 30-60 minute iterative time function. The end point for the calculation is assumed to be when the day tank is refilled. The fourth step approximates the heat transfer from the tank to the surrounding environment due to the temperature difference between the fuel mix temperature and the ambient temperature. This convective heat transfer then determines the resultant tank temperature. The fifth step evaluates the impact of the final fuel supply temperature on the engine's maximum power capability.

The included example calculations should only be used to provide general guidance. If the day tank size is marginal use a fuel cooler.

To simplify the following calculations, it is assumed the day tank walls are surrounded by free moving air. If the tank walls are contiguous to the shell plating, heat transfer from the day tank will be enhanced. Conversely, if the day tank is bounded by void spaces and cofferdams, heat rejection from the day tank will be retarded. Typically, most day tanks are located with various combinations of the preceding boundary elements. The individual performing the evaluation must be familiar with the installation as well as the fundamental engineering concepts of the formulas used in the calculations.

Day Tank Calculations

The following information is required to perform the calculations:

- Engine model
- Engine developed power (MCR or CSR)
- Engine speed
- Brake specific fuel consumption (bsfc)
- Initial day tank fuel temperature
- Storage tank fuel temperature (Make-up)
- Ambient air temperature
- Day tank length, width, and height
- Typical full day tank fuel height (assume 95% of tank capacity)
- Engine fuel transfer pump flow rate (see page 6 of this section)
- Fuel heat rejection from the engine (see page 6 of this section)
- Incremental time element

Day Tank Thermal Capacity Calculation

Example:

- Application: Single main engine
- Engine Model: 3612
- Rated Power: 4640 bhp (CSR)
- Rated Speed: 900 rpm
- bsfc: 0.326 lb/bhp-hr
- Initial Day Tank Fuel Temperature = 85°F
- Storage Tank Temperature = 85°F
- Ambient Air Temperature = 95°F
- Day Tank Dimensions:
  - Length (L) = 12 ft.
  - Width (W) = 8 ft.
  - Height (H) = 8.42 ft.
- Fuel Height (@ 95% of total Capacity) (H) = 8 ft.
- Engine Fuel Oil Transfer Pump Flow Rate (q_{xfer}) = 19.0 gpm
- Heat rejection from engine to fuel oil (Q) = 1252 Btu/min
- Incremental time element, (t) = 60 min.

Assume that the day tank will be replenished from the vessel's storage tanks when the day tank level falls to approximately 50-55% of normal operating capacity.

Some of the data above must be converted to other units prior to beginning calculations. The following formulas can be used:

a) Engine Driven Transfer Pump Mass Flow Rate = M_{xfer} (lb/min)
   Assume: #2 DO with an API gravity of 35 (7.1 lb/gal)

$M_{xfer} = q_{xfer} \times 7.1$ lb/gal = 19.0 gpm x 7.1 lb/gal = 134.9 lb/min

b) Engine burn rate under full load conditions

1) Burn rate (gpm) =

$$\frac{\text{bsfc x bhp x 1 Hr.}}{\text{Fuel density x 60 min.}}$$

$$= \frac{0.326 \text{ lb/bhp - hr x 4640 bhp x 1 hr.}}{7.1 \text{ lb/gal. x 60 min.}}$$

= 3.55 gpm

2) Fuel mass flow burn rate = M_{BR} (lb/min)

= 3.55 gpm x 7.1 lb/gal
= 25.21 lb/min

c) Engine fuel return rate under full load conditions:

1) Fuel return flow rate = q_{rtn} (gal/min)
= Supply rate - burn rate
= 19.0 gpm - 3.55 gpm
= 15.45 gpm

2) Fuel return mass flow rate = M_{RTN} (lb/min)
= 15.45 gpm x 7.1 lb/gal
= 109.70 lb/min

d) ΔT_{ENG} of fuel = ($T_{supply} - T_{rtn}$)

$$\Delta T_{ENG} = \frac{Q}{M_{RTN} \times c_p}$$

$$= \frac{1252 \text{ Btu/min}}{(109.70 \text{ lb/min x } 0.5 \text{ Btu/lb-°F})}$$

= 22.83°F

e) 95% Capacity of Diesel Oil Day Tank, (lb)
Weight density (p) for #2 diesel oil = 52.42 lb/ft^3
$M_{DT} = L \times W \times H \times p_{DO}$
= 12 ft x 8 ft x 8 ft x 52.42 lb/ft^3
= 40258.6 lb.

Step 1

Calculate the fuel mass in the day tank at specific time intervals:

Day Tank Fuel Quantity = $M_{DT} - (M_{BR} \times t)$

Where:
M_{DT} = Day tank contents at a specific time step (lb)
M_{BR} = Engine fuel consumption (lb/min)
t = Incremental time step (min)

Assume the day tank is replenished at 55% of initial quantity of fuel. Prepare a table of volumes as shown below for our example.

Incremental Time (Min)	Tank Fuel Quantity (lb)	Capacity (%)
0	40258.6	100.0
60	38746.0	96.2
120	37233.4	92.5
180	35720.8	88.7
240	34208.2	85.0
300	32695.6	81.2
360	31183.0	77.5
420	29670.4	73.7
480	28157.8	69.9
540	26645.2	66.2
600	25132.6	62.4
660	23620.0	58.7
720	22107.4	54.9
Refill	40258.6	100.0

Step 2

Calculate the fuel oil mix temperature (T_{mix}):

$$\frac{\left[(M_{DT(t-1)} - [(M_{xfer} \times t)]) \, T_{DT(t-1)} + (M_{RTN} \times t) \times (T_{DT(t-1)} + \Delta T_{ENG}) \right]}{M_{DT(t-1)} - (M_{BR} \times t)}$$

Where:

M_{DT} = Day tank contents at a specific time step (lb)

M_{xfer} = Engine transfer pump mass flow rate (lb/min)

t = Incremental time step (min)

$T_{DT(t-1)}$ = Day tank temperature for previous time step or starting temperature (°F)

M_{RTN} = Engine return mass flow rate (lb/min)

ΔT ENG = Fuel temperature rise across the engine (°F)

M_{BR} = Engine fuel consumption (lb/min)

Values for the example calculation:

$M_{DT(t-1)}$ = Day tank contents from previous time step (lb)

M_{xfer} = 134.9 lb/min

t = 60 min.

$T_{DT(t-1)}$ = Initial day tank temperature is used for first iteration, 85°F

M_{RTN} = 109.70 lb/min

ΔT_{ENG} = 22.83°F

M_{BR} = 25.21 lb/min

$$T_{mix} = \frac{[(40258.6 - (134.9)(60))(85)] + [(109.70)(60)(85 + 22.83)]}{[40258.6 - (25.21)(60)]}$$

= 88.9°F @ t = 60 min.

This calculation is repeated for each increment (t).
Prepare a summary table as shown below for each increment (t).

Incremental Time (Min)	Mix Temperature (°F)
0	85.0
60	88.9
120	92.9
180	97.1
240	101.5
300	106.1
360	110.9
420	116.0
480	121.3
540	126.9
600	132.9
660	139.3
720	146.1
Refill	

Step 3

Calculate the height of fuel contained in the day tank at t = incremental time step. Prepare a summary table for each time increment (t).

$$H = \frac{M_{DT}}{p \times L \times W}$$

Where:

H = Height of fuel in the tank

M_{DT} = Fuel contained in the day tank at each incremental time step

p = Weight density of #2 DO ($52.42\ lb/ft^3$)

L = Length of day tank (12 ft)

W = Width of day tank (8 ft)

Incremental Time (min)	Height (ft)
0	8.0
60	7.7
120	7.4
180	7.1
240	6.8
300	6.5
360	6.2
420	5.9
480	5.6
540	5.3
600	5.0
660	4.7
720	4.4
Refill	8.0

Step 4

Calculate the heat transferred between the fuel in the day tank and the atmosphere, the ΔT of the fuel in the day tank due to the heat transfer, and the resulting fuel day tank temperature.

a) Heat transferred between the day tank and the atmosphere:

$$Q_{TK} = \left[U \times [\,(H \times (2L + 2W) + (L \times W)\,] \times [\,T_{AMB} - \frac{(T_{MIX} + T_{DT})}{2}\,] \right] \times t$$

Where:

Q_{TK} = Heat transfer to/from atmosphere (Btu)

This considers 6mm (0.25 in.) steel plate forming the tank boundaries, and the film coefficient for air and oil. The air side film coefficient is predominant when compared to the oil side film. The tank thickness has a negligible effect.

U = Coefficient of heat transfer, ($0.0424\ Btu/min \cdot ft^2 \cdot °F$)

L = Day tank length (ft)

W = Day tank width (ft)

T_{AMB} = Ambient temperature (°F)

T_{MIX} = Mix temperature of return fuel and fuel in tank (°F)

T_{DT} = Day tank temperature resulting from heat transfer to/from day tank (°F)

t = Incremental time step (min)

H = Fuel height for specific time step (ft)

b) Temperature change in the day tank resulting from heat to/from day tank:

$$\Delta T_{DT} = \frac{Q_{TK}}{M_{DT} \times C_p}$$

Where:

ΔT_{DT} = Temperature change of fuel in the day tank (°F)

Q_{TK} = Heat transfer to/from atmosphere (Btu)

M_{DT} = Mass of fuel in day tank (lb)

c_p = Specific heat of #2 MDO = $0.5\ Btu/lb \cdot °F$

c) Day tank temperature resulting from heat transfer to/from day tank:

$$T_{DT} = T_{MIX} + \Delta T_{DT}$$

Where:

T_{DT} = Day tank temperature (°F)

T_{MIX} = Mix temperature of return fuel and tank fuel (°F)

ΔT_{DT} = Temperature change of day tank (°F)

These three calculations are interdependent in nature. First, Q_{TK} is determined for the first incremental time step. The resulting value for Q_{TK} is then used to compute the ΔT_{DT}. ΔT_{DT} is then used to determine T_{TK}. This process is then repeated for each incremental time step.

Example a):

$$Q_{TK} = [U [H \times (2L + 2W) + (L \times W)] \times [T_{AMB} - \frac{(T_{MIX} + T_{DT})}{2}]] \times t$$

$$Q_{TK} = 0.0424 \times [7.7 (40) + 96] \times [95 - \frac{(88.9 + 85)}{2}] \times 60$$

$$= 8283.6 \text{ Btu}$$

Example b):

$$\Delta T_{DT} = \frac{Q_{TK}}{M_{DT} \times c_p}$$

$$= \frac{8283.6 \text{ Btu}}{(38746.0 \text{ lb}) (0.5 \text{ Btu/lb °F})}$$

= 0.43 °F (From atmosphere to day tank)

Example c):

T_{DT} = $T_{MIX} + \Delta T_{DT}$
= 88.9 °F + 0.43 °F
= 89.3 °F

This series of calculations is then repeated for the subsequent incremental time steps.

Prepare a summary table for each time increment (t).

Incremental Time (min)	Heat Rejection to/from Day Tank (Btu)	Temperature Chg. in Day Tank (°F)	Day Tank Temperature (°F)
0	-	-	85.0
60	8283.6	0.43	89.3
120	4069.7	0.22	93.2
180	-4.0	0.00	97.1
240	-4022.0	-0.24	101.3
300	-7966.3	-0.49	105.6
360	-11818.7	-0.76	110.2
420	-15561.4	-1.05	114.9
480	-19257.8	-1.37	120.0
540	-22802.6	-1.71	125.2
600	-26253.3	-2.09	130.8
660	-29655.5	-2.51	136.8
720	-32973.6	-2.98	143.1
Refill	-	-	116.9

The last part in Step 4 determines the day tank temperature after refilling ($T_{DT\,refill}$):

$$T_{DT\,refill} = \frac{[(M_{DT_{full}} - M_{DT_{tn}}) \times T_{MUF}] + (M_{DT_{tn}} \times T_{TK_n})}{M_{DT_{full}}}$$

Where:

$M_{DT_{full}}$ = Capacity of day tank, (lb)

$M_{DT_{tn}}$ = Fuel in day tank prior to refilling, (lb)

T_{MUF} = Temperature of make-up fuel, (°F)

T_{TK_n} = Temperature of tank fuel prior to refilling, (°F)

Example:

$$T_{DT\,refill} = \frac{[(40258.6 - 22107.4) \times 85] + (22107.4 \times 143.1)}{40258.6 \text{ lb}}$$

$= 116.9°F$

Step 5

The last step calculates the maximum power capability of the engine at the resultant day tank temperature for each time interval. A summary table for each increment (t) is also prepared:

Note*: The engines are power set at the factory with 30 ± 3°C (86 ± 5°F) fuel to the engine transfer pump. Higher fuel temperatures reduce maximum power capability. The fuel stop power reduction is 1% for each 5.6°C (10° F) fuel supply temperature increase above 30°C. If the engine is operating below the fuel stop limit, the governor will add fuel as required to maintain the required engine speed and power.*

$$P_{corr} = P_{rated} \times (1 - [\frac{(T_{DT} - T_{ref})}{10°F} \times \frac{1}{100}])$$

Where:

P_{corr} = Corrected Engine Power, bhp

P_{rated} = Rated bhp

T_{ref} = 86° (Power setting)

T_{DT} = Actual day tank fuel temperature, °F

Example:

For t = 60, the corrected power of the engine is:

P_{CORR} =

$$4640 \text{ bhp} \times (1 - \frac{[(89.3°F - 86°F) \times 1]}{(10°F)(100)})$$

$= 4625$ bhp

Incremental Time (min)	Day Tank Temp. (°F)	Corrected Engine Power (bhp)
0	85.0	-
60	89.3	4625
120	93.2	4607
180	97.1	4588
240	101.3	4569
300	105.6	4549
360	110.2	4528
420	114.9	4506
480	120.0	4482
540	125.2	4458
600	130.8	4432
660	136.8	4405
720	143.1	4375
Refill	116.9	4497

Conclusion

The previous calculations indicate day tank fuel temperatures can have an effect on the maximum power capability of the engine. The example was based upon a fixed pitch propeller application. Typically, a fixed pitch propeller is selected and sized to absorb 85-90% of the engine's name plate rating. In this example, this would equate to 3950-4175 bhp. The lowest calculated corrected power was determined to be 4375 bhp. This would leave a 5-10% power margin and vessel performance would not be affected.

While vessel performance may not be affected in this example, the maximum fuel temperature of 143.1°F will put the fuel viscosity near or below the minimum allowable viscosity of 1.4 cSt at the injectors depending on the type of distillate fuel being used. In addition, the temperature of the fuel in the tank after refill is now 116.9°F instead of 85°F as used at the beginning of the iteration. Therefore, continued operation at full load on this fuel tank would cause the fuel temperature to rise even higher than the maximum temperature shown in this iteration. To protect the fuel injectors a fuel cooler should be used in this application, despite the fact that available engine power is still acceptable.

Aside from the impact on engine performance, maximum fuel tank temperatures are also established by various marine classification societies and regulatory bodies. Their interest is based upon the increased risks of fire that results from elevated fuel temperatures.

Fuel Heaters

Cold weather can form wax crystals in No. 1 or No. 2 diesel fuel if temperatures go below the cloud point. Small amounts of heat added to the fuel before the filters can prevent clogging problems due to wax. At temperatures below the cloud point, fuel will flow through pumps and lines but not filters. At temperatures below the pour point, fuel will not flow in lines or pumps. The use of fuel with a pour point above the minimum expected ambient temperature is not recommended. Fuel heaters will often solve cloud point problems but not pour point problems unless applied to the entire fuel storage volume.

The following are several suggestions for applying fuel heaters:

- Use fuel heaters when the ambient temperature is below the fuel cloud point. Many types of heaters can be used. Heat the fuel before the first filter in the fuel system. *Do not use fuel heaters when the ambient temperature exceeds 15°C (60°F). The maximum fuel temperature at the outlet of the fuel heater must never exceed 72°C (162°F).*
- Use heaters capable of handling the maximum fuel flow of the engine. The restriction created must not exceed the maximum allowable.
- Coolant may be taken from taps on the engine when using the engine as a heat source. Care must be taken to assure that coolant shunting to one system does not adversely affect another system, and that both have adequate flow.

Caution: *Failed water sourced fuel heaters can introduce excessive water into the engine fuel system and cause injector failure. Maintenance responsibility of this type of heater must be clearly defined.*

When fuel heaters are used in ambient temperatures below 0°C (32°F), start the engine and run at low idle until the engine temperature rises slightly. This allows heat transfer to the fuel before high fuel flow rates at high power output occur, reducing fuel filter wax plugging.

Useful Fuel Formulas and Data

The following information can be useful in sizing fuel coolers and heaters:

Specific Gravity (SG) and Density

API Gravity = (141.5/SG) - 131.5

SG = 141.5/(API Gravity + 131.5)

$$SG = \frac{\text{Density}}{998 \text{ kg/m}^3}$$

Density (kg/m^3) = SG x 998 kg/m^3

$$\text{Density (lbm/gal)} = \text{SG} \times 998 \text{ kg/m}^3 \times \frac{1 \text{ lbm/ft}^3}{16.02 \text{ kg/m}^3} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}}$$

Mass Flow Rate

$$\dot{M} \text{ (kg/sec)} = \text{Density (kg/m}^3) \times \frac{1 \text{ m}^3}{1000 \text{ L}} \times \frac{\text{Flow Rate (L/min)}}{60 \text{ (sec/min)}}$$

$$\dot{M} \text{ (lbm/min)} = \text{Density (lbm/gal)} \times \text{Flow Rate (gal/min)}$$

Specific Heat (c_p)

The following table shows typical specific heat values for two different API gravity fuels in Btu/lbm-°F:

API Gravity	100°F (38°C)	140°F (60°C)	180°F (82°C)	200°F (93°C)	240°F (115°C)
30	0.463	0.482	0.501	0.511	0.530
40	0.477	0.497	0.516	0.526	0.546

1 Btu/lbm-°F = 4.186 kJ/kg-°C

Heat Rejection

$$Q \text{ (kW)} = \dot{M} \text{ (kg/sec)} \times c_p \text{ (kJ/kg-°C)} \times \Delta T \text{ (°C)}$$

$$Q \text{ (Btu/min)} = \dot{M} \text{ (lbm/min)} \times c_p \text{ (Btu/lbm-°F)} \times \Delta T \text{ (°F)}$$

Burning Used Crankcase Oil

With legislation and ecological pressures, it is becoming increasingly difficult to dispose of used oil. Burning of used crankcase oil in 3600 engines is **not** recommended due to the detrimental effects on exhaust emissions. However, if ancillary methods of reducing exhaust emissions to acceptable limits are used, or if emissions are not a problem, burning crankcase oil in 3600 engines is possible with these guidelines:

- Only diesel engine crankcase oils can be mixed with the diesel engine fuel supply. The ratio of used oil to fuel **must not exceed 5%**. Premature filter plugging will occur at higher ratios. ***Under no circumstances should gasoline engine crankcase oil, transmission oils, special hydraulic oils not covered by Caterpillar recommendations, greases, cleaning solvents, etc., be mixed with the diesel fuel***. Do not use crankcase oils containing water or antifreeze from engine coolant leaks or from poor storage practices.

- *Adequate mixing is essential*. Lube oil and fuel oil, once mixed, will combine and not separate. Mix used crankcase oil with an equal amount of fuel, filter, and then add the 50-50 blend to the supply tank before new fuel is added. This procedure will normally provide sufficient mixing. Failure to achieve adequate mixing will result in premature filter plugging by slugs of undiluted lube oil.

- Filter or centrifuge used oil prior to putting it in the fuel tank to prevent premature fuel filter plugging or accelerated wear or plugging of fuel system parts. Soot, dirt, metal, and residue particles larger than 5 microns (.0002 in.) must be removed.

Caution: *Diesel fuel day tank sight glasses may blacken. Ash content of the lube oil in the fuel may also cause more accumulation of turbocharger and valve deposits.*

Continuous Blending
If the installation warrants, used lubricating oil can be blended and used in the engine in a continuous manner. The normal method uses a centrifuge module similar to Figure 8. The following information describes the system:

Centrifuge No. 1
Engine crankcase oil is continuously centrifuged except when the clean waste oil tank is low, at which time the dirty waste oil is centrifuged and directed to the clean waste oil tank.

Centrifuge No. 2
Distillate fuel/oil mixture daytank is continually centrifuged.

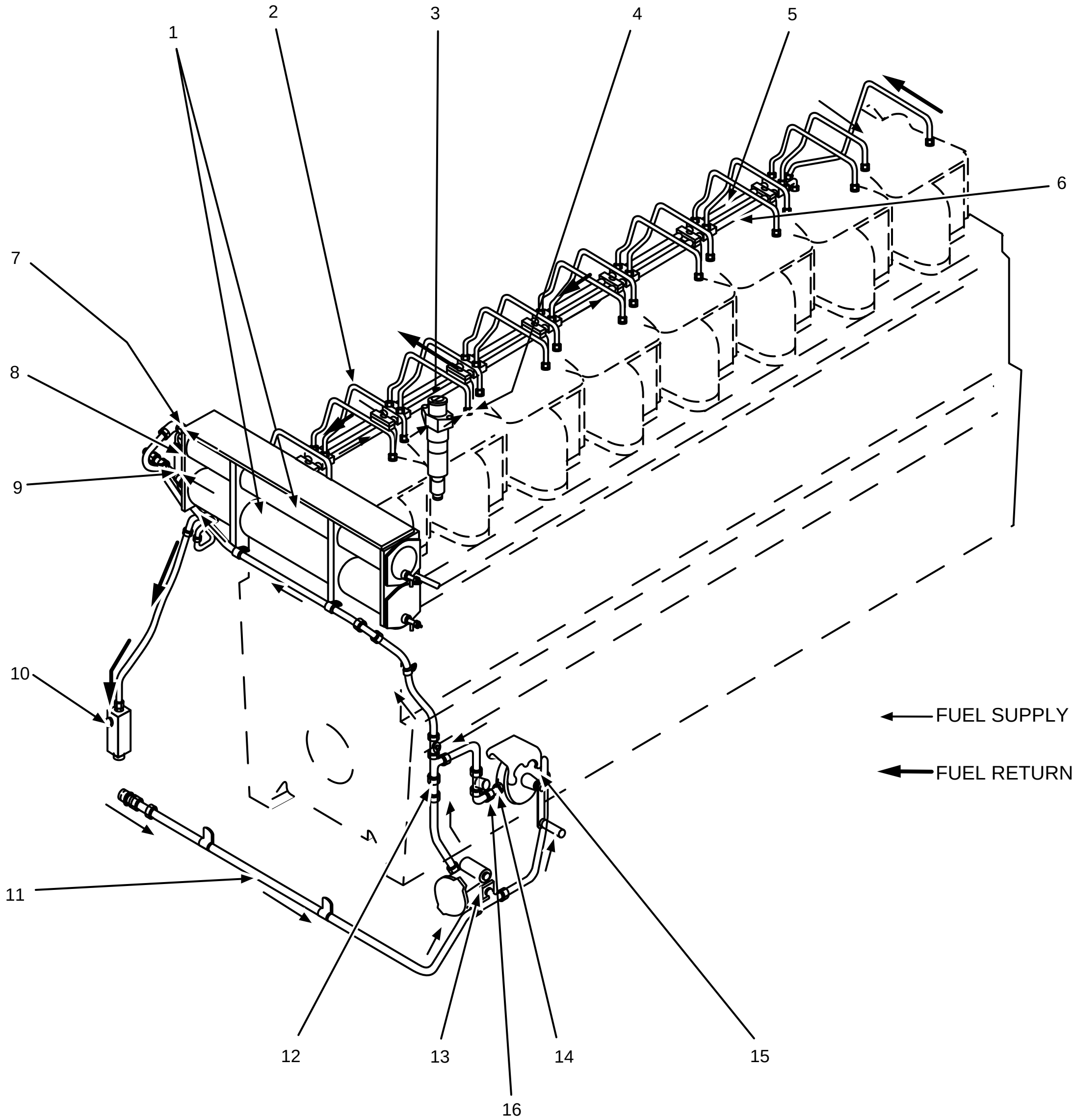
Metering Pump
Adds up to 5% clean waste oil to the distillate fuel (from the main supply tank) when the daytank low level switch calls for more fuel.

Static Mixer
Runs when the metering pump is on to insure a proper homogeneous mixture of the fuel and clean waste oil.

The centrifuge module is electronically controlled and includes the components within the dotted line. Size the system for appropriate fuel delivery.

Reference Material

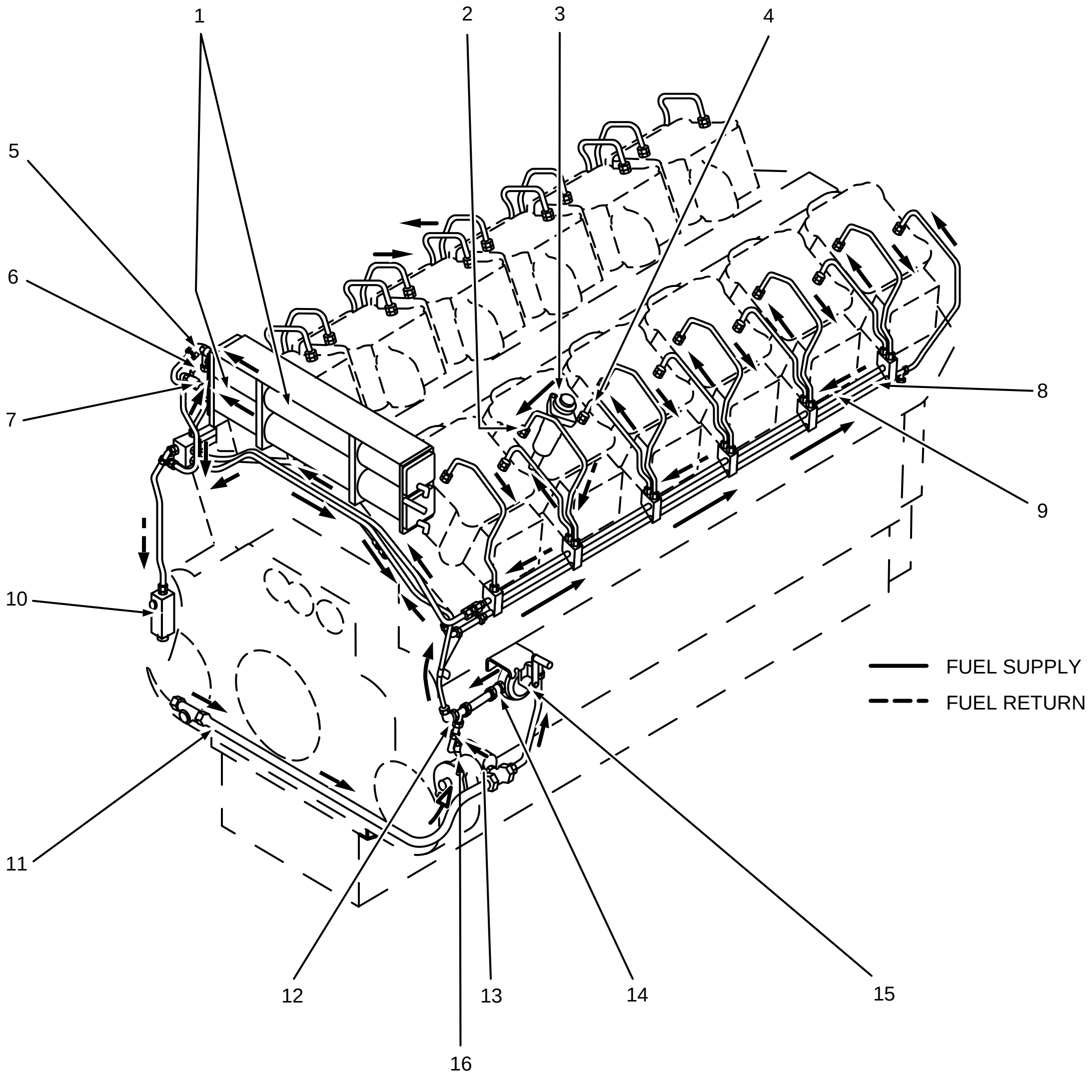
SEHS9031 *Special Instructions - Storage Recommendations*
SEBD0717 *Diesel Fuel and Your Engine*
SEBD0640 *Oil and Your Engine*
LEKQ4219 *EDS 60.1 – Fuel Recommendations for Caterpillar Diesel Engines*



3606 and 3608 Engines
Fuel Flow Schematic

1. Fuel Filter Housings
2. Fuel Inlet Line
3. Unit Injector
4. Fuel Outlet Line
5. Fuel Return Manifold
6. Fuel Supply Manifold
7. Check Valve
8. Fuel Filter Change Valve
9. Check Valve
10. Fuel Pressure Control Valve
11. Fuel Supply Line
12. Check Valve
13. Fuel Transfer Pump
14. Check Valve
15. Fuel Priming Pump
16. Emergency Fuel Connection

Figure 1



3612 and 3616 Engines Fuel Flow Schematic	
1. Fuel Filter Housings	9. Fuel Return Manifold
2. Fuel Outlet Line	10. Fuel Pressure Control Valve
3. Unit Injector	11. Fuel Supply Line
4. Fuel Inlet Line	12. Check Valve
5. Check Valve	13. Fuel Transfer Pump
6. Fuel Filter Change Valve	14. Check Valve
7. Check Valve	15. Fuel Priming Pump
8. Fuel Supply Manifold	16. Emergency Fuel Connection

Figure 2

Fuel System Schematic

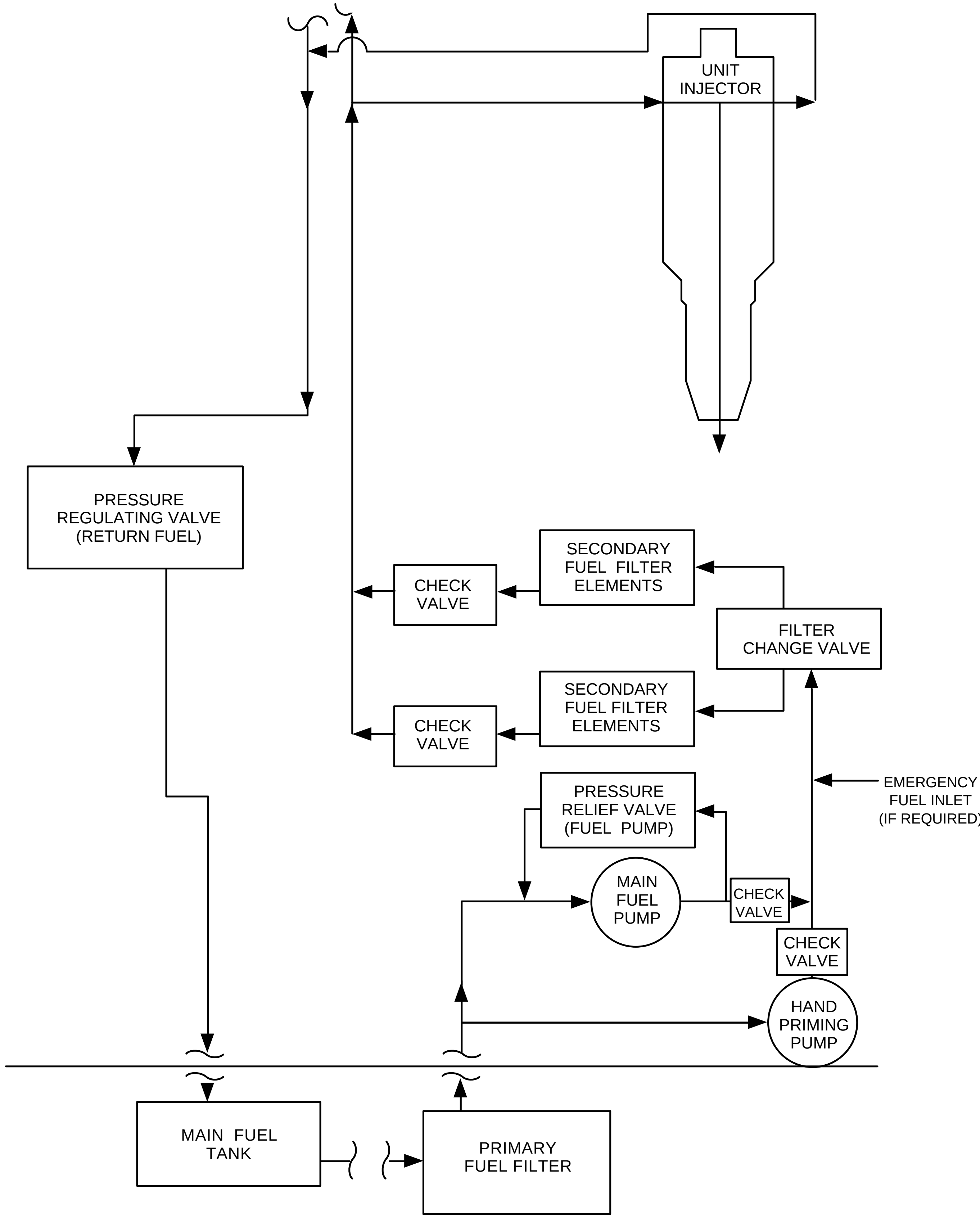


Figure 3

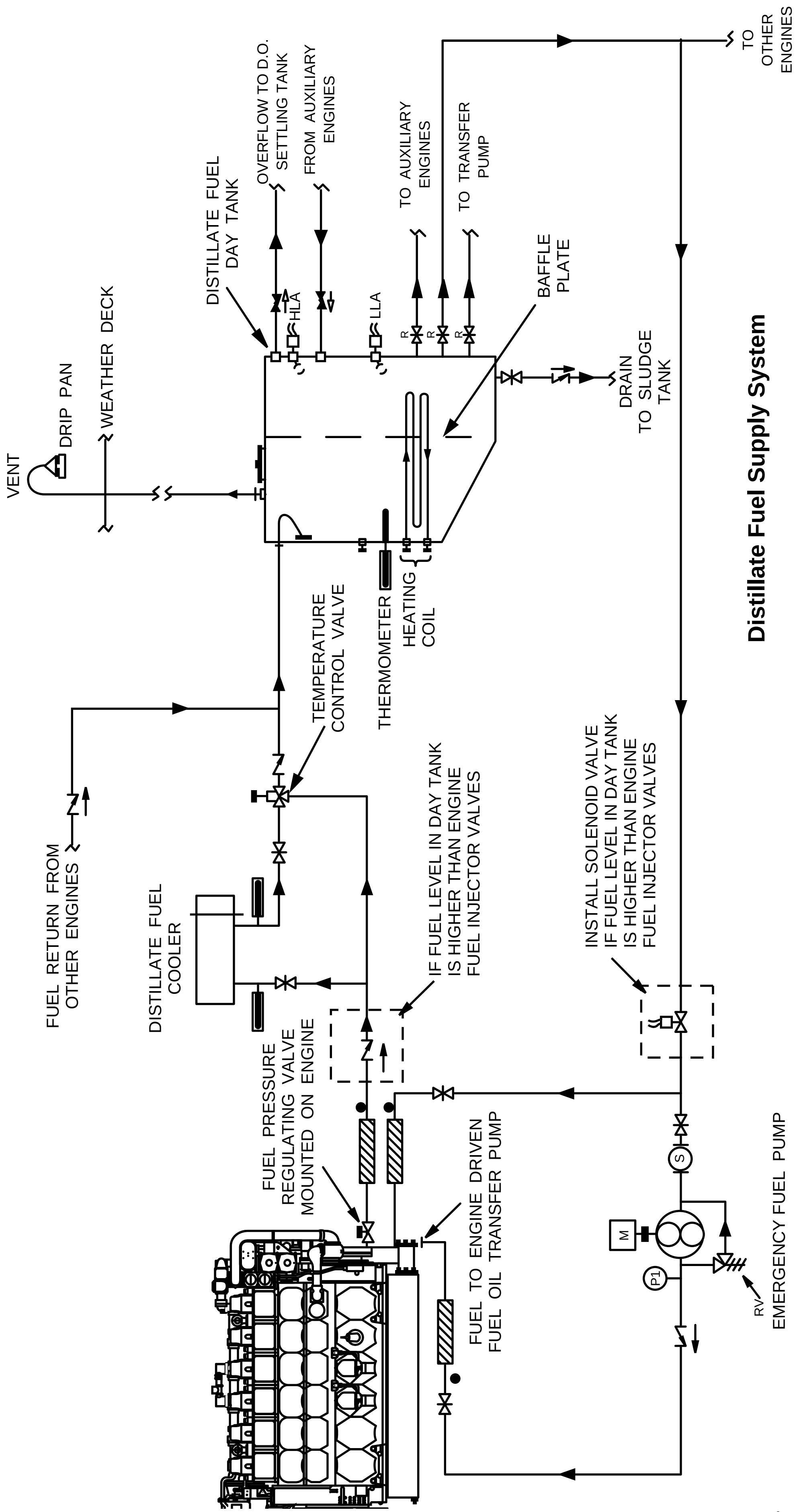
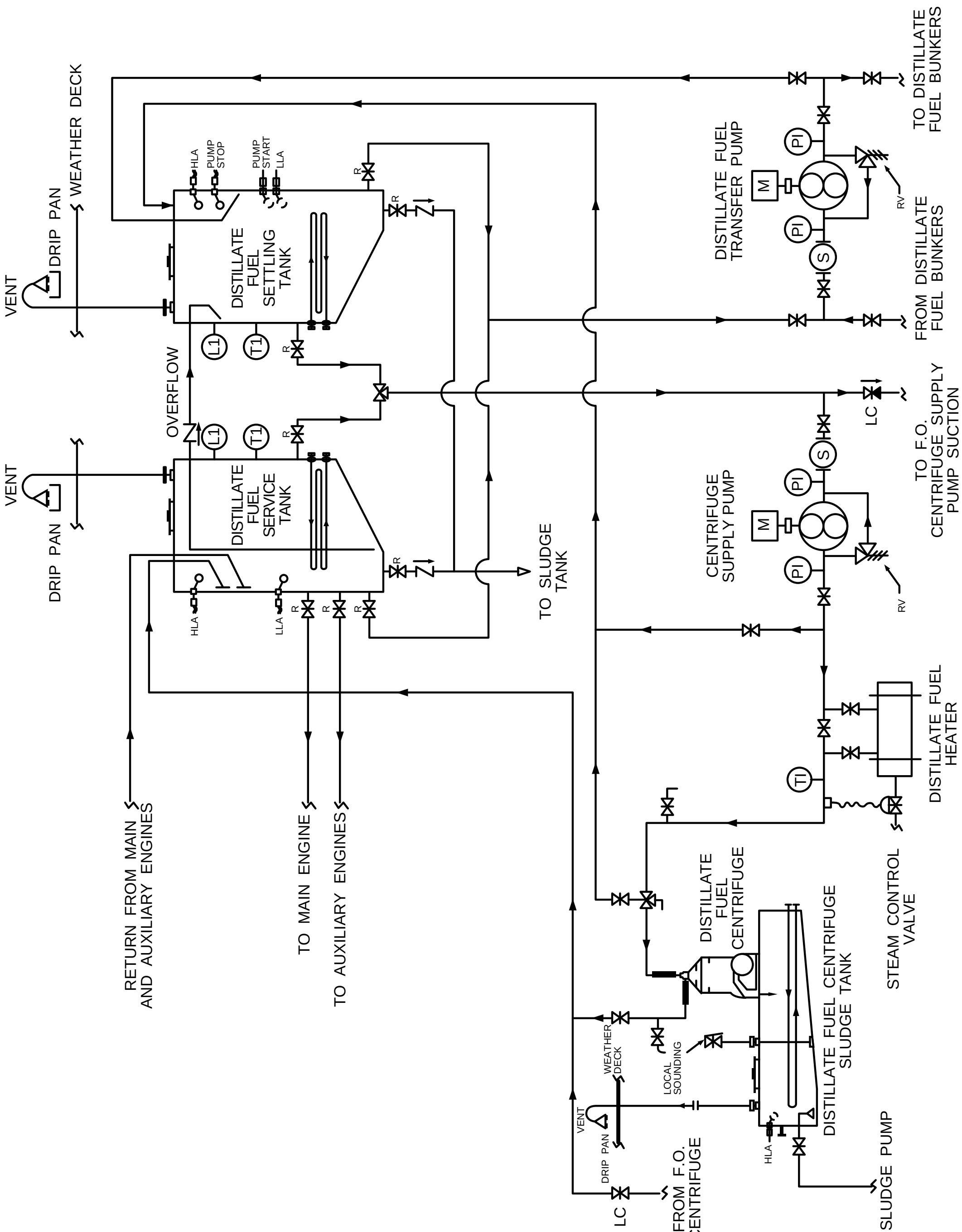
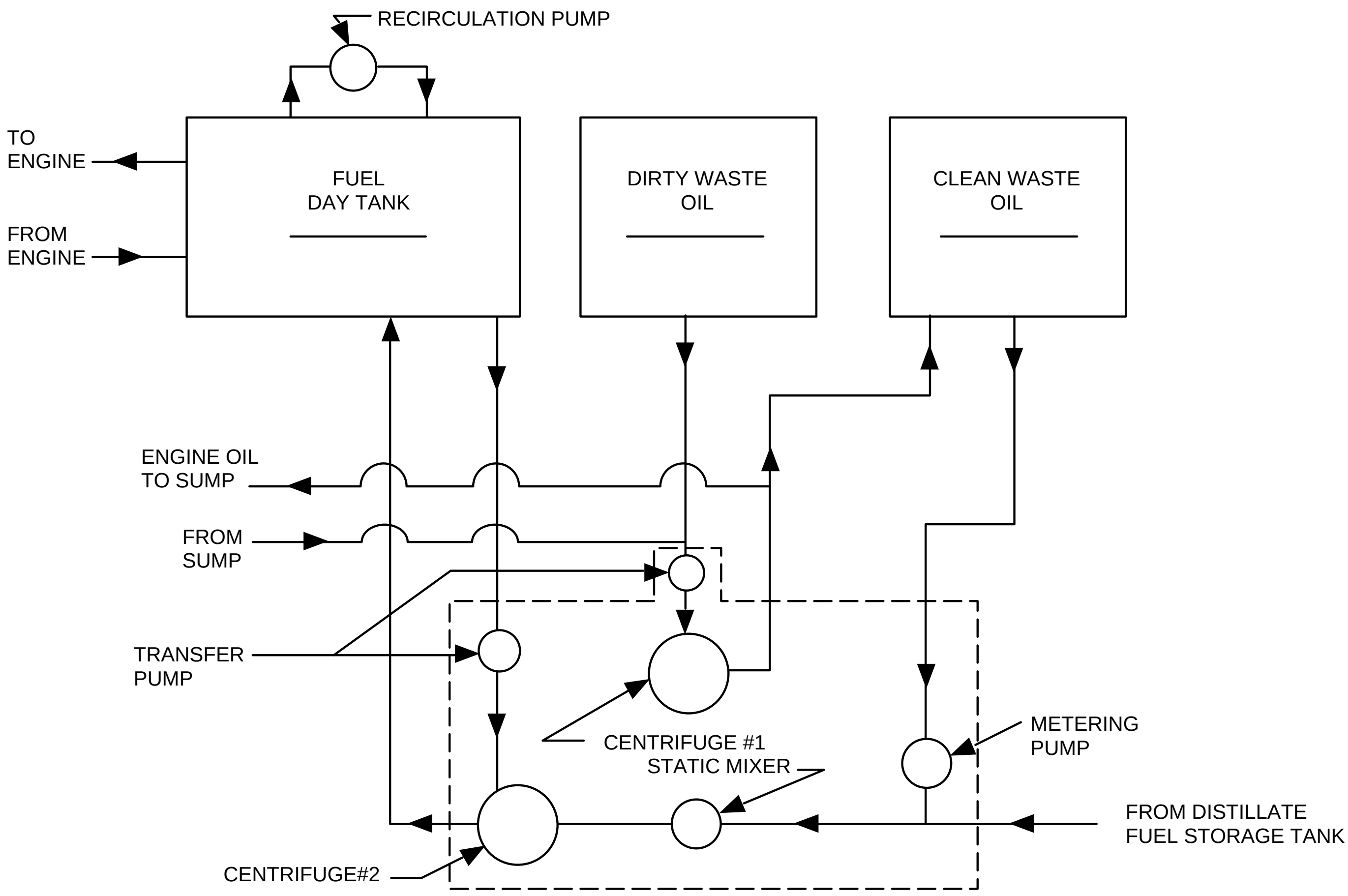

Distillate Fuel Supply System
VENT
DRIP PAN
WEATHER DECK
DISTILLATE FUEL
DAY TANK
OVERFLOW TO D.O.
SETTLING TANK
FROM AUXILIARY
ENGINES
HLA
LLA
R
R
R
TO AUXILIARY
ENGINES
TO TRANSFER
PUMP
TO
OTHER
ENGINES
BAFFLE
PLATE
DRAIN
TO SLUDGE
TANK
THERMOMETER
HEATING
COIL
TEMPERATURE
CONTROL VALVE
FUEL RETURN FROM
OTHER ENGINES
DISTILLATE FUEL
COOLER
IF FUEL LEVEL IN DAY TANK
IS HIGHER THAN ENGINE
FUEL INJECTOR VALVES
INSTALL SOLENOID VALVE
IF FUEL LEVEL IN DAY TANK
IS HIGHER THAN ENGINE
FUEL INJECTOR VALVES
FUEL PRESSURE
REGULATING VALVE
MOUNTED ON ENGINE
FUEL TO ENGINE DRIVEN
FUEL OIL TRANSFER PUMP
S
M
P1
RV
EMERGENCY FUEL PUMP

Figure 4



Distillate Fuel Centrifuge System

Figure 6



Centrifuge Module Schematic
For Burning Used Crankcase Oil
(Continuous Blending Method)

Figure 8

CATERPILLAR®

Engine Systems - Heavy Fuel Oil

Heavy Fuel Usage

Caterpillar 3600 engines are designed to operate on heavy fuel oils. Fuel oil cost represents 60-90% of the operating expenses of an engine. Therefore, reducing the cost of the fuel oil by burning heavy fuel can make economic sense. The Caterpillar 3600 series engine has been designed to burn CIMAC K-55 fuel oil (see *Heavy Fuel Characteristics* for important information) which maximizes the savings potential for fuel oil costs.

Caterpillar Special Instruction REHS0104 (7/97) entitled *Guidelines for 3600 Heavy Fuel Oil (HFO) Engines* contains very detailed information on using heavy fuel oil. However, some of the mandatory attachments listed in section 5 are not applicable for marine propulsion applications.

3600 Heavy Fuel Engines	
Valve rotators	Standard on all engines
Special valve material	Standard on heavy fuel engines
Recessed exhaust valves	Standard on heavy fuel engines
Watercooled exhaust valve seats	Standard on heavy fuel engines
Increased air flow components	Standard on heavy fuel engines
Lower inlet air temperature	Standard on heavy fuel engines
Inlet manifold air temperature control	Required for heavy fuel engines for extended low load operation
Cuffed liners	Standard on all engines

The 3600 engine philosophy has been to offer engines optimized for fuels including crude, distillate and heavy fuel oils. Components in the engine are changed to optimize reliability and efficiency. Some of the components that are changed for a heavy fuel engine are:

Economic Studies

While there is a potential for lower fuel costs, there are a number of trade-offs when operating on heavy fuel. These trade-offs must be evaluated against the fuel oil savings. Some of the trade-offs for operating on heavy fuel versus distillate fuel include increased capital costs, reduced engine component life, higher maintenance costs, shorter times between overhaul and increased personnel costs.

Installation Costs

Typical installation costs for a heavy fuel application range from 25-85% more than distillate fuel applications. The additional installation costs are a result of additional equipment required to treat the heavy fuel and lube oil. Some of this equipment includes:

- Additional tanks
- Additional fuel oil transfer pumps
- Fuel oil separators
- Fuel oil conditioning equipment (booster module)
- Lube oil separator
- Tank heater
- Steam system or electric heating system
- Insulation and heat tracing on fuel oil piping
- Additional equipment on engine

Operational Costs

The cost of operating a heavy fuel plant is generally lower than operating a distillate plant because of the lower fuel costs already described. However, there are a number of additional costs that must also be considered:

- Additional operators to maintain additional equipment
- Greater spare parts usage as a result of more frequent overhaul intervals
- Increased downtime as a result of more frequent overhaul intervals
- Additional lube oil costs as a result of contamination
- More educated operators to service more sophisticated equipment

Heavy Fuel Characteristics

Viscosity

Viscosity of a fuel oil is a measure of the fuel's resistance to flow. In other words it is a measure of the consistency or *thickness* of the fuel oil. Proper viscosity can aid the combustion process by helping to insure the proper spray pattern from the injector. Incorrect viscosity can cause increased thermal or mechanical loading on a number of engine components.

The required injection viscosity of heavy fuel is 10-17 cSt (injection temperature not to exceed 135°C). To obtain the proper injection temperature the heavy fuel must be heated prior to injection. Refer to Figure 9 to determine the approximate injection temperature.

Example:
Determine the injection temperature for a fuel oil with a viscosity of 380 cSt at 50°C.

Solution:
1. Find 50°C on the horizontal axis and draw a vertical line through that point.
2. Find 380 cSt on the vertical axis and draw a horizontal line through that point.
3. Find the intersection of the two lines.
4. Draw a line parallel to the fuel lines in the chart through the intersection point. A line already exists for 380 cSt fuel at 50°C (IBF 380).
5. Draw two horizontal lines, one through the 17 cSt point on the vertical axis and one through the 10 cSt point on the vertical axis.
6. Where these two lines intersect the 380 cSt fuel line draw vertical lines to determine the upper and lower temperature limits for injection.
7. For this example, the lower injection temperature limit is approximately 127°C and the upper limit is 148°C. Since injection temperature may not exceed 135°C, injection viscosity would be limited to between 13 and 17 cSt.
8. Note that the viscosity of the heavy fuels shown in Figure 9 are for typical fuel oils. A fuel sample must be obtained with the viscosity measured at a minimum of two points (ideally 95°C and 50°C) to determine the true viscosity characteristics of the fuel oil.

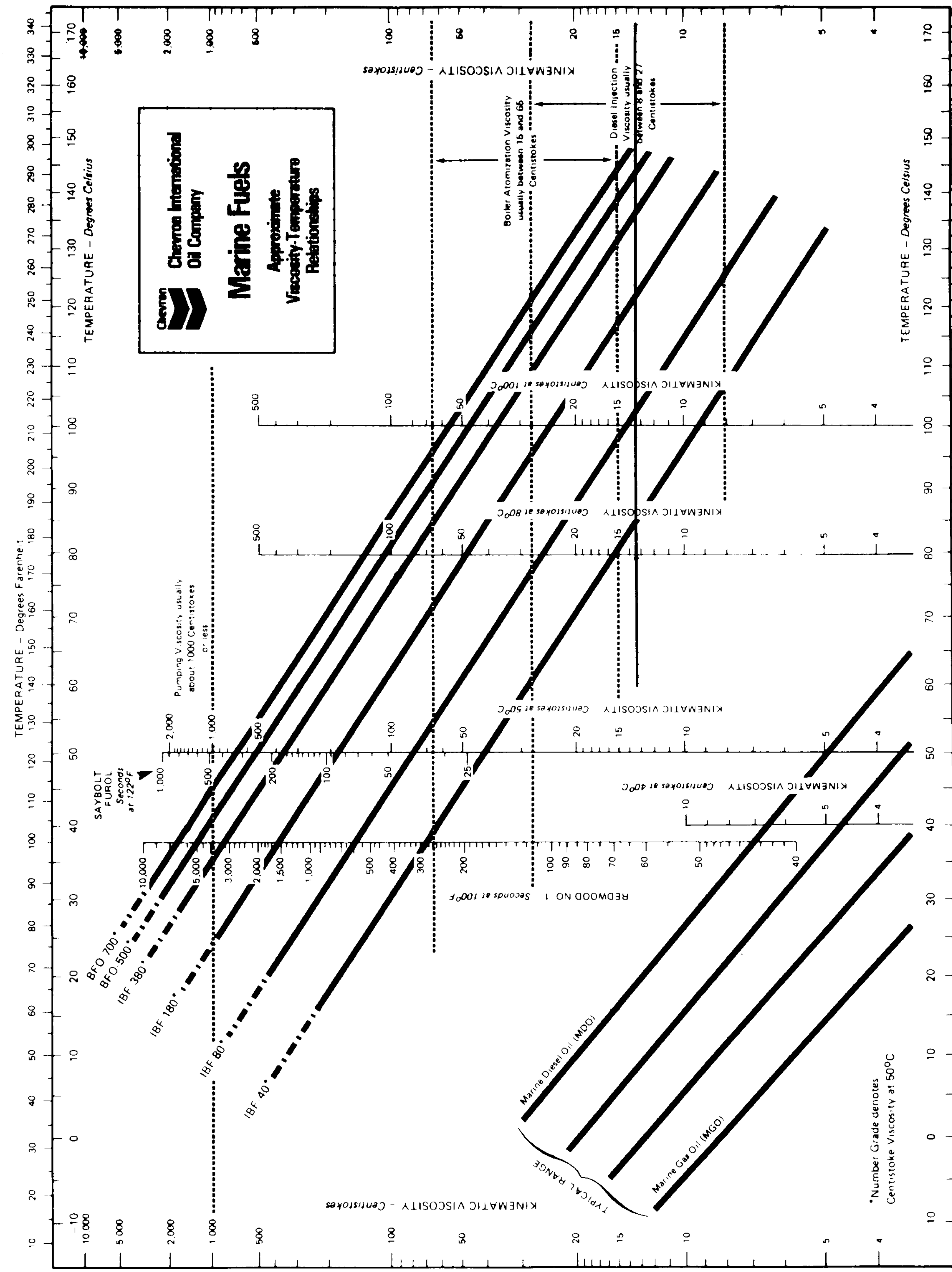

Chevron International Oil Company
Marine Fuels
Approximate Viscosity-Temperature Relationships
TEMPERATURE – Degrees Celsius
TEMPERATURE – Degrees Farenheit
KINEMATIC VISCOSITY – Centistokes
KINEMATIC VISCOSITY Centistokes at 100°C
KINEMATIC VISCOSITY Centistokes at 80°C
KINEMATIC VISCOSITY Centistokes at 50°C
KINEMATIC VISCOSITY Centistokes at 40°C
SAYBOLT FUROL Seconds at 122°F
REDWOOD NO. 1 Seconds at 100°F
Pumping Viscosity usually about 1000 Centistokes or less
Boiler Atomization Viscosity usually between 15 and 65 Centistokes
Diesel Injection Viscosity usually between 8 and 27 Centistokes
BFO 700*
BFO 500*
IBF 380*
IBF 180*
IBF 80*
IBF 40*
Marine Diesel Oil (MDO)
Marine Gas Oil (MGO)
TYPICAL RANGE
*Number Grade denotes Centistoke Viscosity at 50°C

Figure 9

Density

The density of a heavy fuel oil impacts fuel separator efficiency. Conventional separators can handle fuel oils with a density up to 991 kg/m^3 at 15°C. New types of separators such as Alfa Laval's ALCAP unit can handle heavy fuel oils with a density up to 1010 kg/m^3 at 15°C. The density of a heavy fuel oil will also influence fuel oil consumption when computing the volume of fuel consumed.

Heating Value

There are two heating values for any given fuel oil: the gross heating value, which is also referred to as the total heating value or higher heating value, and the net heating value, which is also referred to as the lower heating value. The gross heating value includes the latent heat of vaporization of the water vapor formed during the combustion process. Since this water vapor is not condensed in a diesel engine the latent heat is not recovered, so the lower heating value of the fuel is used as a reference for fuel consumption. It is important to insure that competitive fuel consumption data references a similar heating value to get an accurate comparison.

Heavy fuel typically has less specific heating value than light crudes and distillates. Heavy fuel also has more sulfur, free water and sediment not contributing to heating value. Figure 10 shows an example for the decrease in heating value for both specific gravity and percent sulfur.

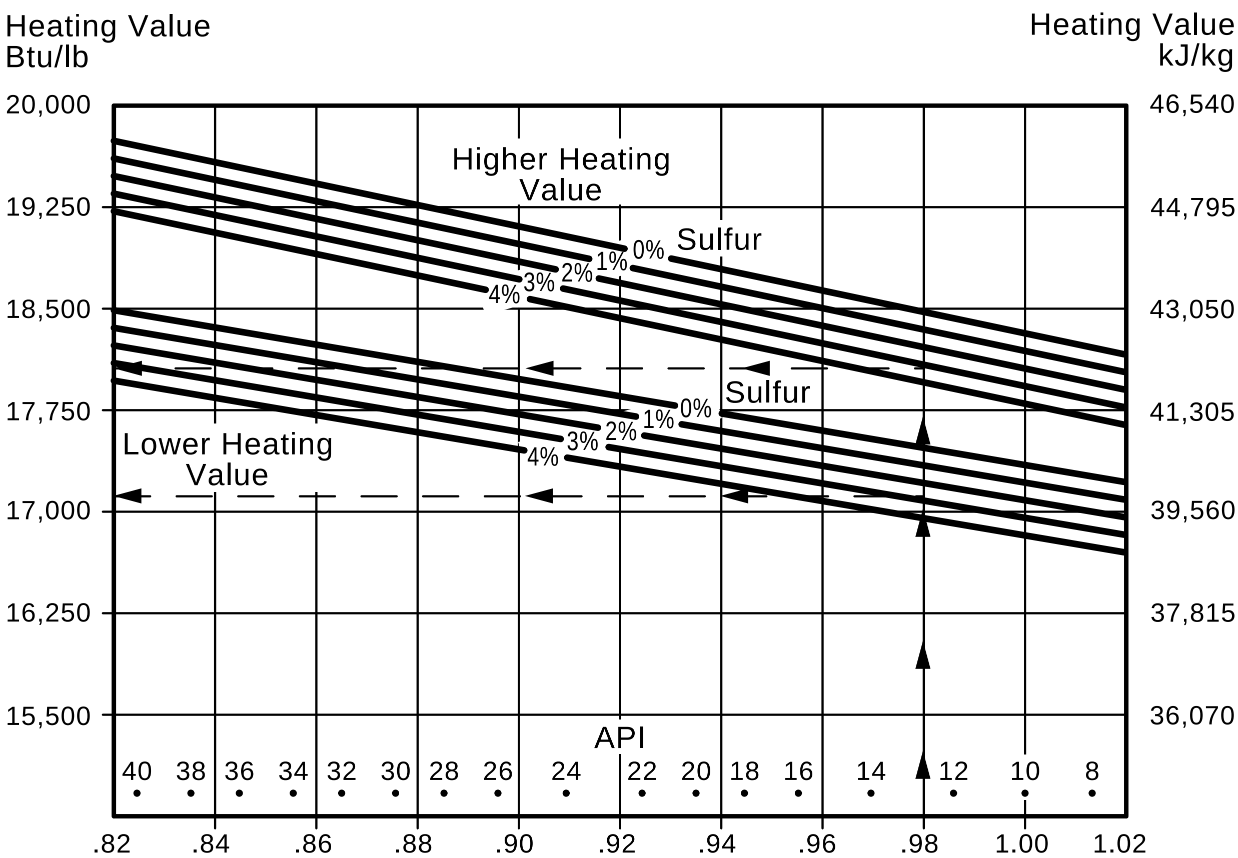


Figure 10

The following table compares the specific gravity and heating value of four different density fuels.

Type	% S	Viscosity Redwood 1	Viscosity cSt 50°C	API° Gravity	Specific Gravity	Lower Heating Value Btu / lb	Lower Heating Value kJ / kg	Density lb / gal	Density g/L
IBF 180	2.5	1500	180	16	0.96	17 225	40 065	8.0	960
Crude	1.0	Alaska	Heavy	17	0.89	17 900	41 635	7.4	890
No.2	0	40	---	34	0.85	18 280	42 520	7.1	850
Crude	0.5	North Sea	Light	36	0.84	18 280	42 520	7.0	840

Fuel Consumption Corrections for Heating Value and Density

Caterpillar uses a standard lower heating value of 42,780 kJ/kg (18,390 Btu/lb) for all 3600 engine fuel consumption data. Based on a given fuel's lower heating value it is possible to calculate the corrected fuel consumption of an engine. As an example, the following table shows a 3606 engine's specific fuel consumption based on the standard reference lower heating value.

Power	Specific Fuel Consumption	Lower Heating Value
1500 bkW	203 g/kW•hr	42,780 kJ/kg
2000 bhp	.334 lb/bhp•hr	18,390 Btu/lb

To correct the specific fuel consumption to a different lower heating value the following formula is used:

$$\text{corrected bsfc} = \text{rated bsfc} \times \frac{\text{standard LHV}}{\text{actual LHV}}$$

Based on this formula it is also possible to calculate the amount of fuel consumed for various fuels in a similar application to compare fuel costs. The following calculations use three of the fuels from the preceding table to show the amount of fuel consumed by weight and by volume for the 3606 engine shown above:

IBF 180 cSt @ 40,065 kJ/kg (17,225 Btu/lb) lower heating value

$$1500\ \text{kW-hr} \times \frac{203\ \text{g}}{\text{kW-hr}} \times \frac{42{,}780\ \text{kJ/kg}}{40{,}065\ \text{kJ/kg}} = 325\ \text{kg}$$

$$\frac{1000 \times 325\ \text{kg}}{960\ \text{g/L}} = 339\ \text{L}$$

$$2000\ \text{hp-hr} \times \frac{0.334\ \text{lb}}{\text{hp-hr}} \times \frac{18{,}390\ \text{Btu/lb}}{17{,}225\ \text{Btu/lb}} = 713\ \text{lb}$$

$$\frac{713\ \text{lb}}{8\ \text{lb/gal}} = 89\ \text{gal}$$

Alaskan Crude @ 41,635 kJ/kg (17,900 Btu/lb) lower heating value

$$1500\ \text{kW-hr} \times \frac{203\ \text{g}}{\text{kW-hr}} \times \frac{42{,}780\ \text{kJ/kg}}{41{,}635\ \text{kJ/kg}} = 313\ \text{kg}$$

$$\frac{1000 \times 313\ \text{kg}}{890\ \text{g/L}} = 352\ \text{L}$$

$$2000\ \text{hp-hr} \times \frac{0.334\ \text{lb}}{\text{hp-hr}} \times \frac{18{,}390\ \text{Btu/lb}}{17{,}900\ \text{Btu/lb}} = 686\ \text{lb}$$

$$\frac{686\ \text{lb}}{7.4\ \text{lb/gal}} = 93\ \text{gal}$$

No. 2 Diesel @ 42,520 kJ/kg (18,280 Btu/lb) lower heating value

$$1500\ \text{kW-hr} \times \frac{203\ \text{g}}{\text{kW-hr}} \times \frac{42{,}780\ \text{kJ/kg}}{42{,}520\ \text{kJ/kg}} = 306\ \text{kg}$$

$$\frac{1000 \times 306\ \text{kg}}{850\ \text{g/L}} = 360\ \text{L}$$

$$2000\ \text{hp-hr} \times \frac{0.334\ \text{lb}}{\text{hp-hr}} \times \frac{18{,}390\ \text{Btu/lb}}{18{,}280\ \text{Btu/lb}} = 672\ \text{lb}$$

$$\frac{672\ \text{lb}}{7.1\ \text{lb/gal}} = 95\ \text{gal}$$

In the same combustion system, more mass of heavier fuel will be required because of lower specific energy. For example, 325 kg of IBF 180 will be required to produce 1500 kW•hr vs 306 kg of No. 2 diesel.

Sulfur

Fuel sulfur increases ring, liner, and valve guide wear. Without engine modifications and with temperatures below the dew point of sulfuric acid, liner wear can increase ten times when fuel sulfur is increased from 0.6% to 3.5%. The most effective treatment of fuel sulfur is to keep the engine liner and valve stem temperature above the dew point of sulfuric acid, neutralize acids with high alkalinity lube oils and maintain high inlet manifold air temperature during light load operation. See Low Load Operation section.

Coping with the effects of fuel sulfur is not a simple task. Even though the use of proper lubricants and correct oil change intervals reduces the degree of corrosive damage, engine wear will increase significantly when high sulfur fuels produce acid products during combustion. These acids chemically attack the engine causing corrosive wear. High TBN oils help to control acid corrosion but also contain higher levels of ash. Unfortunately, high ash oils in the absence of high sulfur fuel increase deposit formation and wear. Here are five steps to combat the corrosive and deposit effects associated with fuel sulfur.

- Know the actual fuel sulfur content of each bulk delivery. Sulfur content can change with each delivery. Have the fuel analyzed by your supplier or independent laboratory. Do not rely on published specifications from the fuel supplier to determine the actual sulfur content.

- As a starting point for selecting the correct TBN oil, follow the recommendations in the appropriate maintenance guide and Figure 11. Let Infrared Analysis, ASTM Procedure D2896 results (performed every 250 operating hours) and Trend Analysis of these data establish the correct oil selection and change interval. Trend Analysis of the test results is the best method to manage the oil selection and change interval. Infrared Analysis determines the amount of sulfur products in the crankcase oil. ASTM D2896 measures the amount of alkaline additive (TBN) in the oil to neutralize acids.

- Use an American Petroleum Institute (API) class CF engine oil. The oil must also meet the requirements of the Caterpillar Micro-Oxidation Test (CMOT) and/or Field Test Qualifications. The percentage of sulfur in the fuel will affect the oil recommendations.

The sulfur products formation depends on the fuel sulfur content, oil formulation, crankcase blowby, engine operating conditions, humidity, and ambient temperature. The effectiveness of an oil formulation will depend on the additive package. A balanced additive package oil of a lower TBN can be more effective in fuel sulfur neutralization and overall performance than some oils with higher TBN values which have additives just for increased TBN.

- Adhere to a 250 operating hours oil Trend Analysis program until the correct oil selection and change interval have been determined. After selection and change intervals have been determined, continue to: 1) Use the scheduled oil sampling (SOS) program to monitor and trend wear metals (iron, chromium, lead) carefully; 2) Use Infrared Analysis Trending to continually determine oil condition; 3) Use ASTM D2896 to measure and trend reserve alkalinity (TBN).

- Be sure jacket water outlet temperature is above 85°C (185°F) to minimize sulfur attack. Select the proper thermostat to be in the preferred range of 85°C-98°C (18°F-208°F).

A minimum initial TBN oil of 20 times the fuel sulfur percent is recommended (within the limits of oil availability). The minimum TBN level of oil in the engine sump is half the initial TBN of the new oil (see Figure 11). Also see the *Lubricating Oil* section of this Guide.

Vanadium

Fuel vanadium forms highly corrosive compounds during combustion. They melt at high temperatures and attack metal surfaces, especially exhaust valve faces. If the temperature is above *stiction temperature,* the molten compounds stick to the valve face, remove oxide coatings, and attack molecular grain boundaries. Leak channels then form on the valve face, reducing valve cooling from seat contact. This accelerates the valve's deterioration as its temperature rises even further.

Vanadium cannot be economically removed from heavy fuel. The engine must be specifically designed to reduce vanadium effects.

Micro Carbon Residue

Micro Carbon Residue (MCR) is a measure of carbon deposit formation trends during combustion. Carbon rich fuels can lead to more soot and deposits, which are sources of abrasive wear and valve and turbocharger deposits.

Asphaltenes

Asphaltenes are large, heavy, hydrocarbon molecules containing heavy metals such as nickel, iron, and vanadium. They are slower burning, affect the combustion process, and require regular exhaust-side turbine washing.

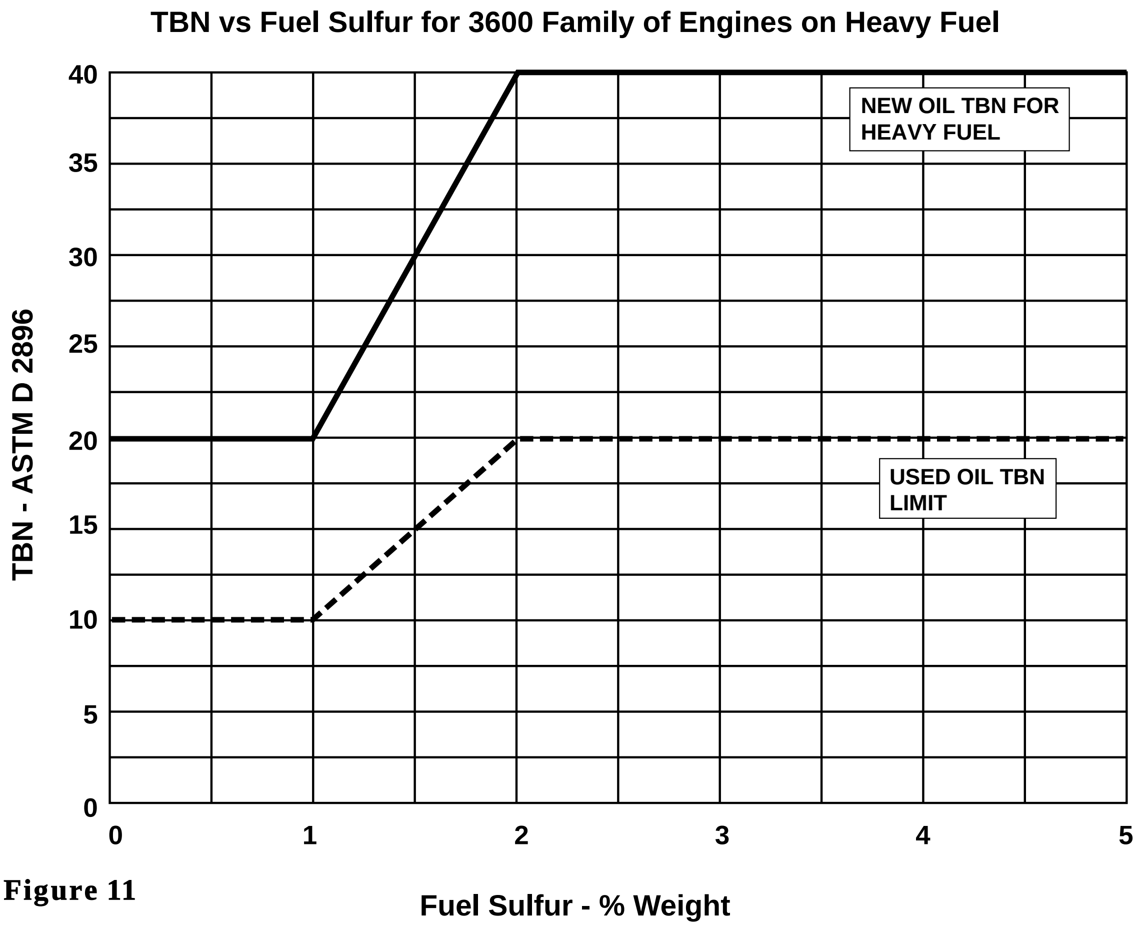


Figure 11

Total Base Number (TBN) for Heavy Fuel Engines:

3600 engines operating on heavy fuel must use an oil specifically blended for heavy fuel engines. Oils for heavy fuel engines are specially blended for use with lube oil centrifuges; these oils must be able to release water and contaminants by centrifuging without the loss of additives. These oils are generally available from 20 TBN to 50 TBN (by ASTM D 2896); however, the majority of Caterpillar experience is with the 30 TBN and 40 TBN oils.

For 3600 engines running on heavy fuel, the minimum new oil TBN must be 20 times the fuel sulfur level, and the maximum TBN is 40 regardless of sulfur level. Oils for heavy fuel 3600 engines must also pass the performance requirements for commercially available oils.

Calculated Carbon Aromaticity Index

The Calculated Carbon Aromaticity Index (CCAI) is an approximate indicator of fuel combustion characteristics. This index was developed by Shell Oil Co. It can be calculated from the viscosity and density of the fuel, using the following formula:

CCAI = D - [log log (V + 0.85)] - 81

Where:
V = Viscosity of Fuel in cSt @ 50°C
D = Density of fuel in kg/m^3 @ 15°C

Fuels with a CCAI greater than 845 may cause engine damage. Consult Caterpillar for fuels with a CCAI greater than 845.

Ash

Ash can exist in fuels and become suspended in oils. Filtering is the most effective method for removal.

Catalytic Fines

Refineries increasingly use catalytic cracking to raise the percentage of distillate fuels from crude. The catalyst residue is small abrasive particles of aluminum and silicon. The particles pass through media type fuel filters, cause damage to fuel injection equipment, and increase ring and liner wear.

Centrifuging can remove a high percentage of catalytic fines. Two centrifuges in series may be required to remove the particles to a safe level.

Water

Water exists in all fuels and can damage fuel injection equipment. Remove water by settling in tanks and centrifuging.

Heavy Fuel Specifications

Limits for fuel as bunkered:

CIMAC designation	K55
Viscosity - cSt @ 50°C	700
Density - kg/m^3 @ 15°C	1010
Sulfur - % by weight	5
Vanadium - ppm	600
Micro Carbon Residue - % by weight	22
Asphaltenes - % by weight	15
Water and Sediment - % by weight	1.0
Ash - % by weight	0.20
Aluminum - ppm	80
Silicon - ppm	80
Flash point	60°C

Limits for fuel at injectors:

Viscosity - cSt @ 135°C max	10-17
Density - kg/m^3 @ 15°C	1010
Sulfur - % by weight	5
Vanadium - ppm	600
Micro Carbon Residue - % by weight	18
Asphaltenes - % by weight	15
Water and Sediment - % by weight	0.5
Ash - % by weight	0.15
Aluminum - ppm	3
Silicon - ppm	3
Vanadium/sodium ratio	10

Blending of Heavy Fuel Oil with Distillate Fuel Oil

The blending of heavy fuel oil with distillate fuel oil should be avoided. It must never be attempted on site without special equipment and trained operators. If blending of the fuel oil is required, approval must be obtained from the factory and the fuel oil supplier.

Addresses for Fuel Oil Sample Analysis

F.O.B.A.S. (Fuel Oil Bunker Analysis and Advisory Service)

TNT-Skypak International (UK) Limited
Unit 6, Spitfire Estate, Spitfire Way,
Hounslow, Middlesex, England, TW5, 9NW
Attn: ACP 80 Code DRX
Skypak Code CB10
If no TNT-Skypak International Service is available, send by air freight via Heathrow Airport to the address above.
Attn: ACP 80 CODE DRX
SKYPAK CODE CB10

For inside U.K. send to the following address:

FOBAS
c/o Caleb Brett Laboratory Limited
Kingston Road, Leatherhead
Surrey KT22 7LZ
Always notify FOBAS by telex when sample is sent @ telex #: 8953603-LR LON G.

Other Addresses:

DNV Petroleum Services Inc.

DNVPS OSLO
Veritasveien 1
N-1322 Hovik
Norway
phone: 47 67 57 9900
fax: 47 67 57 9393

DNVPS ROTTERDAM
Haastrechtstraat 7
3079 DC Rotterdam
phone: 31 10 292 2600
fax: 31 10 479 7141

DNVPS SINGAPORE
10 Science park Drive
DNV Technology Centre
Singapore 118224
phone: 65 779 2475
fax: 65 779 5636

DNVPS TEANECK
111 Galway Place
Teaneck, NJ 07666
USA
phone: 201 833 1990
fax: 201 833 4559

DNVPS FUJAIRAH
Fujairah Port
P.O. Box 1227
Fujairah
UAE
phone: 971 9 228 152
fax: 971 9 228 153

Review analysis results before the fuel is consumed. Separate supply tanks are recommended.

To establish fuel oil trends the same laboratory and/or test methods must be used.

Heavy Fuel Treatment

Fuel Handling Systems

Installation Recommendations for Heavy Fuel

Item	≤ 40 cSt	> 40 cSt - ≤ 700 cSt
Minimum tank temperature for pumping	2°C (36°F)	10°C above pour point
Tank heating required	No	Yes
Minimum fuel temperature at injector to attain 10-17 cSt	See Figure 1	See Figure 1
Normal fuel heating method	Steam and/or electricity	Steam and/or electricity
Fuel Centrifuge	Yes	Yes
Fuel transfer pump	Engine driven	Off engine
Unit injector tip cooling method	Series tip cooling circuit required	Separate tip cooling circuit required
Remote mounted final fuel filters	No	Yes
Starting aid	Jacket water preheat to 45°C (113°F)	Jacket water preheat to 65°C (149°F). Fuel heated to proper viscosity
Turbo wash for exhaust turbine	Yes	Yes

Figure 12

Separate newly bunkered heavy fuel from previous bunkerings. The fuel should remain separated until compatibility is established.

Heat and insulate all heavy fuel piping to allow fuel pumping at ambient temperatures. Piping carrying heavy fuel at injection temperature, including the booster pump suction and recirculation lines, should be heat traced (either steam or electric). Line heating is also required when starting a cold engine on heavy fuel.

Heated heavy fuel storage tanks (bunker, settling, day and drain tanks) must be vented to atmosphere in a safe location. Vents must have a flame screen, check valve, closure (manual vent shut off device) and drip pan as required by classification societies.

Install heating coils in all bunker tanks to maintain a temperature of 10°C (18°F) minimum above the fuel pour point. Heating coil sizing must consider heat transfer required to raise the temperature of the fuel in the tank in a given time frame (for example 0.56°C/hr (1°F/hr). The requirements to maintain the fuel at its final temperature must be considered. Normally, only the bunker tank containing the fuel being used is heated. The others are unheated until ready for use.

The external fuel system design may vary from ship to ship. However, every system must have clean fuel at the correct viscosity and pressure at the engine. The fuel must be free of solid matter and water. In addition to the harm poorly centrifuged fuel will cause to the engine's injection system, a high content of water may also cause serious problems with the fuel feed system components. Install well proven equipment and components in the fuel oil system. Follow centrifuge sizing recommendations closely.

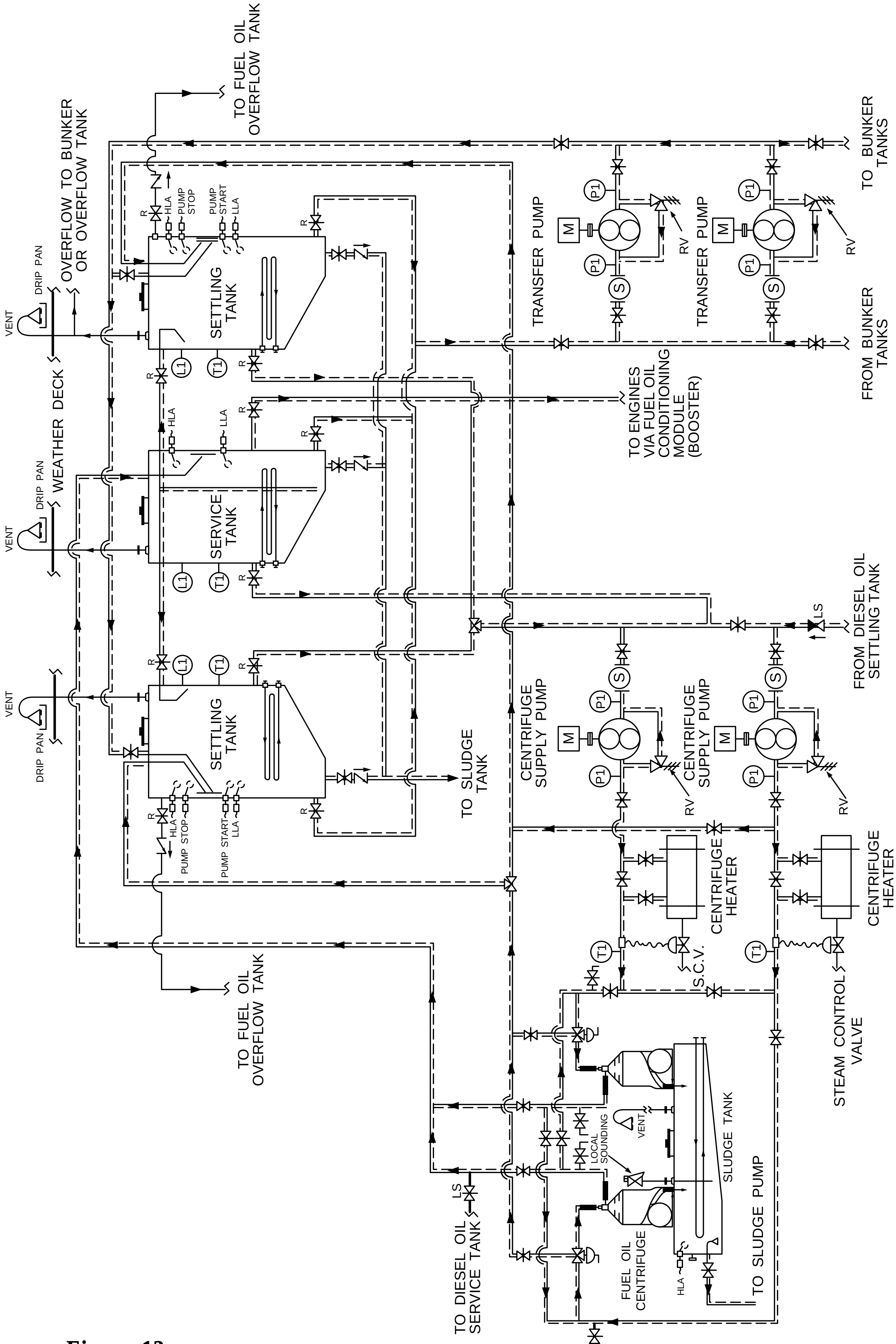
Fuel treatment coordination responsibility must be clearly understood by all concerned early in a project. Consider using a consultant. Caterpillar will advise in a general sense but detailed guidance must be obtained from vendors.

Bunker Tanks
Fuel compatibility problems are eliminated by installing a suitable number of bunker tanks and avoiding mixing fuel from different bunkerings. Heating coils or bunker tank suction heaters should maintain a minimum temperature of 10°C (18°F) above the bunkered fuel's pour point. Heating coil grids should be manufactured from seamless steel pipe with a schedule 80 minimum wall thickness. Use welded joints in the heating coil grids within the tanks.

Heavy Fuel System Components
See Figure 13 for a schematic of the following components.

Transfer Pumps
Provide two transfer pumps (one in standby) for pumping from the bunker tanks to the settling tanks. Screw-type pumps minimize water emulsification during transfer operations. Arrange the pumps for automatic operation and size them to fill the settling tank in 2 to 4 hours. The following pump design characteristics are provided for guidance:

- Operating pressure–to suit conditions of piping system
- Operating fluid temperature = 38°C (100°F)
- Viscosity for sizing pump motor–1000 cSt
- Pump Flow (L/hr) = 2.95 x bkW



Typical Fuel Oil & Centrifuge Piping

Figure 13

Settling Tank

Use two settling tanks to obtain proper settling of solids and water in the fuel and to separate fuels of different bunkerings. Design the tanks to hold a 24 hour supply of fuel at full engine load operation. As a guide, the settling tank volume should be:

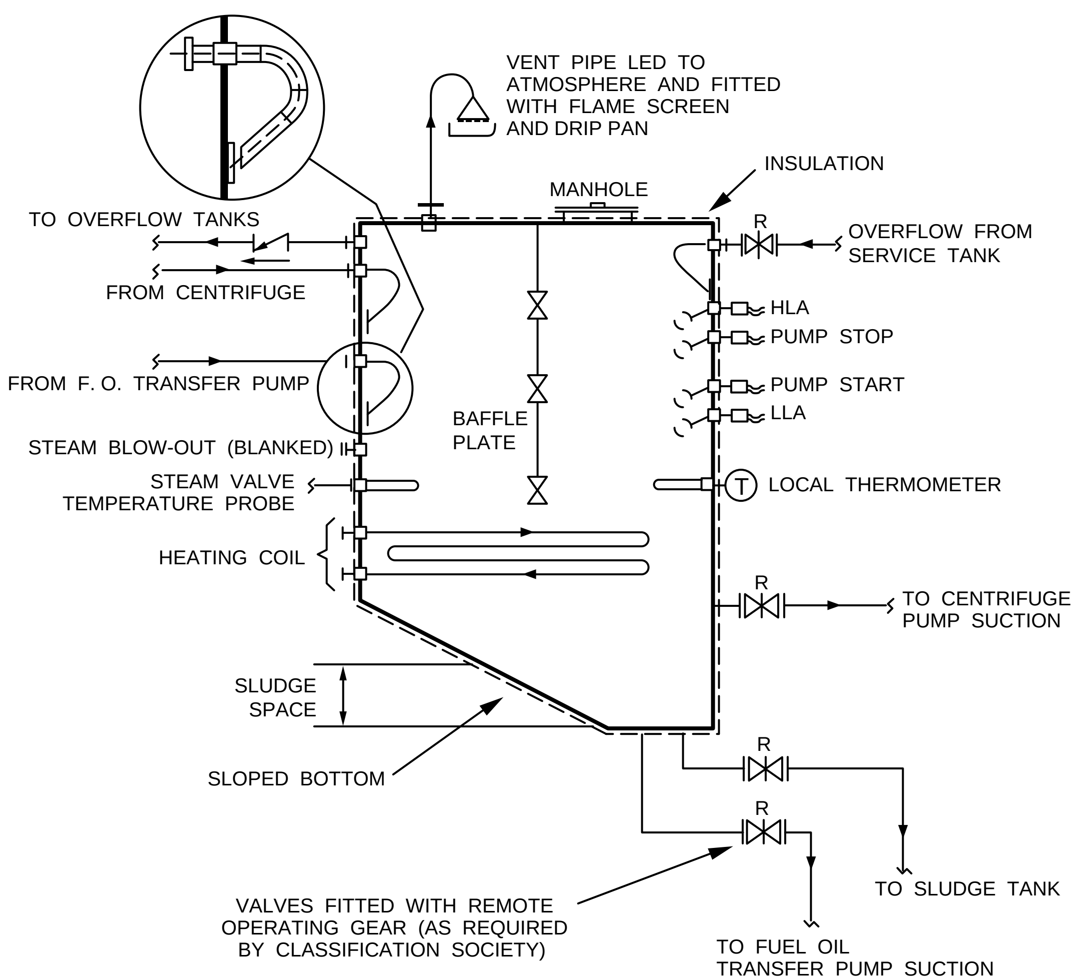
Volume (Liters) = 5.9 x bkW
Volume (gallons) = 1.05 x bhp

A typical settling tank design is shown in Figure 14. Baffle plates reduce fuel agitation in rough seas. Slope the tank bottom to form a sludge space. The tank should be cofferdammed from the ship's side and insulated from thermal losses.

The centrifuge pump suction pipe must be kept above the sludge space and the sludge space fitted with a drain valve. Provide the following additional connections:

- Air vent (sized to meet classification society requirements)
- Overflow pipe
- Filling pipe
- Steam blow-out, (for tank cleaning with steam)
- Inspection manhole and ladder, (if required)
- Local thermometer, (in well)
- High and low tank level alarms
- Pump start/stop level switches
- Fuel transfer pump suction pipe
- Remote and local sounding, (level gauges)

Typical Arrangement of Settling Tank



NOTE: The rules and regulations for fuel tanks issued by the classification society must be observed.

Figure 14

The tank heating coil should heat the fuel evenly to the required temperature within 2 to 3 hours. The steam supply must have a temperature regulating valve to automatically control the tank fuel temperature.

The coil design must avoid:

- Agitation of the sludge due to heating. Locate the heating coil a sufficient distance above the sludge collecting space.
- Fuel temperatures above 75°C (167°F).
- Heat transfer per unit surface area above 1.1 W/cm^2 (24 Btu/hr-in^2). Carbon deposits can form on the heating coil at higher temperature levels.

The following tank temperature information is provided for guidance only:

Settling Tank Temperature		
Fuel	Temperature	
cSt @ 50°C	°C	(°F)
80	45	(113)
81-180	55	(131)
181-380	60	(140)
381-700	60	(140)

Suction Strainer

Install a duplex strainer ahead of the centrifuge supply pumps. It should include stainless steel baskets with perforations sized to protect the supply pumps (approximately 0.8 mm [1/32 in.]).

Centrifuge Supply Pump

The pump must be electrically driven and mounted separately from the centrifuge. A high temperature resistant screw pump is recommended. Size it for the viscosity being pumped and the design centrifuge flow. The flow rate through the centrifuge should not exceed the maximum fuel consumption of the engines by more than 18%. The following pump characteristics are provided for design guidance:

- Operating pressure 5 Bar (75 psi)
- Operating Fluid Temperature 100°C (212°F)
- Viscosity for sizing pump motor 1000 cSt

Follow the fuel oil separator manufacturer's recommendations for the supply pump.

Preheater

The preheater is normally sized based on the centrifuge supply pump capacity and the temperature rise required between the settling tank and the final centrifuge temperatures. The heating surface temperature must avoid fuel cracking and be thermostatically controlled to maintain correct centrifuge temperatures within ± 2°C (± 4°F). The temperatures are determined by fuel viscosity. Contact the centrifuge manufacturer for information regarding purification/separation of heavy fuel with specific gravities above 0.991.

The following table indicates the required temperature at the centrifuge for various grades of fuel:

Centrifuge Temperature Ranges		
Fuel	Temperature	
cSt @ 50°C	°C	(°F)
80	80 - 98	(176 - 208)
81-180	95 - 98	(203 - 208)
181-380	98	(208)
381-700	98	(208)

As a general rule the minimum heater capacity is:

$$P = \left\{\frac{M \times \Delta T}{1700}\right\}$$

Where:

P = Heat required, kW

M = Capacity of separator feed pump, L/hr

Δ T = Temperature rise in heater, °C

$$P = (M \times SH \times \Delta T)$$

Where:

P = Heat required, Btu/hr

M = Capacity of separator feed pump, lbs/hr

Δ T = Temperature rise in heater, °F

SH = Specific heat of fuel, assume 0.48 Btu/lb/°F

Centrifuges

The fuel oil centrifuge, or separator, must be sized in accordance with the recommendations of the supplier. Install two automatic programmable centrifuges as shown in Figure 13. Traditionally fuel oil separators for heavy fuel have been operated with two in series as a purifier-clarifier (the first centrifuge is a purifier removing entrained water and the second centrifuge is configured as a clarifier by replacing the gravity disc, thereby allowing removal of solid contaminants). The current recommendation is to use two separators in parallel with controlled partial discharge of sludge that operate on a continuous basis.

Centrifuge Sizing

Major factors to consider when selecting fuel oil centrifuges include the number of engines operating, engine rating, specific fuel consumption and fuel density. The minimum separator system capacity is determined using the following formula:

$$Q_{min} = N \times \left[1.18 \times \frac{(P \times b \times 24)}{(R \times t)} \right]$$

Where:

Q_{min} = minimum separator system capacity (L/hr)

N = number of engines

P = Maximum Continuous Rating of engines (bkW)

b = Brake specific fuel consumption (g/bkW-hr)

R = Density of the fuel oil (kg/m^3) (use 950 kg/m^3 for typical heavy fuel oil)

t = Daily separation time in automatic service (hr) (23 for purifier-clarifier mode, 24 for controlled partial discharge separators)

Note: *The margin of 18 percent (1.18 in the above formula) allows for non-ISO conditions, wear, fuel contamination, etc. The margin for a fuel oil separator system may be reduced if the contaminant levels of the fuel oil are low and an allowance is made for non-ISO standard conditions. However, the reduced margin requires factory approval.*

Example:
Calculate the minimum separator system capacity for two 3616 engines operating at 900 rpm with a published brake specific fuel consumption of 202 g/bkW-hr. The maximum continuous rating of the engine is 4600 bkW and the density of the fuel is 950 kg/m^3. A controlled partial discharge separator will be used.

N = 2 engines

P = 4600 bkW

b = 196.5 g/bkW-hr

R = 950 kg/m^3

t = 24 hours

$$Q_{min} = 2 \times \left[1.18 \times \frac{(4600 \text{ bkW} \times 196.5 \text{ g/bkW-hr} \times 24 \text{ hr})}{(950 \text{ kg/m}^3 \times 24 \text{ hr})} \right]$$

Q_{min} = 2,245 L/hr

Note: *The fuel consumption of additional auxiliary engines or boilers that will use heavy fuel oil from the day tank needs to be added to the minimum separator system capacity.*

The number of separators required can be determined by dividing the minimum separator system capacity (Q_{min}) by the maximum flow of the separator for the given viscosity of the fuel oil. Refer to the separator manufacturer's specifications to determine the maximum flow through the separator for a given fuel oil viscosity. All separators are derated from their rated capacity based on the viscosity of the fuel oil (refer to the table below for typical separator derates).

Typical Separator Derates

Fuel Oil Viscosity - cSt @ 50°C (122°F)	Separation Temperature °C (°F)	Maximum Throughput (% of rated capacity)
180	95-98 (203-208)	31
380	95-98 (203-208)	26
460	95-98 (203-208)	22
700	95-98 (203-208)	18

Note: *Follow the manufacturer's recommendations in determining the maximum throughput of the separator. Under no circumstances should the throughput rate of a separator exceed the manufacturer's recommendations.*

Caterpillar recommends supplying a minimum of one redundant fuel oil separator in all applications except for single engine installations. In this case distillate fuel may be made available as a backup in the event of a separator failure.

Example:
Select a fuel oil separator with sufficient capacity to clean 2,245 L/hr of 380 cSt @ 50°C (122°F) fuel oil. The following information is provided by the separator manufacturer:

Manufacturer Information for 133-0831 Centrifuge Module Group		
Viscosity - cSt @ 50°C (122°F)	Capacity L/hr	Separation Temperature
Rated	16,000	-
180	4,400	98°C (208°F)
380	**3,000**	**98°C (208°F)**
460	2,550	98°C (208°F)
600	2,100	98°C (208°F)

Note: *Capacity data is for example purposes only. Follow the separator manufacturer's recommendations to determine actual capacity.*

Number of separators = minimum separator system capacity [Q_{min} (L/hr)]/ [maximum separator capacity (L/hr)]

Number of separators = (2,245 L/hr)/ (3,000 L/hr)

Number of separators = 0.75 separators rounded up to 1, plus one redundant separator

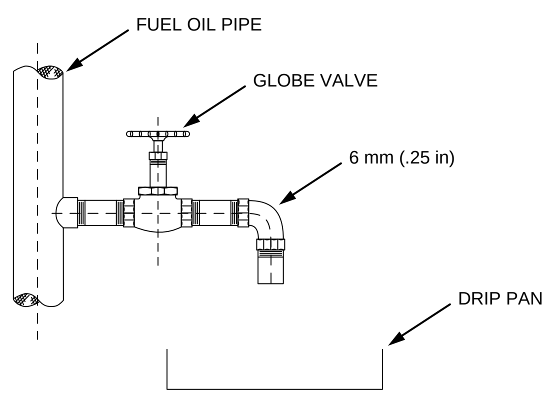
A total of two (2) 133-0831 fuel oil separators would be required for this example.

Caterpillar recommends operating the redundant separator during normal operation. The throughput of the separators should be adjusted so the total separator throughput is no more than 110 percent of the plant's total fuel consumption. This will increase the efficiency of each separator. If one separator is out of operation for an extended period of time, the flow of the remaining separator(s) should be increased so the total separator throughput is no more than 110 percent of the plant's fuel oil consumption.

The separators should be installed in accordance with the manufacturer's recommendations. Ancillary equipment for the separator should be provided or approved by the separator manufacturer.

Sampling Points

Centrifuge efficiency is determined by taking fuel oil samples upstream and downstream of each centrifuge. Figure 15 is a typical arrangement.



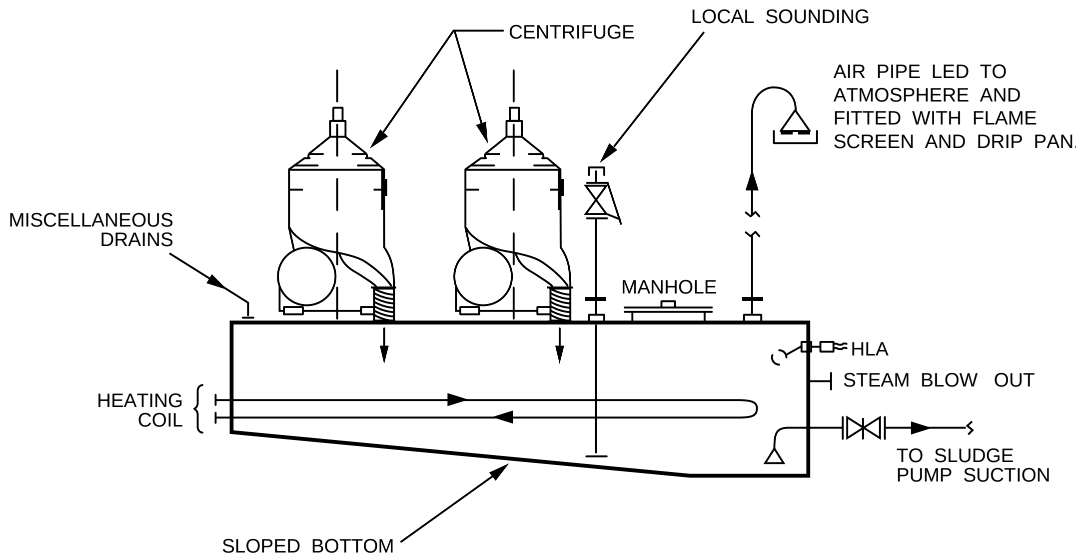
Typical Sampling Connection

Figure 15

Sludge Tank

Locate the sludge tank below and as close as possible to the centrifuges (see Figure 16). The centrifuge sludge pipe must have a continuous downward slope toward the sludge tank with no horizontal sections. Insulate and heat trace long sludge pipes. Follow the fuel oil separators manufacturer's recommendations for sludge system design and construction.

Typical Arrangement of Sludge Tank



NOTE: The rules and regulations for fuel tanks issued by the classification society must be observed.

Figure 16

Sludge tank capacity is determined by:

- Fuel cleanliness
- Time between emptying
- Number, size and type of centrifuges discharging to the sludge tank including fuel oil, diesel oil and lube oil units.
- Other sludge sources using the tank

The final volume of the sludge tank is normally determined by the system designer, based on consultation with the ship's operator and centrifuge manufacturer.

Fuel Feed Systems

Two heavy fuel oil systems are described. System 1 is a pressurized fuel delivery system typically used with viscosities greater than 180 cSt @ 50°C. System 2 is an atmospheric fuel delivery system typically used with viscosities up to 180 cSt @ 50°C.

Consider a pressurized fuel delivery system for all heavy fuel systems because of the possibility of deteriorating fuel quality and to minimize the flow of fuel at high temperature. It eliminates gas formation in the fuel return lines from the engines. As discussed in the fuel treatment system, heat trace and insulate all heavy fuel lines.

System 1 — Pressurized Fuel System

(viscosities above 180 cSt @ 50°C, see Figure 17 on page 60).

Service Tank-Heavy Fuel

Treated heavy fuel from the centrifuges discharges to the service tank. The tank and centrifuge piping should allow continuous centrifuge operation and also continuously fill the service tank.

A twenty-four hour fuel supply (at full load engine operation) in the service tank provides a reasonable time for centrifuge maintenance. Figure 18 depicts a typical service tank. Baffle plates reduce fuel agitation in rough seas. The tank bottom is sloped to form a sludge space. It should also be cofferdammed from the ship's side and insulated from thermal losses. The supply pump suction pipe must be kept above the sludge space and the sludge space fitted with a drain valve. Provide the following additional connections:

- Air vent (sized to meet Classification Society requirements)
- Over flow pipe
- Filling pipe
- Steam blow out (for tank cleaning with steam)
- Inspection manhole and ladder (if required)
- Local thermometer (in well)
- High and low tank level alarms
- Fuel transfer pump suction pipe
- Remote and local sounding (level gauges)
- Drain to sludge tank

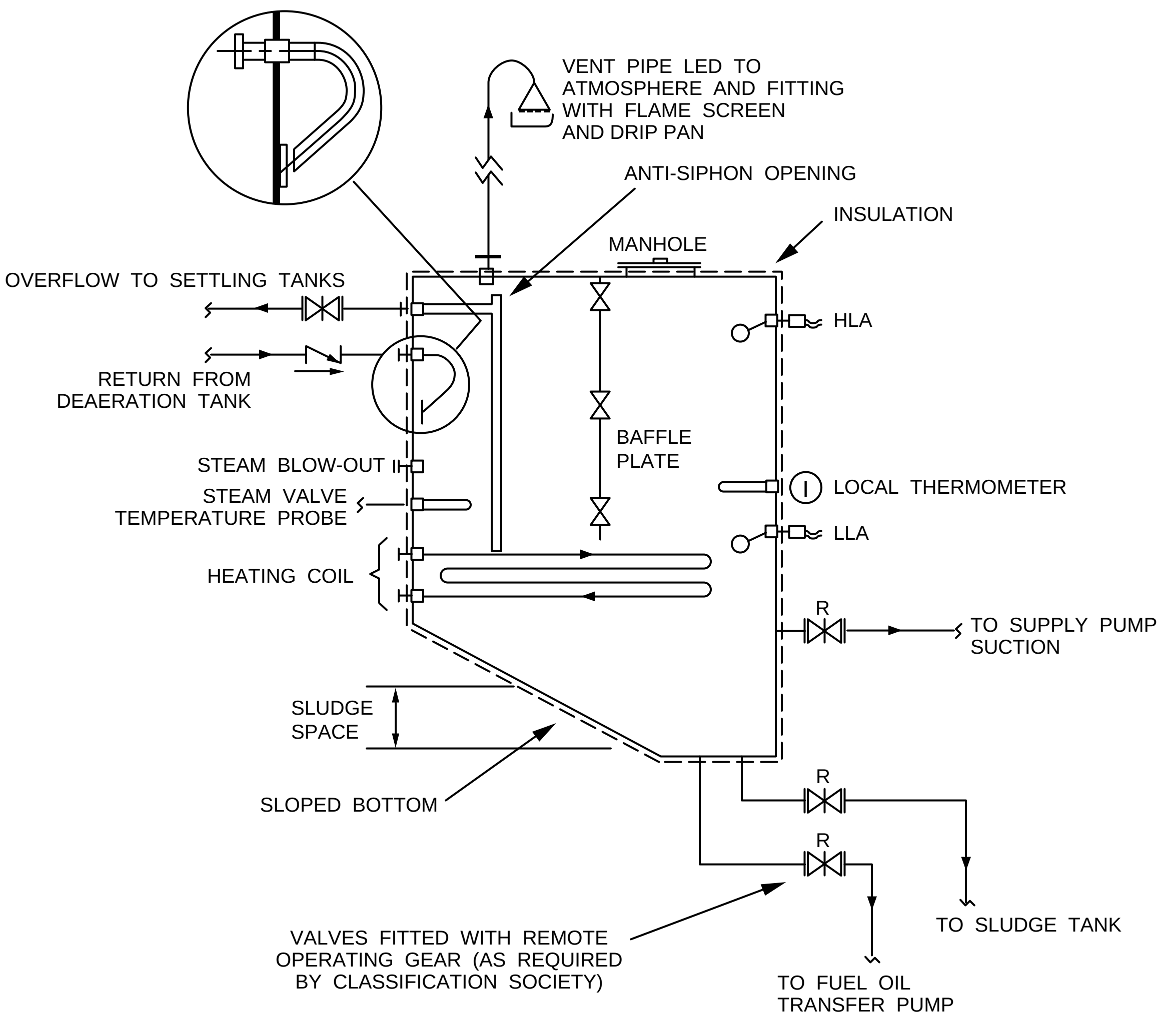
Depending on fuel viscosity, the tank heating coil should maintain approximately 60°C (140°F) fuel temperature during engine operation.

Fit the steam supply with a regulating valve to automatically control tank fuel temperature.

Locate the tank to keep an approximate 42 kPa (6 psi) positive static head on the supply pump inlet.

Service Tank-Distillate Fuel
A separate, additional centrifuge is used to clean distillate fuel. The centrifuge flow rate is normally selected to meet the requirement of the auxiliary generator diesel plant. However, when heavy fuel main engines are used the tank minimum capacity should include an additional 8 hour minimum supply for the main engines operating at full load. Tank design should be similar to the heavy oil service tank in Figure 18.

Typical Arrangement of Service Tank



Note: The rules and regulations for fuel tanks issued by the classification society must be observed.

Figure 18

Heavy Fuel/Distillate Fuel Change Valve

This valve allows the system to be changed between heavy fuel and distillate fuel. The valve is normally remotely controlled from the engine room by a pneumatic or electric motor. Limit switches on the valve indicate the valve position mode. The switches are connected to indicator lights in the control room. The valve body must be manufactured from cast steel or bronze and the valve trim and seals must be suitable for the temperature involved. Include a manual control override in the valve.

Suction Strainer

Install a simplex strainer ahead of each supply pump. It should be heat traced and have stainless steel baskets with perforations sized to protect the supply pumps. The strainer body is normally manufactured from cast steel or bronze.

Supply Pumps

Provide two electric motor driven supply pumps with one arranged as a standby. A high temperature resistant screw type pump is recommended. Size it to deliver about 150% of the consumed fuel. The pressure losses in the piping system including the filter and flow meter (if fitted) must be considered.

The following pump characteristics are provided for design guidance for pump selection:

- Operating pressure - 690 kPa (100 psi)
- Operating fluid temperature - 75°C (167°F)
- Viscosity for sizing pump motor 1000 cSt
- Flow - 150% of consumed fuel requirements

Fuel Cooler

An air cooled fuel cooler is normally installed in the pump outlet line. This prevents excessive recirculating system heat buildup when the supply pump is operating and the engine is shutdown. The cooler must be sized to dissipate the heat produced by the operating pump. The cooler may not be required in all fuel oil systems.

Pressure Control Valve

The pressure control valve maintains constant fuel pressure at the required level. Size the valve to return the following quantities of fuel to the pump inlet side:

- With engine(s) shutdown - 100% of supply pump flow
- With engine(s) at full load - 33% of supply pump flow

The valve must be adjustable and set between 350 and 400 kPa (51 to 58 psi).

Automatic Back Flush Filter

An automatic back flush filter should be installed in the supply line to the deaeration tank. Install a bypass filter in parallel with the automatic filter to act as a standby. The bypass filters should not cause a pressure drop in the system during the flushing cycle. The automatic back flush filter can also be installed on the hot side of the fuel oil conditioning module. It would then be located after the viscosity controller.

The following filter design characteristics are provided for guidance:

- Fuel oil viscosity - to suit fuel specification
- Operating fluid temperature - 38° to 150°C (100 to 302°F)
- Flow - see supply pump flow
- Operating pressure - to 1000 kPa (145 psi)
- Steam jacketed or insulated
- Filter rating - back flush filter: 90% separation above 5 micron (mesh size 10 micron maximum)
  Filter rating - bypass filter: 20 micron nominal and 35 micron maximum
- Maximum pressure drop across filter at normal operating viscosity to be approximately:
  - clean filter - 21 kPa (3 psi)
  - dirty filter - 85 kPa (12 psi)
  - alarm - 152 kPa (22 psi)

Fuel Flow Meter

If used, locate the flow meter between the supply pumps and the deaeration tank. Install isolation valves at the inlet and outlet connections. Use a manually controlled valved bypass for service.

Deaeration Tank

The deaeration tank is arranged to collect the gas/air entrained in the fuel. Equip the tank with a vent valve actuated by a level switch installed in the tank, and insulate the tank. Base the volume of the tank on about 10 to 15 minutes of operation with the engine at half-load consumption. Before prolonged shutdowns, change the system over to distillate fuel to allow gradual temperature equalization. Fit the tank with the following connections:

- Clean out connection
- Outlet valved for service requirements
- Filling pipe
- Vent connection with automatic air pressure relief valve
- Pressure gauge
- Local thermometer (in well)
- Low level alarm
- Level switch
- Fuel return
- Manual controlled drain valve

The tank should be capable of 1000 kPa (145 psi) working pressure and be approved by the appropriate Classification Society rules and regulations.

Circulating Pumps

Circulating pumps ensure the fuel injectors are supplied with sufficient fuel at the correct viscosity and pressure.

Provide two pumps with one for standby operation. A high temperature resistant screw type pump is recommended. Each pump must circulate at least four times the maximum required fuel consumption. The pump discharge pressure should be approximately 690 - 880 kPa (100-128 psi) to allow for pressure losses in piping, heaters, filters, and the viscometer. Adjust the engine mounted pressure valve on site to supply 500-690 kPa (73-100 psi) to the injectors. The engine mounted pressure valve is used to regulate pressure to the engine. Set the circulating pump relief valve high enough (900 - 965 kPa [130 - 140 psi]) to prevent fuel recirculating around the pump under normal conditions.

The following pump design characteristics are provided for guidance in pump selection:

- Design pressure – 1000 kPa (145 psi)
- Operating fluid temperature – 150°C (302°F)
- Viscosity for sizing pump motor – 500 cSt
- Flow – 4 times consumed fuel requirements (minimum)

Final Heater

The heater must maintain a viscosity of 10-17 cSt at the engine injectors. Increase the outlet temperature at the heater by approximately 4°C (7°F) to compensate for piping losses between the engine and the heater. Normally two final heaters are installed, each sized to handle the total engine's fuel flow. The heaters can be steam or electric.

As a general rule the required minimum capacity of the heater is:

$$P = \left\{\frac{M \times \Delta T}{1700}\right\}$$

Where:

P = Heat required, kW

M = Capacity of circulating feed pump, L/hr

Δ T = Temperature rise in heater, °C

or:

$$P = \left\{M \times SH \times \Delta T\right\}$$

Where:

P = Heat required, Btu/hr

M = Capacity of circulating feed pump, lb/hr

Δ T = Temperature rise in heater, °F

SH = Specific heat of fuel, assume 0.48 Btu/lb/°F

The following heater temperature rise can be used, assuming a temperature in the service tank of 60°C (140°F).

Temperature Rise thru Heater		
Fuel	Temperature	
cSt @ 50°C	°C	(°F)
180	50	(90)
380	71	(128)
700	83	(150)

Viscometer
A viscometer installed between the heater outlet and the engine fuel manifold controls the final fuel heaters. It must withstand the pressure peaks caused by the engine fuel injectors.

The following fuel characteristics at the engine are provided for design guidance:
- Viscosity range (at injectors) - 10-17 cSt
- Operating fluid temperature - 150°C (302°F)
- Operating pressure - 965 kPa (140 psi)

For steam heated heavy fuel systems the viscometer should automatically control the steam regulating valve, which is installed on the steam inlet line to the heater. If an electric heater is used, the viscometer should control the contacts that energize and deenergize the heating coils as required to maintain the proper fuel temperature.

Final Filter
Caterpillar supplied final filters are remote mounted and installed in the supply line directly ahead of the engines. The filter handles the total circulated fuel flow, and has isolating valves for element service on each filter canister. The valve is normally in the center run position, but can be used to isolate half the elements for service. The filter must be steam jacketed or heat traced, and provided with a differential pressure gauge and alarm, and a drain connection.

The following filter design characteristics are provided for guidance:
- Fuel viscosity - 10-17 cSt
- Operating temperature - 38° to 150°C (100° to 302°F)
- Flow - see supply pump flow
- Operating pressure - 965 kPa (140 psi)
- Steam Jacketed operating pressure:
  - 150 psig of steam
  - 7 lbs/hr - Inline
  - 6800 Btu/hr - Inline
  - 10 lbs/hr - Vee
  - 10,240 Btu/hr - Vee
- Filter rating - 5 micron nominal
- Maximum pressure drop across filter at operating viscosity to be approximately:
  - Clean filter - 14 kPa (2 psi)
  - Dirty Filter - 84 kPa (12.0 psi)
  - Alarm - 103 kPa (15.0 psi)

System 2 — Atmospheric Fuel System

(Viscosities below 180 cSt @ 50°C, see Figure 19, page 61).

Service Tank-Heavy Fuel
See page 49 under the topic *Pressurized Fuel System - Service Tank-Heavy Fuel*.

Service Tank-Distillate Fuel
See page 50 under the topic *Pressurized Fuel System - Service Tank-Distillate Fuel*.

Heavy Fuel/Distillate Fuel Change Valve
See page 51 under the topic *Pressurized Fuel System - Heavy Fuel/Distillate Fuel Change Valve*.

Fuel Flow Meter
If a flow meter is used, locate it between the service tanks and the mixing pipe. Provide isolation valves at the inlet and outlet connections and a valved bypass.

Mixing Pipe
The mixing pipe is fabricated from 200 to 300 mm (8 to 12 in.) diameter schedule 40 seamless pipe and collects the gas/air entrained in the fuel during startup. Equip the pipe with an adequately sized vent line led directly to atmosphere above the weather deck. Install a condensate trap in the vent line. Insulate and fit the pipe with a heating coil.

Base the volume of the pipe on about 10 to 15 minutes of operation with the engine at half-load consumption. Before prolonged shutdowns the system is changed over to diesel oil operation. This allows for gradual temperature equalization. Fit the pipe with the following connections:

- Fuel oil filling
- Fuel return
- Valved drain
- Vent connection with condensate trap
- Valved outlet
- Thermometer (with well)
- Heating coil
- Clean out connection

Design the mixing pipe for a pressure to suit the height of the vent pipe and approval by the applicable classification society.

Suction Strainer
Install a simplex strainer ahead of each circulating pump. It should be steam jacketed or heat traced and use stainless steel baskets with perforations sized to protect the supply pumps. The strainer body is normally manufactured from cast steel or bronze.

Circulating Pumps
See page 52 under the topic *Pressurized Fuel System -Circulating Pumps*.

Final Heater
See page 52 under the topic *Pressurized Fuel System -Final Heater*.

Viscometer
See page 53 under the topic *Pressurized Fuel System - Viscometer*.

Final Filter
See page 53 under the topic *Pressurized Fuel System - Final Filter*.

Burning Used Crankcase Oils
See page 23 under the heading *Burning Used Crankcase Oils* of *Engine Systems - Distillate Fuel Oil* in this guide.

Unit Injector Tip Cooling

To control erosion and deposit formation, the unit injector tip is cooled for heavy fuel operation. With fuels up to 40 cSt @ 50°C, *series circuit* cooling is provided by routing combustion fuel through the injector tip. The engine is equipped with the required hardware and additional external plumbing is not required. Figures 20 and 21, on pages 62 and 63, show the engine piping for series circuit tip cooling for an in-line and vee engine respectively.

Separate Circuit Tip Cooling

For heavy fuels above 40 cSt @ 50°C, a *separate* external cooling circuit is designed in the injector to supply and circulate coolant around the tip. SAE 10W lubricating oil is normally used for the coolant.

A cooling module must be used when the engine is equipped with *separate* circuit tip cooling. Typical schematics are shown in Figure 22, page 64, for a single engine installation and Figure 23, page 65, for multiple engine usage at the end of this section. The module design should provide for coolant pressure and temperature measurement capability. Engine connections are made at the right front of the engine.

Operate the module when the engine is running, regardless of the fuel being burned. By continually supplying fresh coolant to the injector tips, high temperature degradation of the coolant is prevented. The module does not require operation before engine start up.

The recommended separate circuit injector cooling system is shown in detail in Figure 24, page 66.

Typical Injector Tip Cooling Circulating Tank

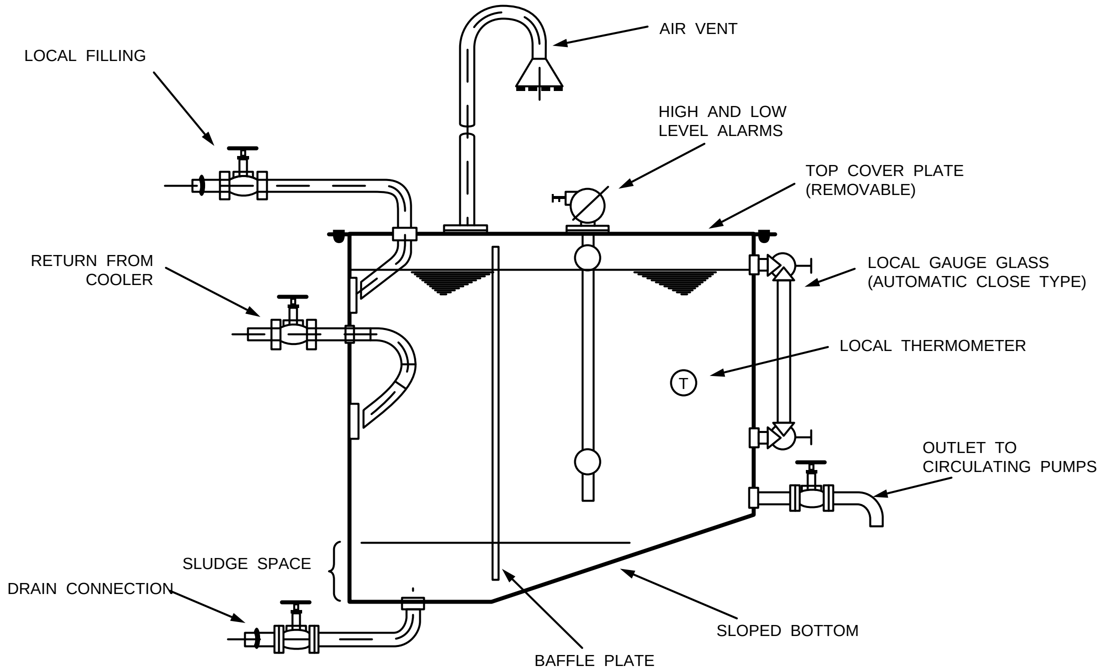


Figure 25

Circulating Tank

A baffle plate isolates the coolant return from the circulating pump suction to minimize air entrainment in the suction piping (see Figure 25). Slope the tank bottom to form a sludge space with a drain valve. Locate the pump suction above the sludge space. Provide the following additional connections: air vent, filling pipe, access cover, local thermometer, high and low level alarm, gauge glass (automatic close) and pump suction.

The inner tank surfaces must be accessible for cleaning. Clean it prior to filling the tank after construction or repairs.

Size the tank to prevent overflowing due to thermal expansion when the system is shutdown as well as to maintain a minimum circulating volume while operating. If one cooling module is used for multiple engines, proper flow levels must be maintained when one or more engines are isolated for service.

Strainer

Install a simplex strainer ahead of the circulating pumps and include a 400 micron (0.016 in.) stainless steel basket. The strainer should also have a differential pressure gauge and alarm. The strainer body is normally manufactured from cast iron or bronze.

Circulating Pumps

Provide two pumps with one acting as a standby. Screw or gear pumps fitted with a pressure relief valve are recommended. The flow required for each pump depends on the engine model installed and the number of engines. The coolant flow required for each engine is as shown in the following table, *Coolant Flow and Heat Dissipation*.

The following pump design characteristics are provided for guidance:

- Design Pressure - 518 kPa (75 psi)
- Operating Temperature - 65°C (150°F)
- Viscosity for Sizing Electric Motor - 1000 cSt

Heat Exchanger

A heat exchanger is used in the circuit when it is not practical to size the circulating tank large enough to remove the heat added to the coolant from the injector tip. Information for tank sizing to remove the required amount of heat is included in the *Distillate Fuel* section of this guide. If a cooler is required it can be either shell and tube or plate type, and include:

- Drains
- Air vents
- Zinc anodes (fitted in each head)

The suggested material for the shell and tube heat exchanger is:

- Shell - Steel
- Heads - Cast iron
- Tubes - 90/10 CuNi
- Tube Sheets - 90/10 CuNi
- Baffles - Steel

The suggested material for a plate type heat exchanger is:

- Frame - Mild steel
- Plates (sea water) - Titanium or aluminum brass; (Raw fresh water) - Stainless steel
- Nozzles (sea water) - Steel, coated; (fresh water) - Steel, coated
- Gaskets - Nitrile

Classification societies may require a spray shield around the plates to prevent liquid spraying on equipment or personnel.

The heat exchanger should be sized based on the following:

Coolant Flow & Heat Dissipation			
Engine Model	Flow (minimum) L/min	(GPM)	Dissipation kW (Btu/hr)
3606	36	(9.5)	6 (20,472)
3608	48	(12.7)	8 (27,296)
3612	72	(19.0)	12 (40,944)
3616	96	(25.3)	16 (54,592)

Temperature Regulating Valve

Install a self-contained temperature regulating valve with manual override as shown in Figure 24. Select the valve to control the temperature of the coolant back to the circulating tank at 50 to 65°C (122 to 150°F).

The following valve characteristics are provided for guidance:

- Design pressure - 517 kPa (75 psi)
- Design temperature - 65°C (150°F)
- Cast iron or bronze body

Series Circuit Tip Cooling

Engines operating with heavy fuel viscosities up to 40 cSt @ 50°C are not normally provided with a separate circuit injector cooling system. The fuel circulated within the injector tip maintains the proper tip temperature. The fuel flow can be found in *Distillate Fuel* section of this guide. The heat rejection is the same as in the separate circuit tip cooling description.

Lube Oil Recommendations

Lubricants for 3600 heavy fuel engines depend on the fuel to be used and will be evaluated on an individual basis. See the *Lubricating Oil* section of this guide.

Lubricating Oil Centrifuging

A higher level of combustion products is introduced into the lube oil with heavy fuel operation. Remote mounted centrifuges are recommended. See the *Lubricating Oil* section of this guide.

Start/Stop Procedures

The 3600 Engines are designed to start and stop on heavy fuel and this is the preferred practice. Changing to diesel can result in incompatible mixtures in the fuel system leading to injector sticking. However, in some instances it may be necessary to use diesel oil and depending on conditions, use the following procedures.

- Temporary shutdown - If the engine is shutdown for less than 12 hours, the jacket water should be at least 65°C (150°F).

- *Extended shutdown* – If the engine is shutdown for more than 12 hours and less than three days, use the engine jacket water heater. The fuel circulating system can be shut down or adjusted to a lower temperature. If shut down it must be heat traced to allow restart. Shut off the injector tip cooling circuit. Before the engine is restarted, the fuel must be circulated at the proper viscosity until all parts of the fuel system, including the engine mounted fuel lines, have proper temperature and flow.

- *Indefinite shutdown* – If the engine is shutdown for more than three days (or for an unknown length of time) it should be done using distillate fuel. Switch the engine to distillate fuel 15-30 min. before shutdown to purge the fuel system of heavy fuel. Shutting down on distillate allows the jacket water heater and fuel conditioning systems to be shut off. Use this procedure when maintenance to the fuel handling equipment is needed, or when work on the fuel injectors or fuel lines is required.

Operational constraints may require the above recommendations to be modified. The important considerations that must be adhered to are:

- Circulation of proper viscosity fuel prior to startup.
- Jacket water heating anytime the engine is not running and heavy fuel is in the system.

If the engine is shut down for a long period of time with the fuel system operating, there is the possibility of a malfunctioning fuel injector leaking fuel into the cylinder. To avoid the possibility of hydraulic lock, bar the engine over with a cylinder pressure indicator valve open prior to startup.

Do not start and idle the engine for short periods to maintain jacket water temperature. This will produce excessive deposits in the combustion chambers and gasways. Use the jacket water heater to maintain jacket water temperatures.

Low Load Operation

Heavy fuel with poor ignition quality requires higher cylinder air temperature and pressure for satisfactory ignition. This can be a significant problem at idle and light load conditions in *pier-to-pier* operations. For these applications, the cooling system is modified to a two step inlet air temperature control system regulating engine combustion air temperature. At engine loads below 40% of maximum, a significant increase in the temperature of compression is achieved. This allows extended periods of light load operation on heavy fuel without switching to distillate fuel.

Figure 24 is an estimate of time allowed at part load while using heavy fuel. If operation is expected beyond these times, provide the capability to operate the engine on distillate fuel. Switch-over must be done so the fuel injectors are never running without fuel.

The shaded portion of the graph indicates the area with a two step cooling system to heat the intake air. See the section in this guide on *Fresh Water Cooling* for cooling system schematics.

3600 Heavy Fuel Operational Requirements

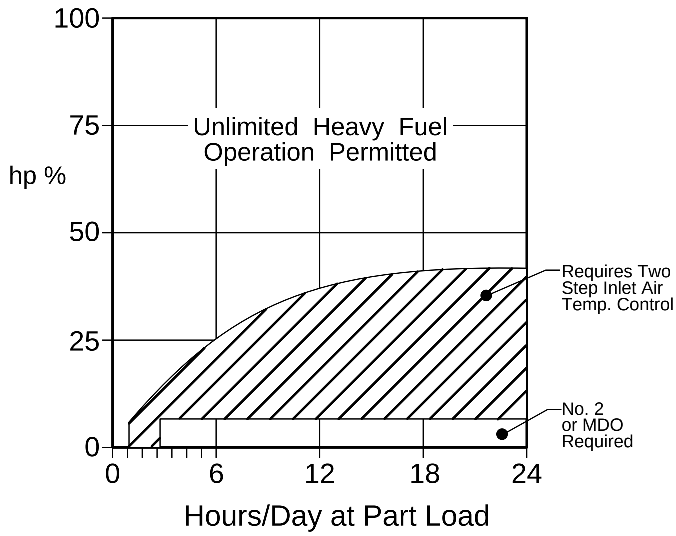


Figure 26

Typical Turbocharger Washing Arrangement for In-Line Engines

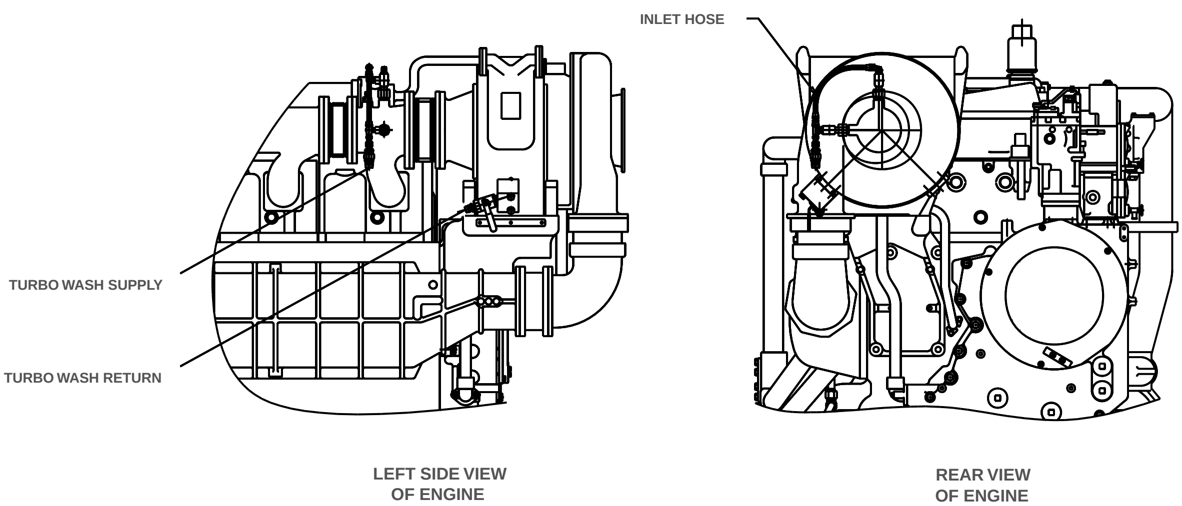


Figure 27

Turbocharger Wash

Heavy fuel engines are equipped for water washing of the turbine side of the turbocharger. Scheduled washing at 100 hour intervals removes deposits from the nozzle ring and turbine wheel and extends turbocharger overhaul intervals. To clean the turbocharger the engine must operate at reduced load for 5-10 min.

A 137-7024 tool group is supplied with each heavy fuel engine. Special Instruction SEHS9929 describes the washing procedure and provides a data sheet to determine the effectiveness of the process.

Dry particle cleaning of the turbine side is also acceptable, allowing full load cleaning. For additional information contact Caterpillar Inc.

Engine Jacket Water Preheating

Heat the engine jacket water prior to starting on heavy fuel. This reduces the viscosity of the fuel in the unit injector and aids in starting. Turn off the jacket water preheater when the engine is running.

Fuel Viscosity	Jacket Water Temperature
≤ 40 cSt at 50°C	45°C (113°F)
> 40 cSt at 50°C	65°C (150°F)

The jacket water heater is factory supplied when heavy fuel codes are selected. The heater is sized to raise the jacket water temperature to the required level within two hours.

Additional information is in the *Fresh Water Cooling System* section of this guide.

Fuel Filter Preheating

When operating on heavy fuel with a viscosity above 40 cSt @ 50°C, the final fuel filter is steam jacketed (or optional electric heaters are used) and off-engine mounted. Before the fuel conditioning system is operated, the viscosity of the fuel in the filter housings must be reduced to 1000 cSt or less. This allows fuel to be pumped through the filter without collapsing the elements. Required fuel temperature and heat-up time vary depending on fuel type and installation. Take care not to overheat the fuel or filter elements.

Performance

See guide section on *Engine Data* for ratings of heavy fuel burning engines. See guide section on *Engine Performance* for differences in rating conditions for heavy fuel engines.

Heat Rejection

See guide section on *Engine Data* for heat rejection data. It will differ from a distillate engine due to rating differences, injector tip cooling, and higher air flow required on heavy fuel engines.

Air Flow

See guide section on *Engine Data.* To maintain a lower exhaust valve temperature the air flow is considerably higher than a distillate engine running at the same power and rpm.

Exhaust Backpressure

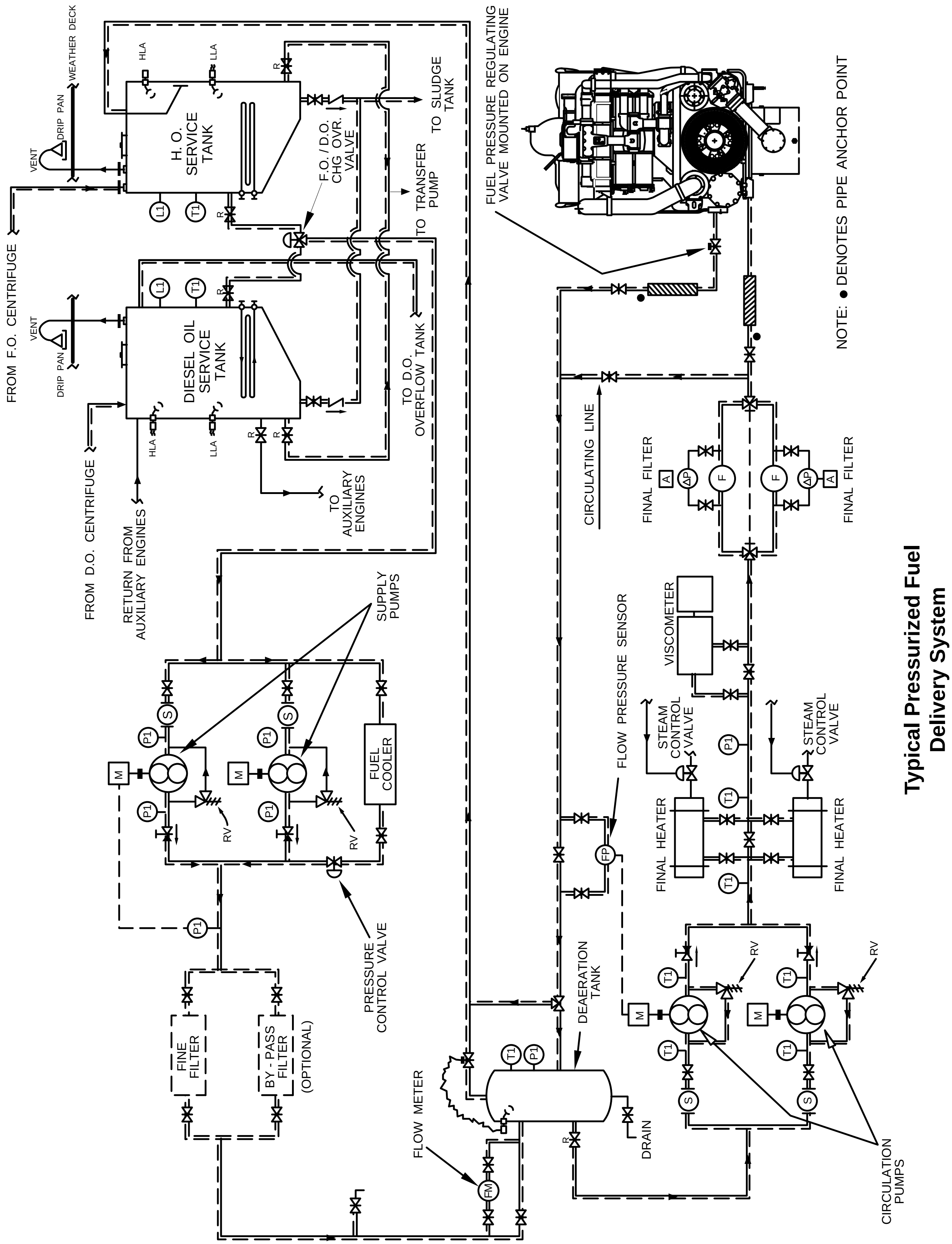
The exhaust backpressure *limit* is 2.5 kPa (10 in. H_2O) when operating on heavy fuel due to the effect of higher backpressure on valve temperature. The exhaust flow is higher for engines capable of burning heavy fuel than on engines configured for distillate fuel (see note above on *Air Flow*).

Reference Material

REHS0104 *Guidelines for 3600 HFO Engines*

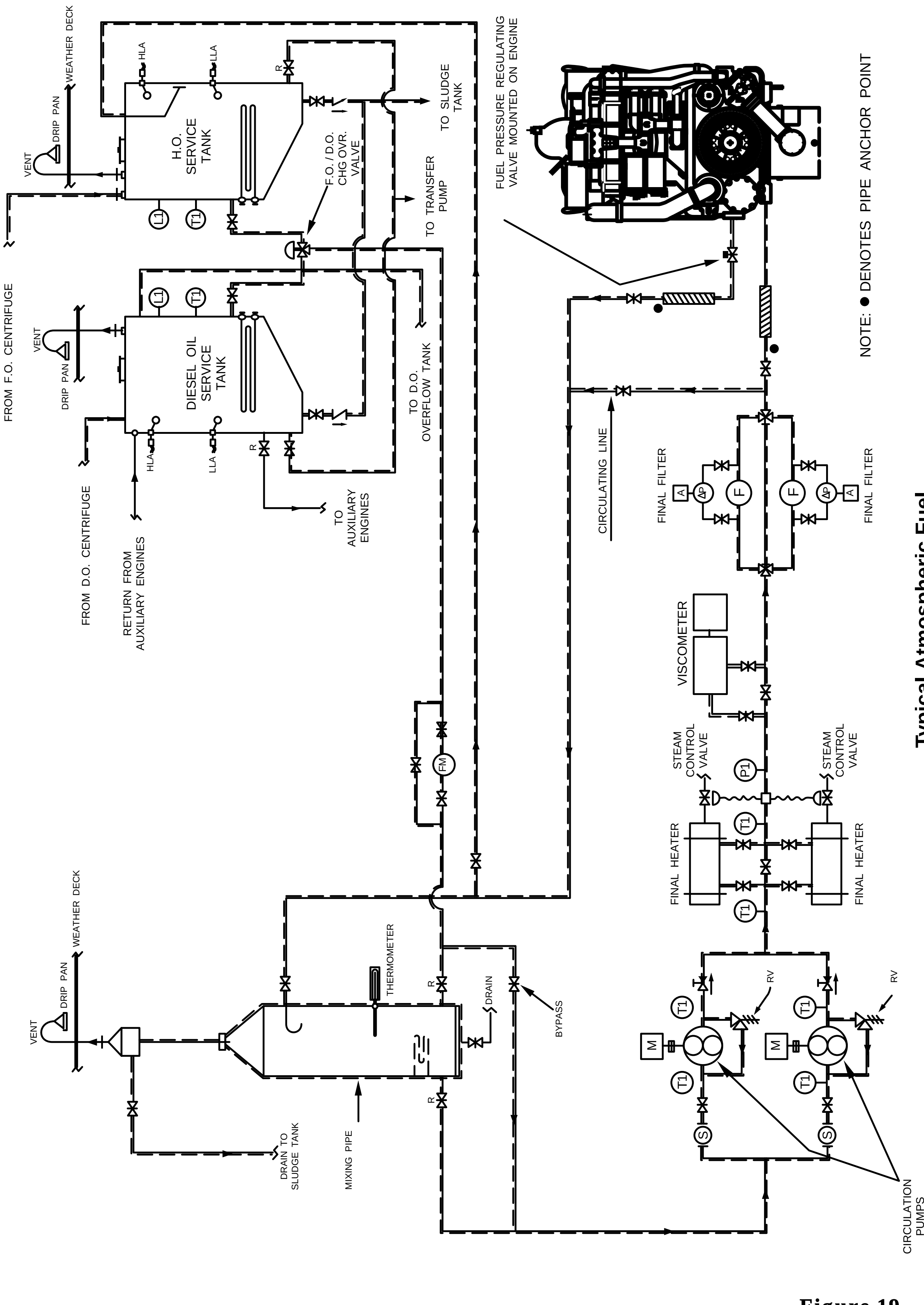
SEBD0717 *Diesel Fuel and Your Engine*
SEBD0640 *Oil and Your Engine*

(Other Publications)
ABS Notes on Heavy Fuel Oil (1984)
American Bureau of Shipping
45 Eisenhauer Drive
Paramus, NJ 07652
USA
Tel. (201)368-9100
Attn: Book Order Department



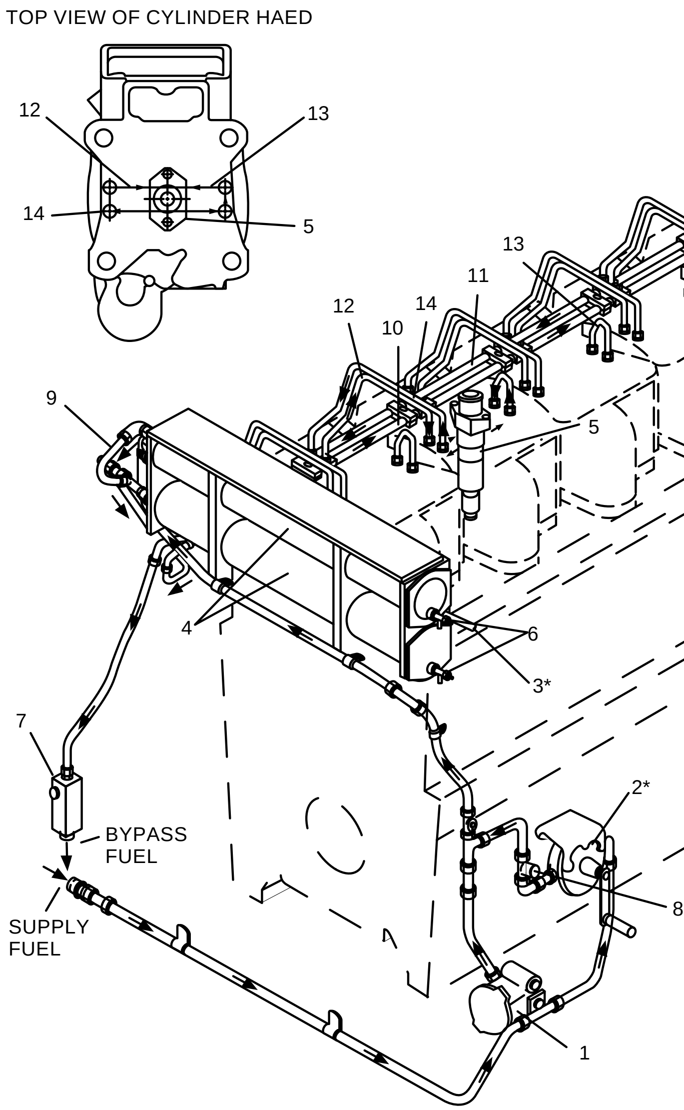
Typical Pressurized Fuel Delivery System

Figure 17



Typical Atmospheric Fuel Delivery System

Figure 19

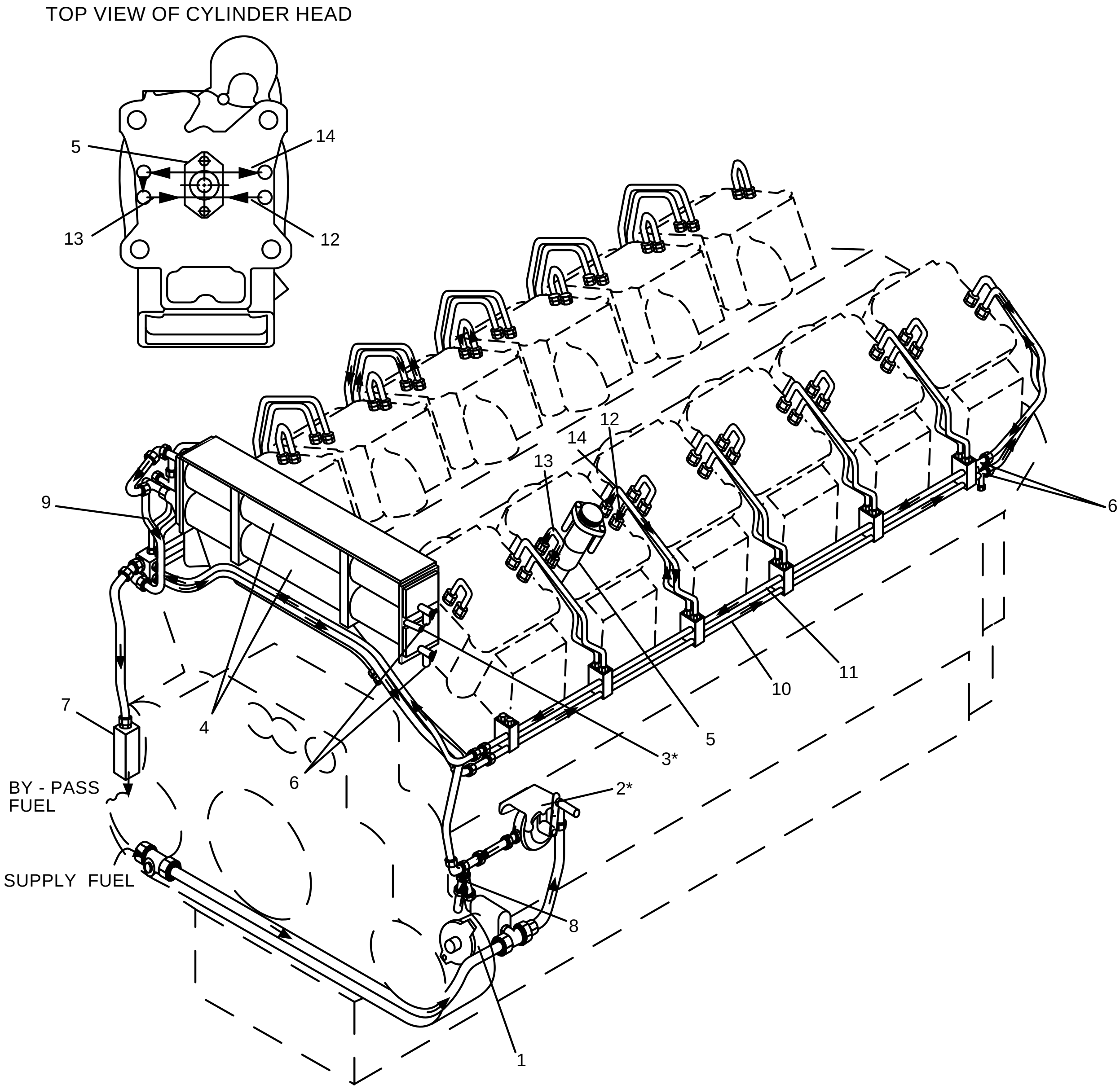


3600 Fuel System Schematic With Series Circuit Injector Tip Cooling
Model 3608

1. Fuel Transfer Pump (Eng. Mounted)	**8. Emergency Fuel Connection**
2. Hand Priming Pump	**9. Filtered Fuel**
3. Fuel Filter Duplex Valve Shaft	**10. Fuel Manifold (Supply)**
4. Fuel Filters	**11. Fuel Manifold (Return)**
5. Unit Injectors	**12. Fuel To Injection**
6. Manual Drain Locations (8)	**13. Bypass Fuel (To Tip Cool Circ.)**
7. Fuel Pressure Regulator	**14. Fuel Return**

*** Left Hand Service Shown – Right Hand Service Available**

Figure 20



3600 Fuel System Schematic With Series Circuit Injector Tip Cooling
Model 3612

1. Fuel Transfer Pump (Eng. Mounted)	**8. Emergency Fuel Connection**
2. Hand Priming Pump	**9. Filtered Fuel**
3. Fuel Filter Duplex Valve Shaft	**10. Fuel Manifold (Supply)**
4. Fuel Filters	**11. Fuel Manifold (Return)**
5. Unit Injectors	**12. Fuel To Injection**
6. Manual Drain Locations (8)	**13. Bypass Fuel (To Tip Cool Circ.)**
7. Fuel Pressure Regulator	**14. Fuel Return**

*** Left Hand Service Shown – Right Hand Service Available**

Figure 21

Typical Injector Tip Cooling Module
Single Engine

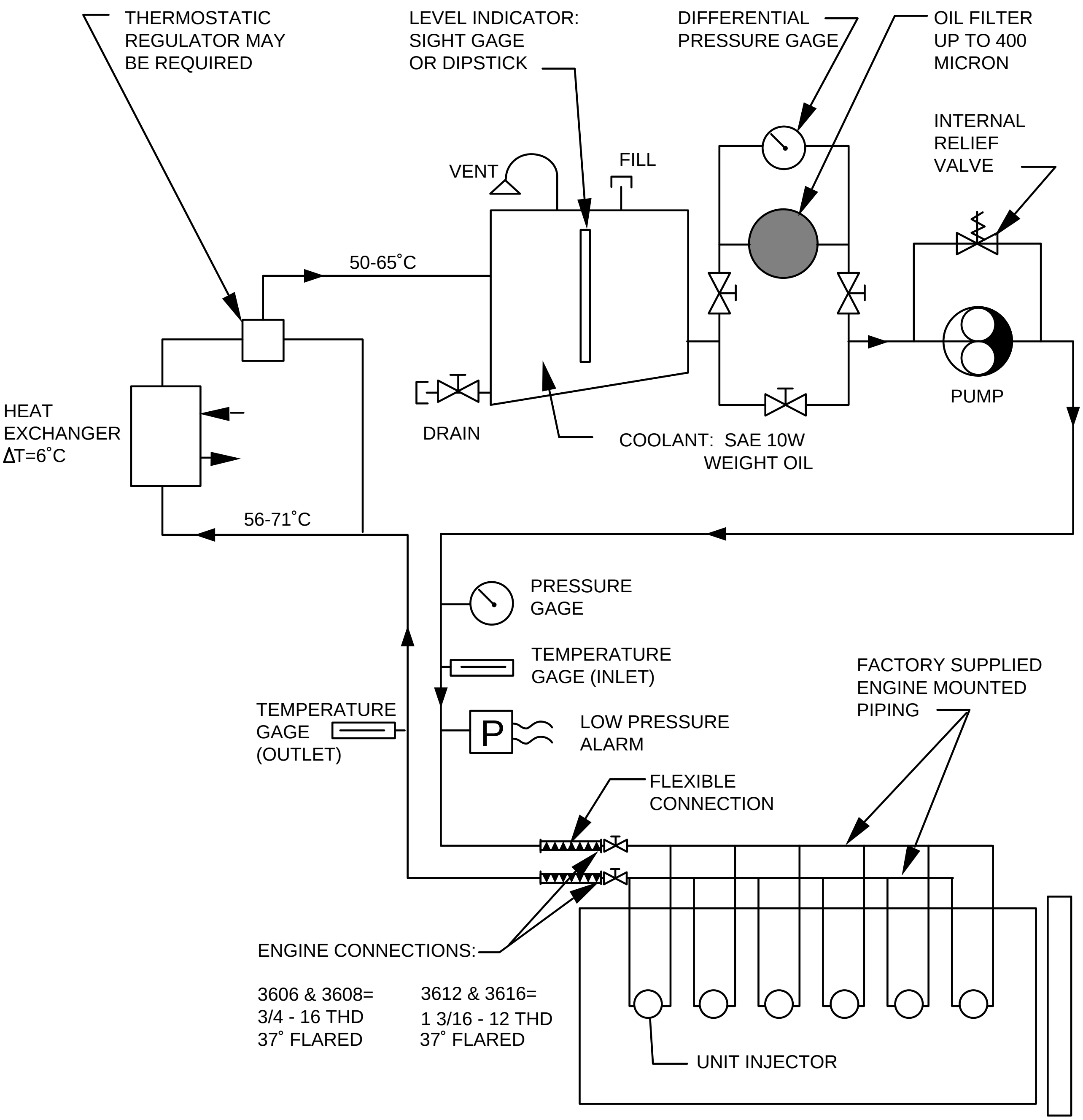
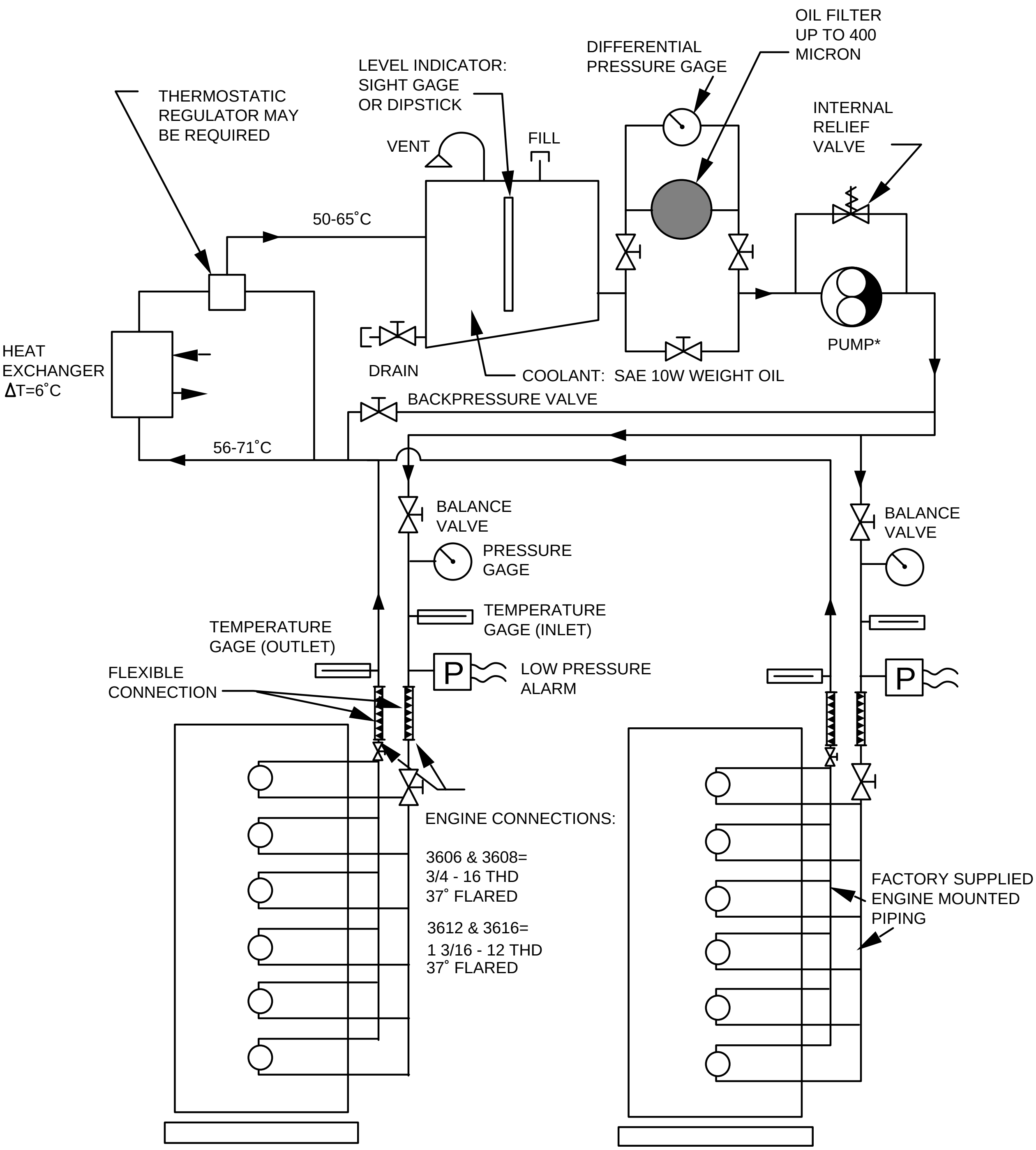


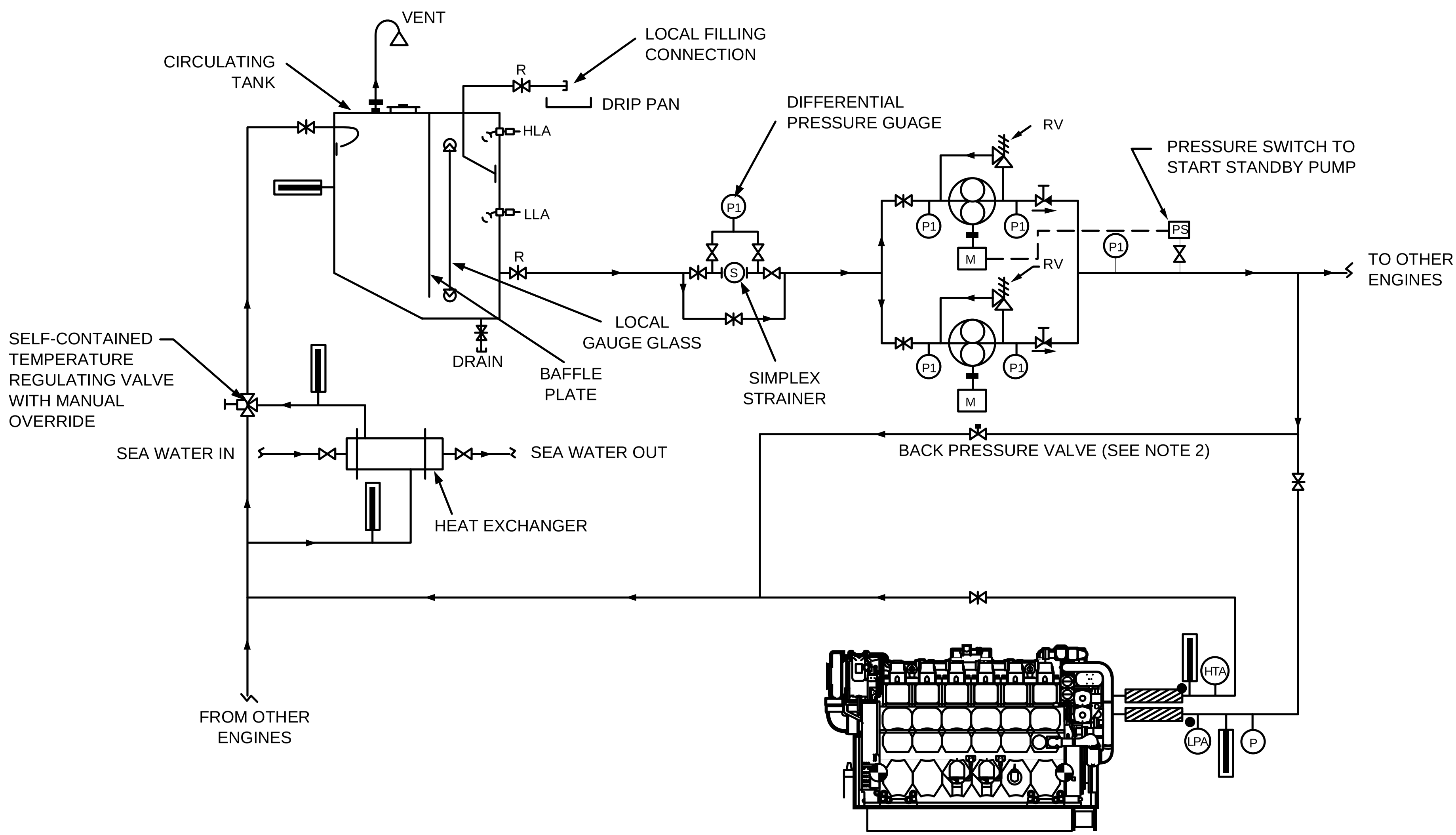
Figure 22

Typical Injector Tip Cooling Module
Multiple Engines



* System must be designed to provide proper flow and temperature to each engine. This must be maintained while an individual engine is isolated for servicing. System may include variable speed pump, flow regulating valves, or bypass plumbing.

Figure 23



NOTE:
1. ● DENOTES PIPE ANCHOR POINT
2. SYSTEM MUST BE DESIGNED TO PROVIDE PROPER FLOW AND TEMPERATURE TO EACH ENGINE. THIS MUST BE MAINTAINED WHILE AN INDIVIDUAL ENGINE IS ISOLATED FOR SERVICING. SYSTEM MAY INCLUDE VARIABLE SPEED PUMP, FLOW REGULATING VALVES AND/OR A BACK PRESSURE VALVE IN THE BYPASS PIPING.

Injection Cooling System

Figure 24

CATERPILLAR®

Diesel Engine Systems - Lubricating Oil

Engine System Description

The lube oil system is engine mounted and factory tested. It provides a constant supply of 85°C (185°F) filtered oil at 430 kPa (62.4 psi) pressure up to the limits of a well designed cooling system. An oil priority valve regulates oil pressure at the cylinder block oil manifold rather than at the oil pump. This makes the oil manifold pressure independent of oil filter and oil cooler pressure drops.

A gear driven oil pump is mounted on the front left side of the engine. Oil to the pump passes through a 650 micron (.025 in.) screen located between the suction bell and suction tube. A scavenge pump can be mounted on the front right side of the engine to transfer oil to, or from, an external oil sump. Schematics of the lube oil system are shown in Figures 1, 2, and 3 at the end of this section.

Oil temperature regulators direct the oil to coolers at oil temperatures above 85°C (185°F). Oil flows from the coolers to the 20 micron (.78 mils) final filters. From the filters, oil flows through the priority valve to drilled oil passages in the cylinder block.

Oil flows to the relief valve and bypass valve ports of the priority valve. Bypass oil also flows to optional engine mounted centrifugal oil filters.

The oil pump relief valve opens at 1000 kPa (145 psi) sending cold oil back to the engine sump, preventing damage to the lubrication system components. The bypass valve opens at 430 kPa (63 psi) to send excess oil back to the engine sump.

Other major features of the system are:

- Tube bundle oil coolers are used with series water flow and parallel oil flow.
- The filters can be changed while the engine is running. The maximum change period is 1000 hrs or when the oil filter pressure drop reaches 104 kPa (15 psi), whichever occurs first. The oil priority valve maintains full oil pressure to the bearings regardless of oil filter pressure drop.
- Engine mounted centrifugal bypass oil filters are available options. They receive 3-4% of the oil pump flow and remove very small, solid, micron size particles and can extend oil filter change periods — but not beyond the 1000 hour change period. The centrifugal filters each have a dirt capacity of 3.6 kg (8 lb) and require cleaning at 1000 hour intervals.
- All engine oil systems are factory installed, plumbed and tested as integralcomponents unless a dry sump, standby oil pump, remote mounted prelube pump, or an oil centrifuge is used. This eliminates contamination during installation and reduces installation costs.
- The engines are shipped without oil from the factory unless specified otherwise.

Oil Pumps

Drive speed ratios are 1.524 times engine speed for the main oil pump and 1.627 for the scavenge pump.

The oil pump provides more than the required engine oil at rated conditions. This allows high oil pressure early in the operating speed range as well as providing flow margins for worn engines. See Figure 4.

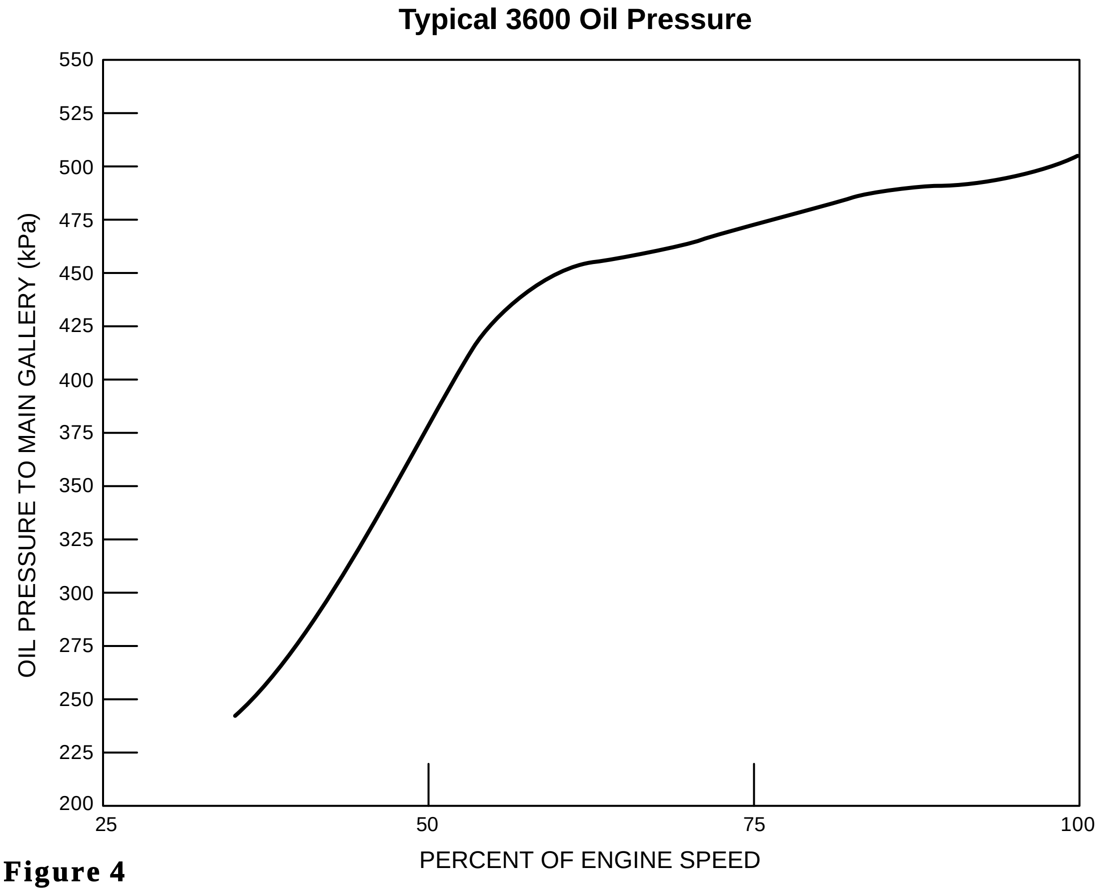


Figure 4

Emergency Pumps

An electric emergency, or standby, oil pump is usually required for single engine marine propulsion applications by the applicable marine society. Other applications may also use an electric standby oil pump. The emergency pump is connected in parallel to the engine driven oil pump. A loss of engine driven oil pump pressure causes an alarm and automatic start of the emergency pump to allow the engine to continue operating. The following engine oil flow rates are the *minimum* requirements at full power and rated speeds between 700 and 1000 rpm.

Engine Flow Rate — L /min (gpm)			
3606	**3608**	**3612**	**3616**
750 (198)	770 (203)	890 (235)	1200 (317)

The emergency oil pump cannot be used for prelubing the engine prior to starting. The emergency pump flow rate and discharge pressure are much higher than a standard prelube pump, and under certain conditions it can cause the oil filter elements to burst. A smaller separate prelube pump is required in addition to the emergency pump.

Prelubrication

Engine prelubrication is required prior to starting or rotating the engine with the barring device. This insures that there is sufficient oil at bearing and other contact faces to prevent direct metal to metal contact before engine driven oil pump pressure is developed. A prelube oil pressure sensor is mounted in the most remote camshaft bearing from the engine oil pump. When sufficient oil pressure is detected at this sensor, the engine control system provides a green light that allows engine starting. This sensor is also configured as a starting interlock to prevent engine starting without oil pressure at the sensor.

Caterpillar has various prelubrication systems available that include the motor (air or electric), prelube pump, electric motor starting box (if applicable), check valve, and engine piping. The check valve is used at the discharge of the prelube pump to prevent pressurized oil from flowing to the prelube pump during engine operation. The Caterpillar prelube system can be engine mounted by the factory prior to shipment, or shipped loose for customer installation. Engine connections for customer supplied prelube systems are also available.

For marine applications in general, Caterpillar recommends remote mounting the prelube pump from the engine. This prevents any engine vibration from affecting the pump and it allows the pump to be mounted in an easily accessible location for service. However, remote mounted prelube pumps must be located and plumbed to prevent excessive pump inlet restriction. For Caterpillar supplied pumps, the maximum allowable velocity in the pump suction line is 1.5 m/sec (4.9 ft/sec) to prevent pump cavitation, and the net positive suction head of the pump is 2 m H_2O (6.6 ft H_2O). See the pump manufacturer's data for customer supplied prelube pumps.

Caterpillar offers prelube pumps powered by compressed air or by single phase AC, three phase AC, or DC motors. Flow characteristics of some Caterpillar supplied pumps are shown in Figure 11 at the end of this section.

Two types of prelubrication systems are available: intermittent and continuous. Intermittent prelube is generally used for marine applications, and involves running the prelube system for a few minutes prior to engine starting or barring device use. With intermittent prelube the engine is not available for immediate starting. Intermittent prelube may take up to several minutes depending on oil viscosity, temperature, engine condition and system configuration. When the prelube pressure sensor measures 10 kPa (1.5 psi) the starting interlock allows the engine to be cranked. *The intermittent prelube pump should not be operated continuously for more than 10 minutes.* Time for engine prelube varies with engine size, oil temperature and viscosity, etc. Typical curves for prelube pump performance are shown in Figures 5 and 6.

Continuous prelube is typically used in emergency generator set applications where the engine must start on loss of power from a main generator and assume load. Continuous prelube systems are designed for constant operation during engine shutdown. A *spill tube* installed at the front of the engine prevents excessive oil from flooding the cylinder heads and causing hydraulic lock on startup. A lower flow pump is also used for continuous prelube systems. A jacket water heater must also be used for emergency generator sets to keep the engine warm for quick starting. An oil heater is generally not required with continuous prelube since the oil circulates through the engine and picks up heat from the engine block that is kept warm by the jacket water.

The prelube pump may also be used as a sump drain pump. Two manual three-way valves are required to configure the prelube pump as a sump drain pump. The oil sump drain valve is connected to the prelube pump suction with one three-way valve, and the pump discharge goes to a waste oil tank via the other three-way valve. The three-way valves are not supplied by Caterpillar. Install a pressure switch at the prelube pump outlet to automatically shut down the pump when there is a loss of discharge pressure. This prevents running the pump dry when draining the oil sump.

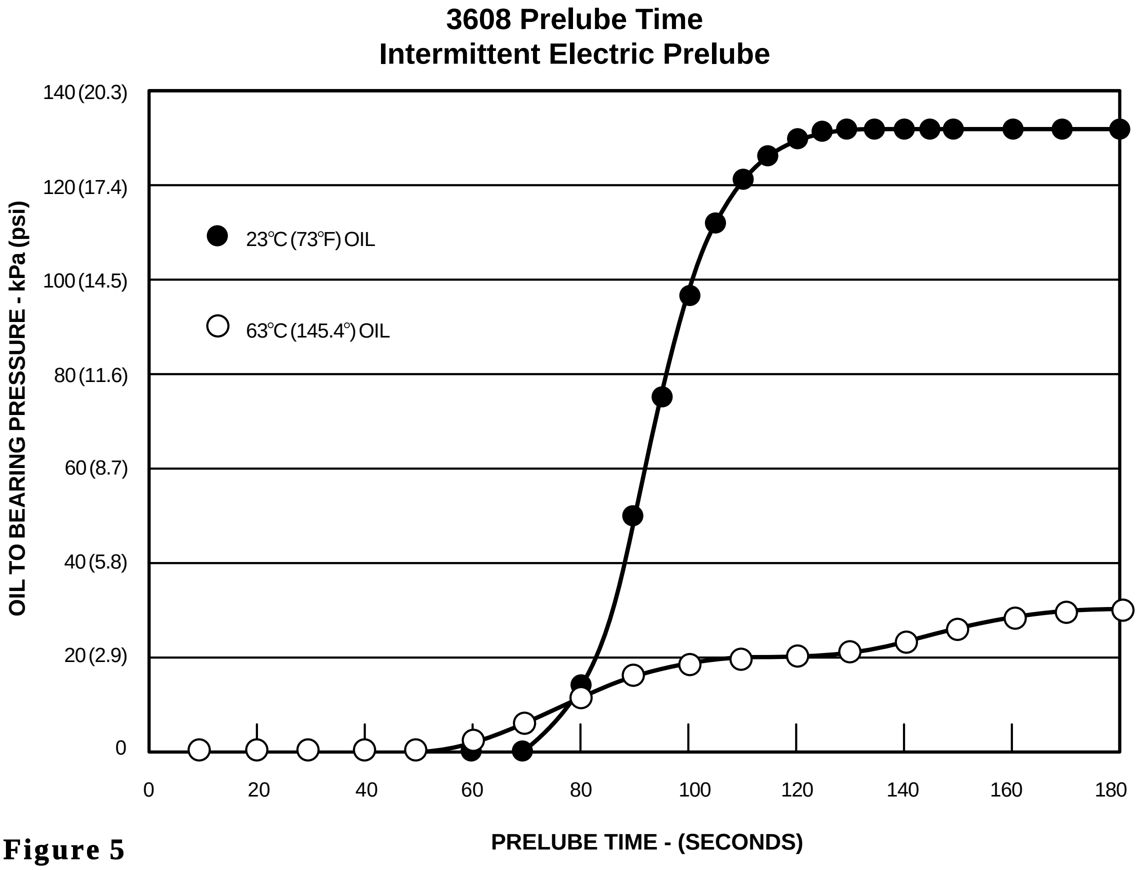


Figure 5

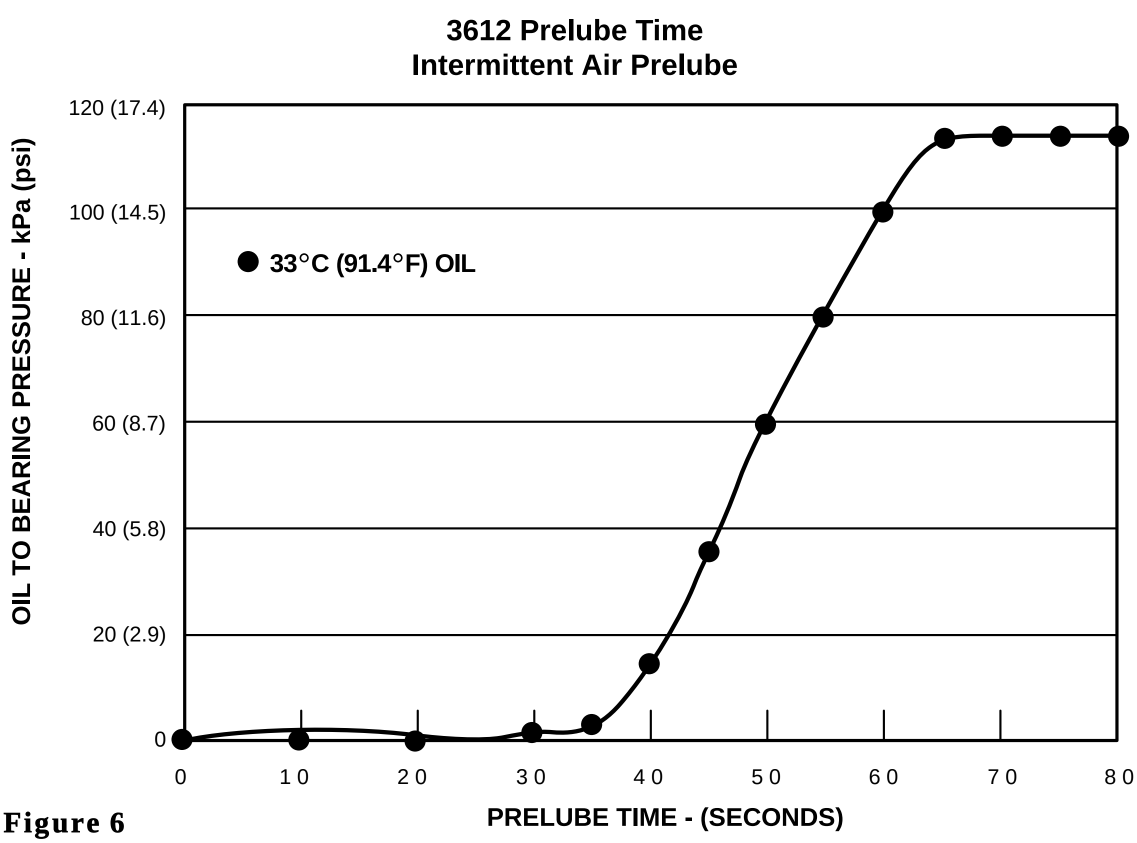


Figure 6

Customer Supplied Prelube Pumps
Locate a gear type pump with a pressure relief valve near the front of the engine with the following characteristics:

	Intermittent	/Continuous
• Flow	76 Lpm (20 gpm)	23 Lpm (6 gpm)
• Operating Pressure	172 kPa (24.5 psi)	
• Operating Temperature	21°C (70°F)	
• Viscosity for sizing electric motor	340 cSt	

Tilt Capability

Continuous Tilt Angle Capability	Marine Propulsion	Marine Auxiliary
Intermittent Tilt Criteria	± 10° Pitch & ± 22.5° Roll (any combination)	± 10° Pitch & ± 22.5° Roll (any combination)
Engine Model	Installation Angle / Rear Down (Degrees) 0 1 2 3 4 5	Level Installation
3606	X X X X X X	X
3608	X X X D D D	X
3612	X X X X X X	X
3616	X X X X D D	X

X = Standard Sump, capable of meeting the indicated tilt criteria.
D = Requires Dry Sump option to achieve the indicated tilt criteria.

Note: If wet sump engine is installed at >0° tilt, it will reduce oil capacity and reduce the oil change interval. Consult Caterpillar for specific details.

Figure 7

Wet Sump

The standard 3600 engine configuration uses a wet oil sump. This is an oil pan mounted directly underneath and connected to the engine block. An oil pump suction pipe with a suction bell near the center of the oil pan exits the oil pan at the front of the engine and connects directly to the engine driven oil pump, (see Figures 1 and 2). See Figure 16 for wet sump oil volumes for each engine model.

External Sump Tank

Engine room space, tilt requirements, or the desire to extend oil change periods may dictate using an external oil sump tank. The following arrangements and Figures 9 and 10 at the end of this module are provided for guidance.

Under the Engine

The suggested design of an external sump tank is shown in Figure 9.

Extend the lube oil sump tank over the entire length of the engine to ensure uniform thermal expansion of the engine foundation structure. Use flanged, flexible, drain connections at each end of the engine mounted sump to prevent damage from vibration and thermal growth. The connections must be compatible with engine lube oil at a temperature up to 130°C (266°F), and should withstand exposure to fuel, coolant, and solutions used to wash down the engine. Terminate the drain pipes from the engine oil sump to the external sump below the minimum oil level. Locate the engine sump drains as far away as possible from the oil pump suction area. The oil should be in the tank for the longest possible time to maximize degassing.

To provide adequate degassing of the external sump, a minimum distance of approximately 150 mm (6 in.) must be provided between the top of the tank and the highest oil level expected in the tank. Provide the transverse structure in the tank with air holes and two 100 mm (4 in.) minimum diameter air vent pipes, one at the forward end of the tank and another at the aft end.

The oil passages in the transverse structure must ensure adequate oil flow to the pump suction piping. Fit the end of each suction pipe with a bell mouth to keep pressure losses to a minimum. The maximum available suction lift to the engine driven lube oil pump, including losses in the piping and strainer, must be kept below 1.3 m (4 ft 3 in.).

Cofferdam the external sump tank from the shell and fit with a coil to heat the oil to 38°C (100°F). The coils should be manufactured from corrosion resistant material.

Locate a collecting sump at the aft end of the tank. When used, the lube oil centrifuge should take oil from the collecting sump at a level below the main lube oil pump suction pipe. Discharge the clean oil from the centrifuge near the lube oil pump suction piping.

The inner surfaces of the external sump tank should be accessible for cleaning. Thoroughly clean the tank after construction or repairs and prior to filling. Use flanged joints on the suction piping to the lube oil pump to allow inspection before use. The surfaces above the minimum oil level must be corrosion protection coated. The tank requires a local sounding tube as well as a low level alarm contactor.

Remote Sump with Scavenging Pump

An engine driven scavenging pump can be provided to empty the oil in the engine pan to a remote storage tank (see Figure 10 at the end of this section). This arrangement is normally used where the foundation structure height is small. Oil from the remote tank is returned to the engine oil system by the engine driven main pressure pump. Due to the importance of the main engine lube oil system, marine societies and/or the owner may require electric motor driven standby pumps. This system can become very complex due to the additional pumps, piping and valves. Also, the oil level in the remote storage tank must be kept below the engine crankcase to prevent oil leak back into the engine when the engine is stopped. This can result in a long narrow tank taking useful space. Incorporate the features recommended in the design of the remote sump tank located below the engine as discussed above.

Piping

The piping must be short with minimum bends and have a continual upward slope towards the pump to avoid pump cavitation and keep suction pressure drops low. Install a non-return valve in the piping to prevent the oil from flowing backwards when the engine is stopped. The pipes must be supported and have flexible connections at the engine and auxiliary connecting points. Provide vent and drain connections at the high and low points in the system.

Suction Strainer

Install a suction strainer in the piping between the tank and the lube oil circulating pumps to protect the pumps from large particles collecting in the tank. It should have stainless steel basket with 650 micron (0.025 in.) perforations and magnetic inserts. Provide a differential pressure gauge to indicate when manual cleaning of the strainer is required.

Lube Oil Centrifuge

The engine is provided with lube oil final filters and centrifugal bypass filters. A lube oil centrifuge, or separator, can also be installed as optional equipment for distillate fuel applications and is required for heavy fuel applications.

Heavy fuel engines produce higher levels of lube oil contaminants than distillate fuel engines. The lube oil separator removes insolubles and water from the lube oil, which increases the life of the lube oil and lube oil filters.

The lube oil separator is sized based on the power output of the engine. For heavy fuel oil applications, the lube oil must be continuously processed by the lube oil separator at a minimum flow rate of 0.14 L/bkW-hr (0.028 gal/bhp-hr). The lube oil centrifuge should be of the self-cleaning type due to the frequent cleaning required. Solid bowl separators must not be used for lube oil service. The fresh water and control air requirements for the centrifuge should be specified by the manufacturer. The sludge discharge process should be automatic with the sludge tank arranged similar to the fuel oil sludge tank as described in the *Heavy Fuel Oil* section of this guide.

There are two methods for configuring the lube oil separator system. The first method is to supply each engine with its own dedicated lube oil separator. The second method is to service up to four engines with one single lube oil separator. Certain requirements must be met in order to use a single separator for multiple engines:

- Only Alfa Laval ALCAP model separators, or similar models from other manufacturers, may be used in multiple engine applications.
- All precautions must be taken to minimize sump cross-contamination. This includes locating the changeover manifold at the separator.
- Utilize Caterpillar PLC and automatic valves for the changeover of sumps.
- Use no more than four oil sumps per separator.
- A redundant separator and the necessary piping for the additional separator must be incorporated into the design of the engine room.
- The lube oil separators shall be oversized (greater than 0.14 L/bkW-hr (0.028 gal/bhp-hr)).

Consult Caterpillar for a specific project or application.

The centrifuge should take oil from the rear of the engine and return it to the front of the engine so that clean oil is as close to the engine oil pump suction as possible. Oil connections are provided at both ends of the oil sump. Shutoff valves are provided for customer connection, but flexible connections must be provided by the customer.

The maximum amount of time a heavy fuel engine can operate without cleaning the lube oil is eight hours.

Centrifuge Supply Pump

The centrifuge supply pump can be either direct driven from the centrifuge or electric motor driven. Size the pump in accordance with the manufacturer's recommendations.

Preheater

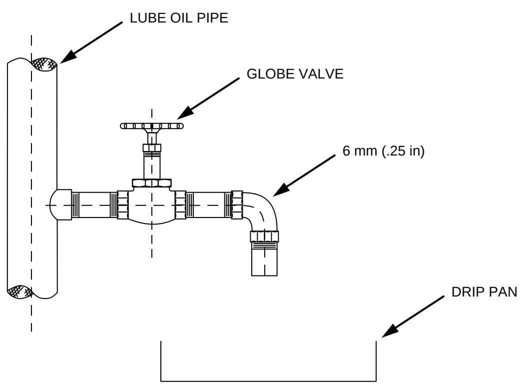
Preheater size is determined by pump capacity and required temperature rise between ambient temperature and the final centrifuge. The final outlet temperature is determined by the centrifuge manufacturer, but will range between 85°-95°C (185°-203°F) depending on the grade and type of oil used. Other heater sizing considerations are:

- Oil temperature must be 95°C (203°F) for engines centrifuging during engine operation.

- The heater must be oversized to account for the heat normally supplied by an operating engine so the centrifuge can be operated when the engine is shut down.
- Thermostatically control the heater to maintain the oil temperature to the centrifuge within 2°C (± 4°F).

Sample Points

Check the centrifuge efficiency by drawing samples from points upstream and downstream of the centrifuge. Figure 11 is a typical arrangement.



Typical Sampling Connection

Figure 11

Lube Oil Storage and Transfer System

Figures 12 and 13 at the end of this section show typical piping schematics for operational lubricating oil storage. It consists of three storage tanks, a centrifuge and a transfer pump arranged as follows:

Clean Oil

Clean oil from the storage tank is piped to supply the engine sump (or sumps) either by gravity, via the centrifuge, or by the transfer pump.

Dirty Oil

Dirty lube oil is removed from the engine sump (or sumps) by the transfer pump and discharged to the dirty lube oil storage and settling tank.

Renovated Oil

Contaminated oil can be cleaned using the lube oil centrifuge and discharged to the renovated oil tank.

Transfer Pump

The lube oil transfer pump can take oil from the engine sump (or sumps), the clean oil storage tank, the dirty lube oil storage and settling tank, and the renovated oil tank. The pump can discharge to the dirty lube oil and settling tank, the sludge tank, and the engine sump (or sumps). Use a gear type pump and include a relief valve. The following characteristics are provided for guidance:

- Flow - 190 Lpm (50 gpm)
- Pressure - 345 kPa (50 psi)
- Operating Fluid Temp. - 130°C (266°F)
- Viscosity for sizing electric motor - 1000 cSt

Storage Tanks

A lube oil storage tank capacity table is provided below for guidance. Many variables go into establishing tank capacity — the number of engines installed, sump volume, lube oil consumption, etc.

Tank Volumes	Liters	Gallons
Lube oil storage tank	**7500**	**2000**
Dirty oil storage and settling tank	**3780**	**1000**
Renovated oil storage tank	**3780**	**1000**

Each tank should have the following connections: filling, vent, local sounding, gauge glass, heating coil, thermometer (with well), transfer pump suction, outlet, steam blowout, manhole and ladder (if required).

Preheat the oil with tank heating coils to approximately 38°C (100°F). When heating with steam or water, the heating coils must be manufactured from corrosion resistant material.

The engine can be filled with oil from the storage tank via the centrifuge, by the lube oil transfer pump (with a strainer) through the forward or aft sump drain valves, or through the filling cap located on the engine crankcase cover.

Oil Guidelines

As with all modern high technology engines, oil selection for the 3600 engines is more critical and possibly more time consuming than for older, lower specific output engines. Even though the process is necessary, it must be recognized that newer engines deliver more power at lower owning and operating cost than their predecessors. Fuel quality has also changed considerably over the past three decades, making the choice of oil even more complicated.

Even though choosing a proper oil for the 3600 engines may not be as simple as with older engines, it can still be a fairly easy process if all variables are understood.

The higher technology associated with modern engines has placed greater demands on the lube oil to perform its functions; this is true with 3600 engine competition as well. The reduced oil consumption of modern engines, while reducing operating cost, does mean the oil is not continually being replaced by oil additions as on older engines.

Oil selection is further complicated by the wide oil performance variations within:

- The API classification (CF)
- The base stocks and additive packages available on a world wide basis

The existence of these known variations make blanket approval by brand name impractical. This is the general practice for 3600 engine competition as well.

To simplify the oil selection process, Caterpillar has developed recommendations to determine the most suitable oils for the 3600 Family of Engines. In most instances, the owner can select the oil company he prefers. Caterpillar will assist the customer and supplier in choosing an oil that meets engine requirements based on the fuel being burned in the engine. *At all times, it is the responsibility of the supplier to maintain the quality and performance level of his product.*

The Caterpillar Micro-Oxidation Test speeds up and simplifies the screening and selection process. Rather than the traditional method of selecting oil through expensive, time consuming engine testing (typical of the method used by competitors as well), the Caterpillar test is an alternative method of initially screening an oil from the selected supplier. Final oil acceptability is obtained through demonstrating satisfactory oil performance during engine operation for an extended period of time.

The Caterpillar Micro-Oxidation Test uses a metal test specimen (same alloy as the 3600 piston crown) heated to a temperature similar to an operating engine. A small amount of test oil is impinged on the metal surface and the induction time to rapid deposit formation is measured.

Caterpillar Micro-Oxidation Test

The following provides interpretation of Caterpillar Micro-Oxidation test induction times:

Induction Time	Oil Status
Less than 90 minutes	Unacceptable
90 minutes or greater	Acceptable

Caterpillar will consider the use of oils below 90 minute test results if the oil supplier can provide comparative field test results in excess of 7000 operating hours. The field test must be at similar or higher load factors than the owner's engine.

Caterpillar has provided Micro-Oxidation Test procedures and analysis techniques to various laboratories as well as worldwide additive package suppliers and major oil companies. Contact them or similar labs for information on their capabilities and fees. Test work done by laboratories other than the Caterpillar lab listed below must be certified by Caterpillar.

Inquiries about Caterpillar Micro-Oxidation testing can be directed to:
Test & Development
Caterpillar Inc.
Technical Center - E
P.O. Box 1875
Peoria, IL 61656-1875
Telephone (309) 578-6604
Fax: (309) 578-4496

Oil Requirements

To be acceptable in a 3600 engine, an oil must demonstrate satisfactory performance in the following areas:

- The oil *must* have an API classification of CF. Military Specification Mil-L-2104D oils also meets this requirement.

- The oil *must* pass the Caterpillar Micro-Oxidation test performed on samples from the suppliers facility supporting the engine. If multiple suppliers are involved, oil must be evaluated from all suppliers. The test can be run at labs having equipment and procedures approved by Caterpillar. The oil acceptability remains valid, consistent with constant oil base stock, formulation, and blending practices.

- Scheduled Oil Sampling (SOS), TBN, viscosity, oil consumption and crankcase pressure trends must be analyzed every 250 hours. An oil change interval chart is provided for installations where SOS is not available for scheduled analysis.

- Depending on oil pan capacity (see Figure 13), oil changes must be made at 1400 hour intervals (maximum) for the first 3000 hours of operation. If no oil related problems are encountered in the first 3000 hours, the change period may be determined by oil analysis. After the initial evaluation, the oil change interval should only be increased at 250 hour increments prior to moving to the next 250 hour interval extension. The oil must be analyzed at each interval.

Based on worldwide testing and quality control measures in blending processes, Caterpillar DEO (CF) SAE 40 oils are recommended for use in the 3600 Family of Engines. It does not require the Micro-Oxidation test. Caterpillar DEO (CF) oil meets the performance requirements of API CF, with high detergency effectiveness. It has high alkalinity (TBN 14) for the neutralization of wear-causing combustion products and higher fuel sulfur.

Note: *Caterpillar DEO multigrade oils are specially formulated for smaller engines and are not recommended for the 3600 Family of Engines.*

Commercial Oils

Caterpillar recognizes commercial oils that have successfully completed 7000 hours of documented field service in 3600 engines. Guidelines for field testing are available through 3600 Customer Services in the Large Engine Center. During the test the engine must operate at normal operating loads and have the following parameters monitored: oil consumption, oil deterioration, and valve recession. At the completion of the field trial, the condition of the oil and the engine must be within the following limits:

- No ring sticking or ring scuffing
- No liner scuffing or carbon cutting from excessive piston top land deposits

- Valve recession must not exceed the limits established by Caterpillar for the engine
- Oil consumption must not exceed two times the initial oil consumption. Initial oil consumption is established during the first 1000 hours of operation.
- At the end of the specified oil change periods, the oil condition must remain within Caterpillar limit for oxidation, nitration, and TBN.

Caterpillar does not recommend lube oils by brand name. Field operation may identify oil brands which yield good results. Oils which may be listed as having good field operating results do not form a Caterpillar recommendation. They serve only as potential oils which may be successful. Each particular oil company has control of its product and should be accountable for its oil performance. Establish product consistency before using any product.

Lubricant Viscosity

Use an SAE 40 grade oil. SAE 30 and some multigrade oils may be used if the application requires. SAE 30 is preferable to a multi-grade oil.

Ambient Temperature Range		
Oil Viscosity	**°C**	**°F**
SAE 40	+5 to +50	+41 to +122
SAE 30	0 to +40	+32 to +104
SAE 20W-40	-10 to +40	+14 to +104
SAE 15W-40	-15 to +40	+5 to +104

Lubricant Total Base Number (TBN)

The TBN recommendation for an oil is dependent on the sulfur level of the fuel used. For 3600 engines running on distillate fuel oil, the minimum new oil TBN (by ASTM D 2896) must be 10 times the sulfur percent by weight in the fuel, with a minimum TBN of 5 regardless of the fuel sulfur content (see Figure 6). In most oil formulations the TBN is a function of the ash bearing additives in the oil. Excessive amounts of ash bearing additives can lead to excessive piston deposits and loss of oil control. Therefore, excessively high TBN or high ash oils should not be used with 3600 engines running on distillate fuel. Successful operation of 3600 engines on distillate fuel has generally been obtained with new oil TBN levels between 10 and 15.

3600 engines running on heavy fuel oil must use an oil specifically blended for heavy fuel engines. Oils for heavy fuel engines are specially blended for use with lube oil separators; these oils must be able to release water and contaminants by centrifuging without the loss of additives. These oils are generally available from 20 TBN to 50 TBN (ASTM D 2896), however most Caterpillar experience is with 30 to 40 TBN oils. For 3600 engines running on heavy fuel oil, the minimum new oil TBN must be 20 times the fuel sulfur percent by weight in the fuel, with a maximum TBN of 40 regardless of the fuel sulfur level (see Figure 15). Oils for heavy fuel 3600 engines must also pass the performance requirements for commercially available oils as previously described.

Always consult a Caterpillar Dealer for the latest lubricant recommendations. For more information on oil and fuel sulfur content refer to:

SEBD0640 *Oil and Your Engine*

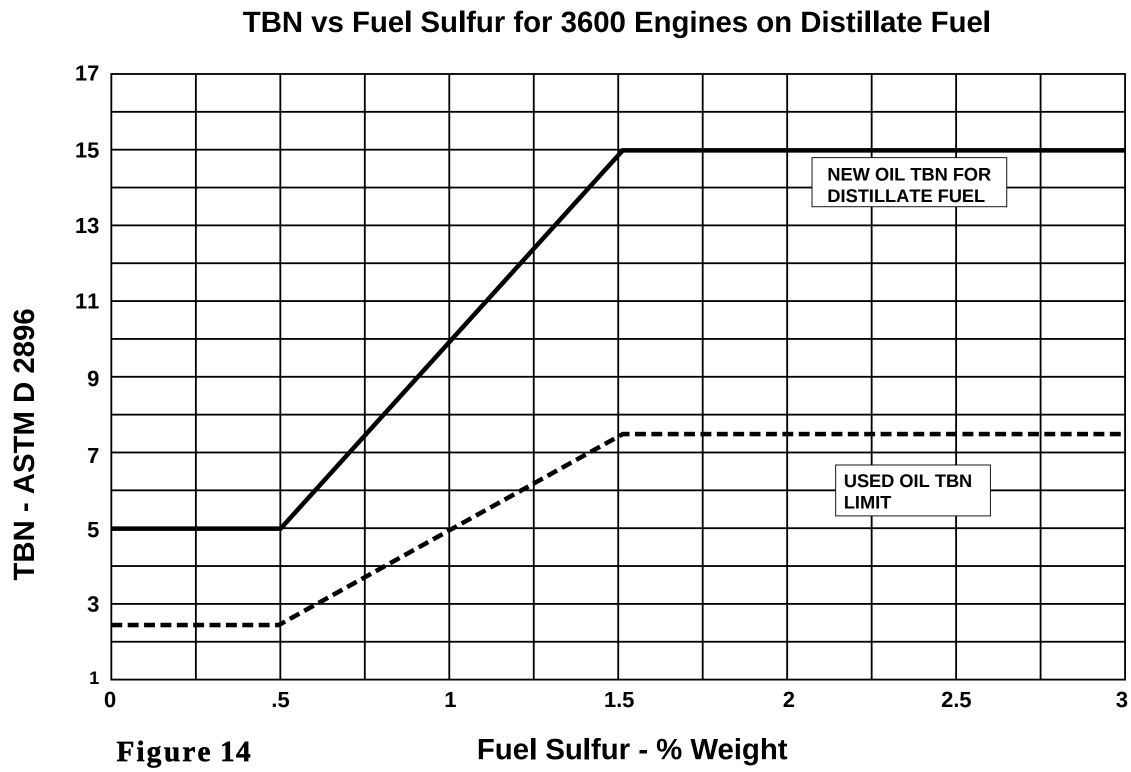


Figure 14

NOTE:
OPERATION AT FUEL SULFUR LEVELS OVER 1.5% MAY REQUIRE SHORTENED OIL CHANGE PERIODS TO MAINTAIN ADEQUATE WEAR PROTECTION.

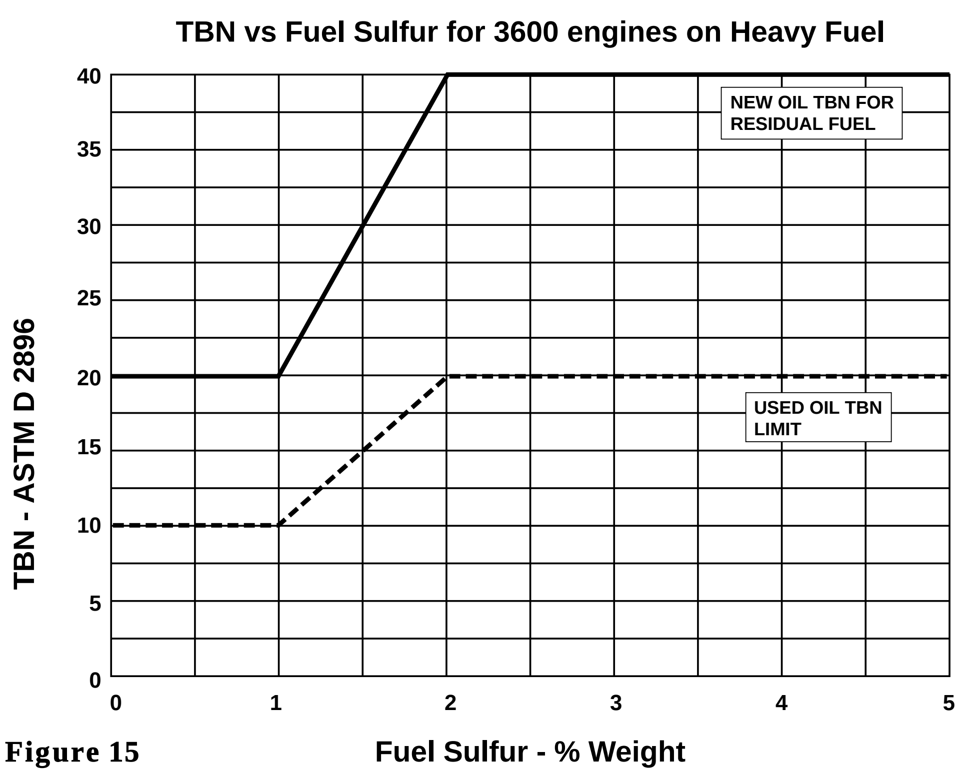


Figure 15

Oil Change Interval

To achieve maximum life from the engine oil and provide optimum protection for the internal engine components, a Scheduled Oil Sampling program (SOS) must be used. Information is available through Caterpillar Dealers. The program will determine oil change intervals based on trend analysis and condemning limits established for the engine. For an optimized program, oil samples must be taken every 250 operating hours throughout the life of the engine.

When extending lube oil life, Caterpillar recommends that the oil change interval not exceed 3000 hours unless the oil is managed through the Caterpillar SOS program.

SOS Analysis

Analysis is performed on samples taken every 250 hours and requires two test procedures:

- Wear Analysis
- Oil Condition Analysis

Wear analysis is usually performed with an atomic absorption spectrophotometer or flame emission spectroscopy (ASTM D3601). After three samples are taken, trend lines for the various wear elements are established. Impending failures can be identified when trend lines deviate from the established norm. The SOS program has also established limits for all appropriate wear metals. Contact a Caterpillar Dealer for more information.

Oil Condition Analysis includes the following:

- Infrared analysis monitors soot, sulfur products (from combustion of the fuel), and oxidation. The soot index correlates to the amount of soot or carbon particles in the oil. Infrared oxidation level correlates with the amount of oil degradation. Use sulfur products readings as part of an oil condition trend analysis.

Caterpillar Dealers can determine acceptable concentration levels for the various elements in the analysis program.

- Other oil condition results determined from SOS include: maximum permissible water (0.5%); glycol is not permitted in the oil and it should be changed if detected (ASTM D 2982 Procedure B); maximum fuel dilution (3%).
- Additional oil condition tests are required until the final change period is established.

  The testing should be continued periodically at oil change intervals and/or oil brand or formation changes. The tests can be arranged through Caterpillar Dealers and/or independent testing facilities:

TBN (Total Base Number)
The limit is reached when the TBN of the used oil is 50% of the new oil TBN as measured by ASTM D 2896.

Viscosity
The limit for used oil viscosity is 3 cSt above the new oil viscosity as measured by ASTM D445 @ 100°C.

Initial Oil Change Interval

The following chart is the required initial oil change based on engine type used and oil sump size.

Engine Model	Oil Pan Capacity Liters	Oil Pan Capacity Gallons	Oil Change Interval (Hours)
3606	697 *	184	1025
	846 **	224	1400
3608	761 *	201	925
	1078 **	285	1325
3612	909 *	240	750
	1268 **	335	1050
3616	1057 *	279	605
	1649 **	436	1025

* Typical marine oil pan; tilt angles > 0° may change volumes.
** Typical generator set or industrial oil pan.

Figure 16

Oil Change Intervals without Oil Analysis Results

If SOS analysis results are not available, see Figure 16 to determine oil change intervals. Even though oil sampling results may not be available on the recommended 250 hour intervals, samples should be analyzed at every oil change period, even if the turn around time for the data may be long.

If oil sample analysis is not available, the oil must be changed in 500 hour intervals when operating on heavy fuel.

Increasing Oil Change Intervals

Change intervals can only be increased when analysis results indicate the oil has not reached the contamination or depletion limits. Trend lines for each measured parameter must have a nearly constant slope and must not reach condemning limits. If conditions are favorable the oil change interval may be increased in 250 hour increments. Oil change interval increases are limited to 250 hours with continuous trending of sample results. Consider the effect of upcoming load or operational changes on change intervals before implementing increases.

Oil change intervals can also be increased by the addition of an external sump located either under or adjacent to the engine (see Figures 9 and 10). The preceding trend analysis requirements still apply.

Estimating Oil Consumption

Oil consumption data along with fuel consumption and maintenance information can be used to estimate total operating cost. Oil consumption data may also be used to estimate the quantity of makeup oil required to accommodate maintenance intervals. Many factors can affect oil consumption including load, oil density, oil additive packages, and maintenance practices.

The rate of oil consumption is called BSOC (brake specific oil consumption) and the unit of measure is grams per brake kilowatt hour (g/bkW-hr) or pounds per brake horsepower hour (lb/bhp-hr). The typical BSOC for *new* 3600 engines operating at 100% load factor is 0.486 g/bkW-hr (0.0008 lb/bhp-hr).

Note: *This value can vary significantly due to engine condition, load factor and maintenance practices. Also, with very low consumption measurement methods become difficult and numbers erratic. Therefore, these values can only be used as a guide for make-up oil requirements. The following formula may be used to estimate oil consumption per hour:*

$$\text{L/hr} = \frac{\text{Engine bkW} \times \text{Load Factor (\%)} \times \text{BSOC (g/bkW-hr)}}{\text{Density of Oil*}}$$

$$\text{gal/hr} = \frac{\text{Engine bhp} \times \text{Load Factor (\%)} \times \text{BSOC (lb/bhp-hr)}}{\text{Density of Oil*}}$$

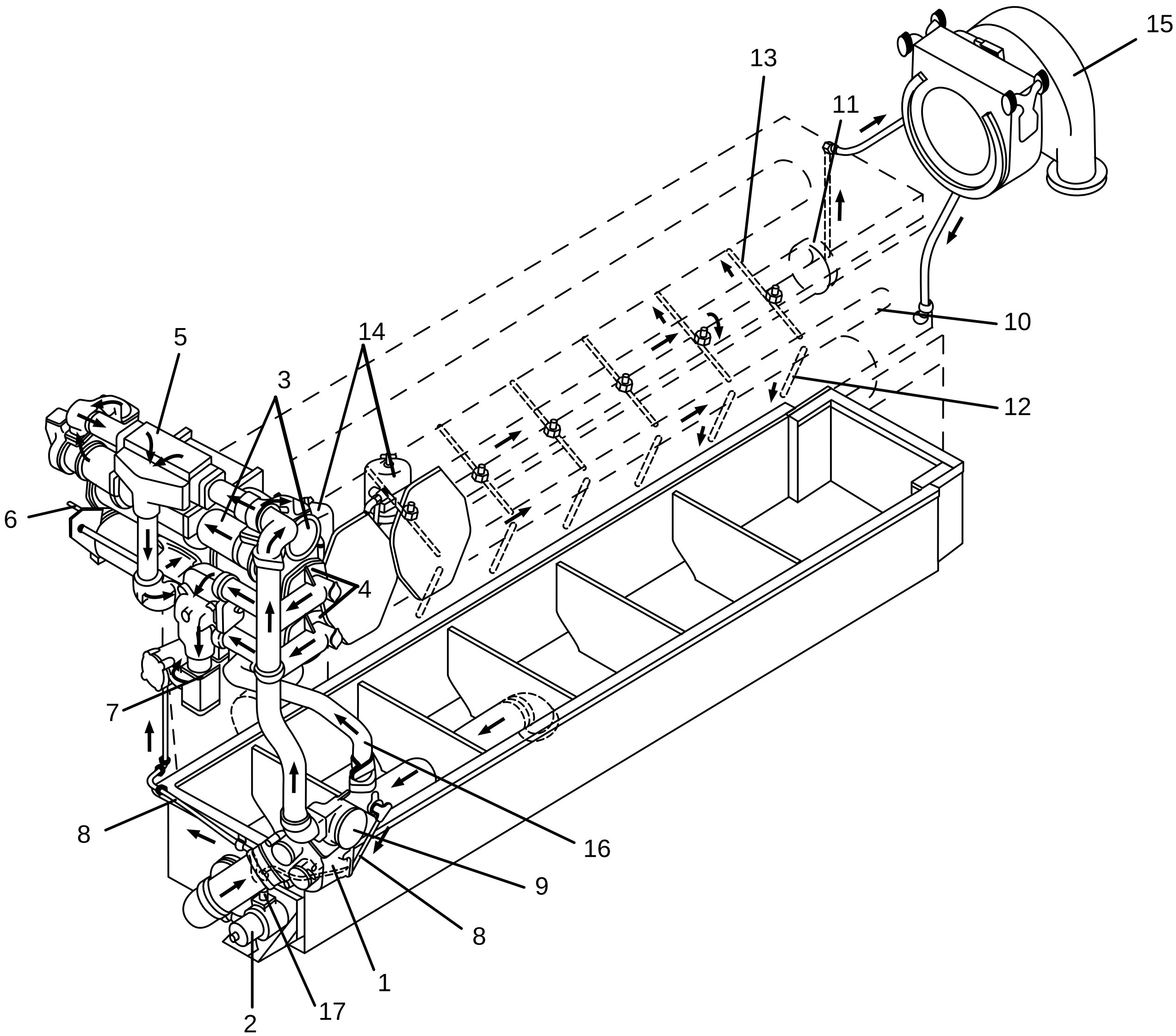
*Typical engine oil has a density of 899 g/L (7.5 lb/gal).

Oil Consumption as an Overhaul Guide

When the oil consumption of an engine has increased to roughly three times the initial (new) consumption due to normal wear, the engine *may* need to be scheduled for overhaul. However, the 3600 engine can easily operate with oil consumption up to 2.2 g/bkW-hr (.0036 lb/bhp-hr) without damage. *The true measure of when to overhaul an engine is performance measured by trend lines of output, specific fuel consumption, and cylinder pressure.* If an engine is still performing at acceptable levels it should not be overhauled. Therefore, to obtain minimum operating cost it is essential to keep trend lines for listed items.

Reference Material

SEBD0640	*Oil And Your Engine*
D2896	*ASTM (American Society of Testing and Materials)*

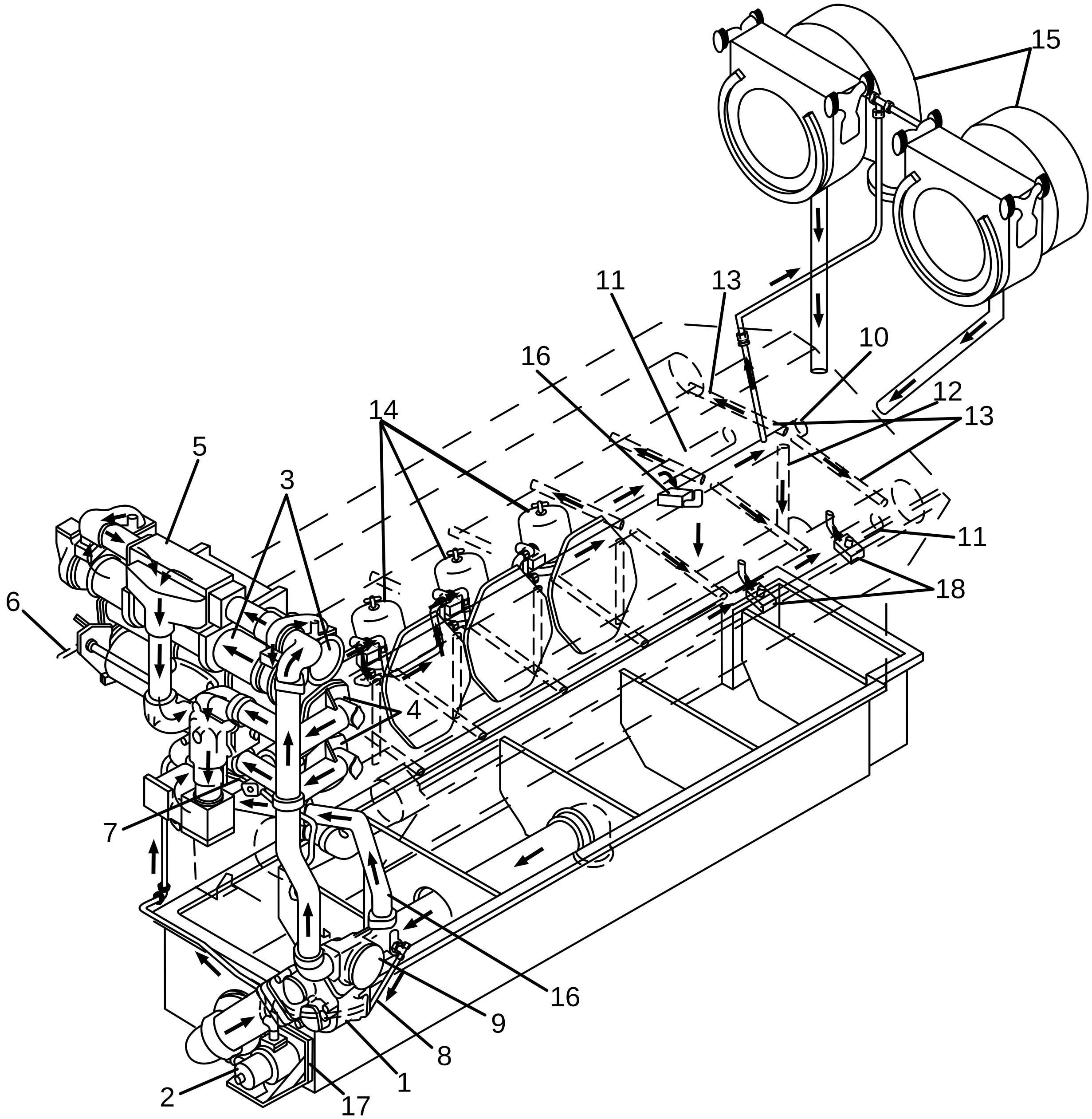


3608 Lube Oil System

1. Oil Pump	**10. Oil Manifold (Oil To Piston Cooling Jets)**
2. Prelube Pump	**11. Oil Manifold (Oil To Bearings)**
3. Oil Coolers	**12. Oil To Main Bearings**
4. Oil Filters	**13. Oil To Camshafts**
5. Oil Thermostat Housing	**14. Centrifugal Filters**
6. Oil Filter Duplex Valve Handle	**15. Turbocharger**
7. Priority Valve	**16. Bypass Oil**
8. Oil To Centrifugal Filters	**17. Check Valve**
9. Emergency Oil Connection	

*** Flow In Opposite Direction During Prelube**

Figure 1



3612 Lube Oil System

1. Oil Pump
2. Prelube Pump
3. Oil Coolers
4. Oil Filters
5. Oil Thermostat Housing
6. Oil Filter Duplex Valve Handle
7. Priority Valve
8. Oil To Centrifugal Filters
9. Emergency Oil Connection
10. Oil Manifold (Oil To Bearing)
11. Oil Manifold (2) (Oil To Piston Cooling Jets)
12. Oil To Main Bearings
13. Oil To Camshafts
14. Centrifugal Filters
15. Turbochargers
16. Bypass Oil
17. Check Valve
18. Piston Cooling Jets

*** Flow In Opposite Direction During Prelube**

Figure 2

Lube Oil System Schematic

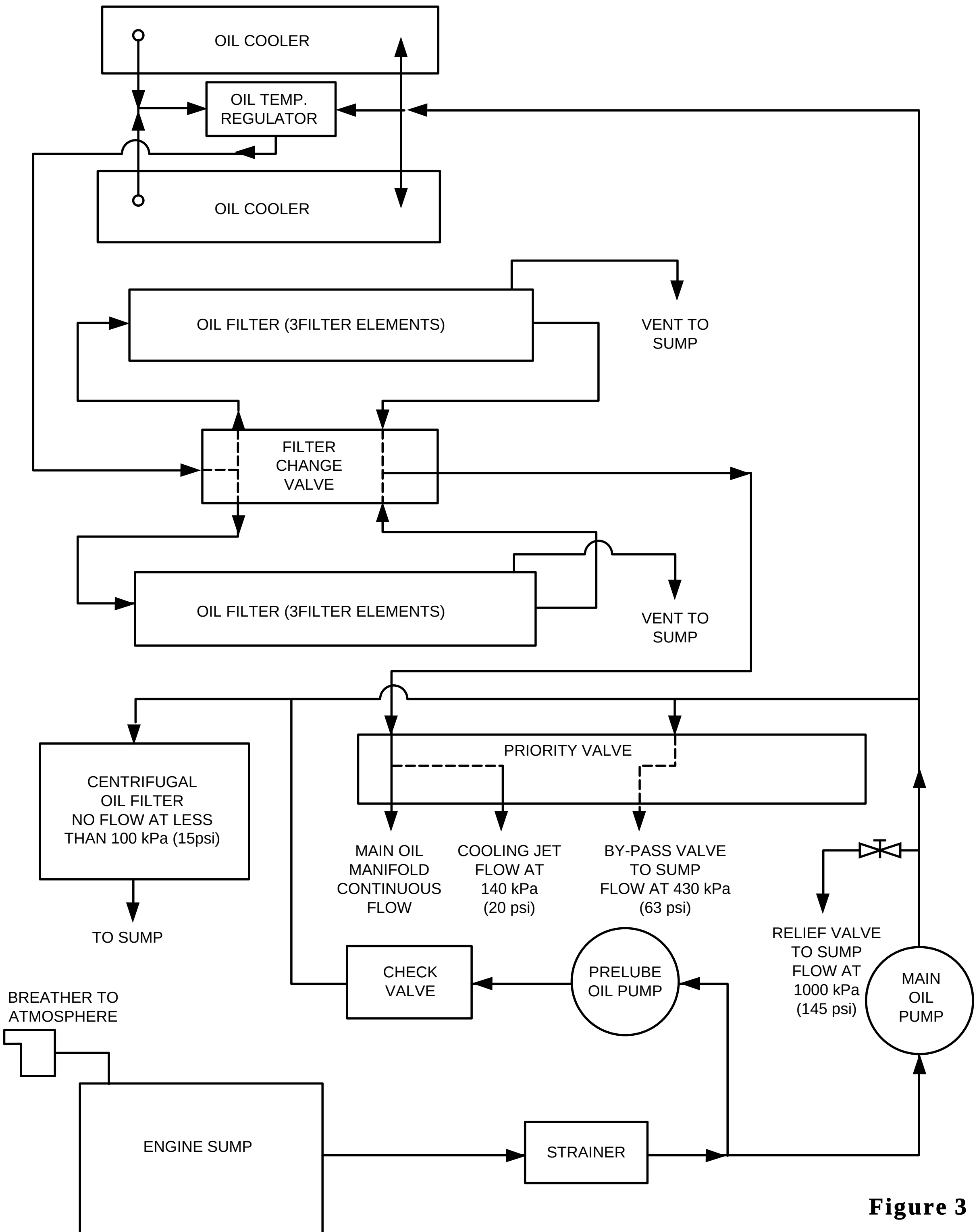


Figure 3

Prelube	Flow	Pressure
Intermittent		
Air	**20 gpm**	**172 kPa**
Electric (110/220 50 Hz)	**17 gpm**	**172 kPa**
Electric (115/230 60 Hz)	**13 gpm**	**172 kPa**
Electric (60-72 VDC)	**16 gpm**	**172 kPa**
Continuous	**6 gpm**	**172 kPa**

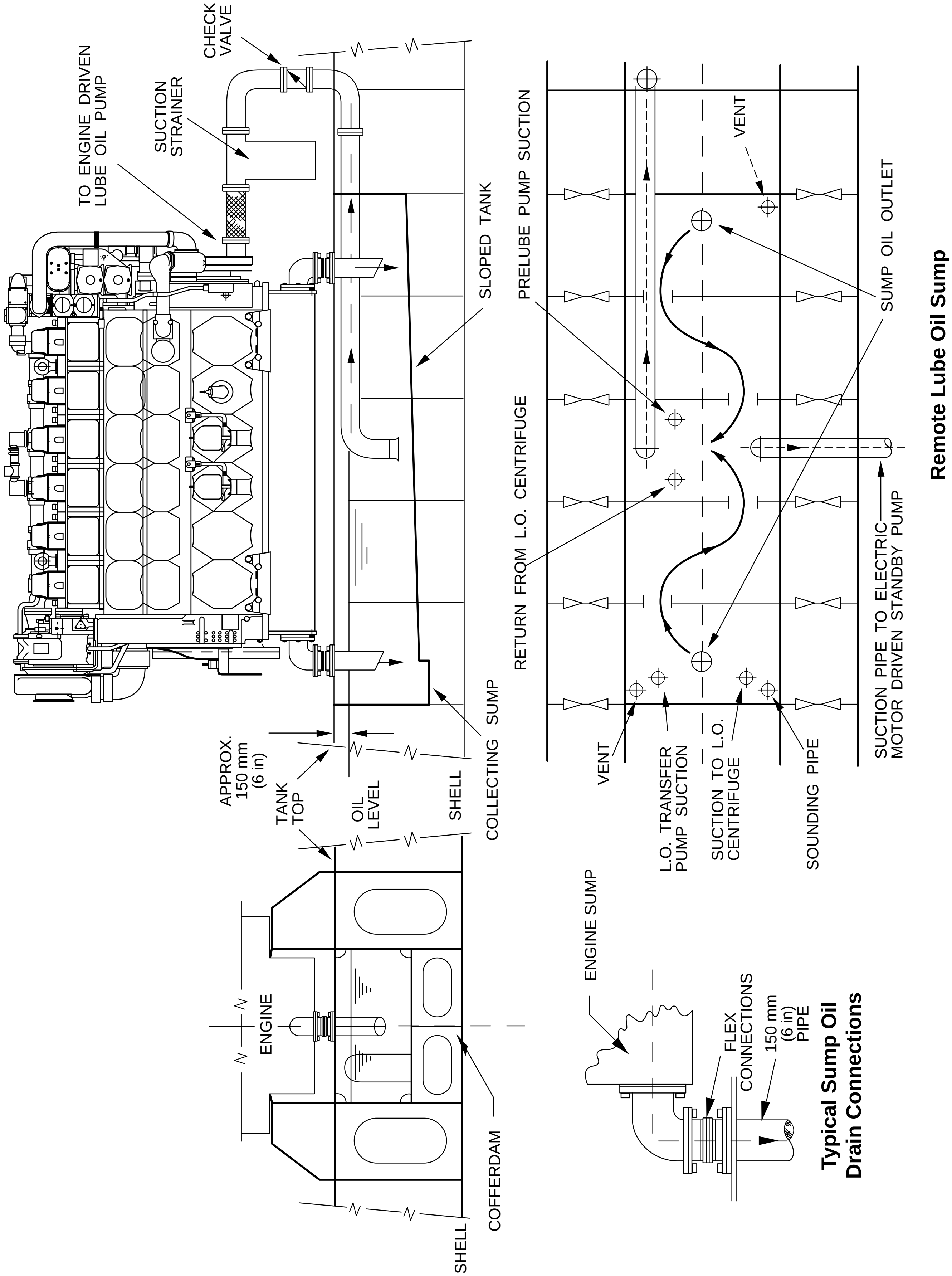
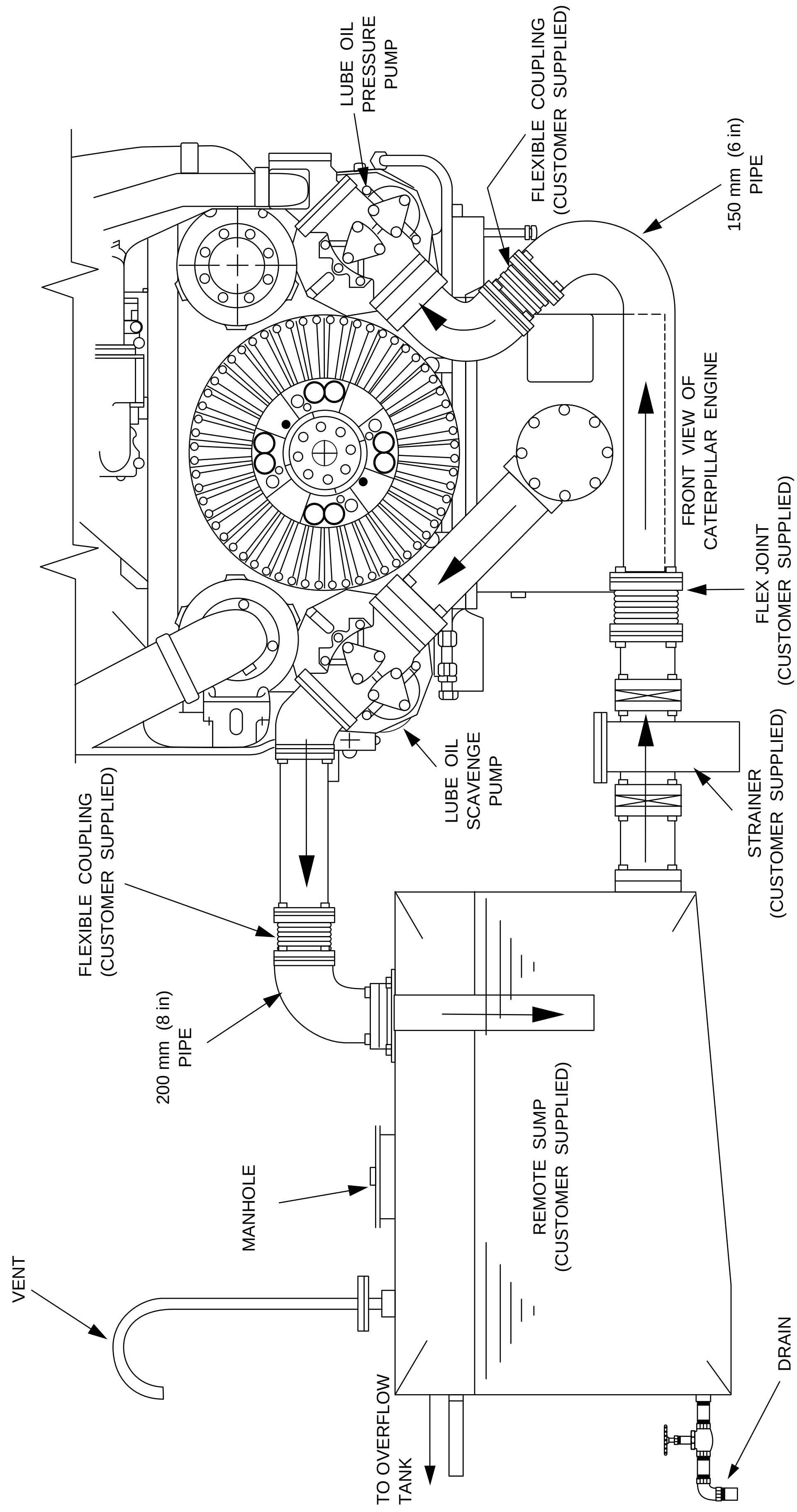
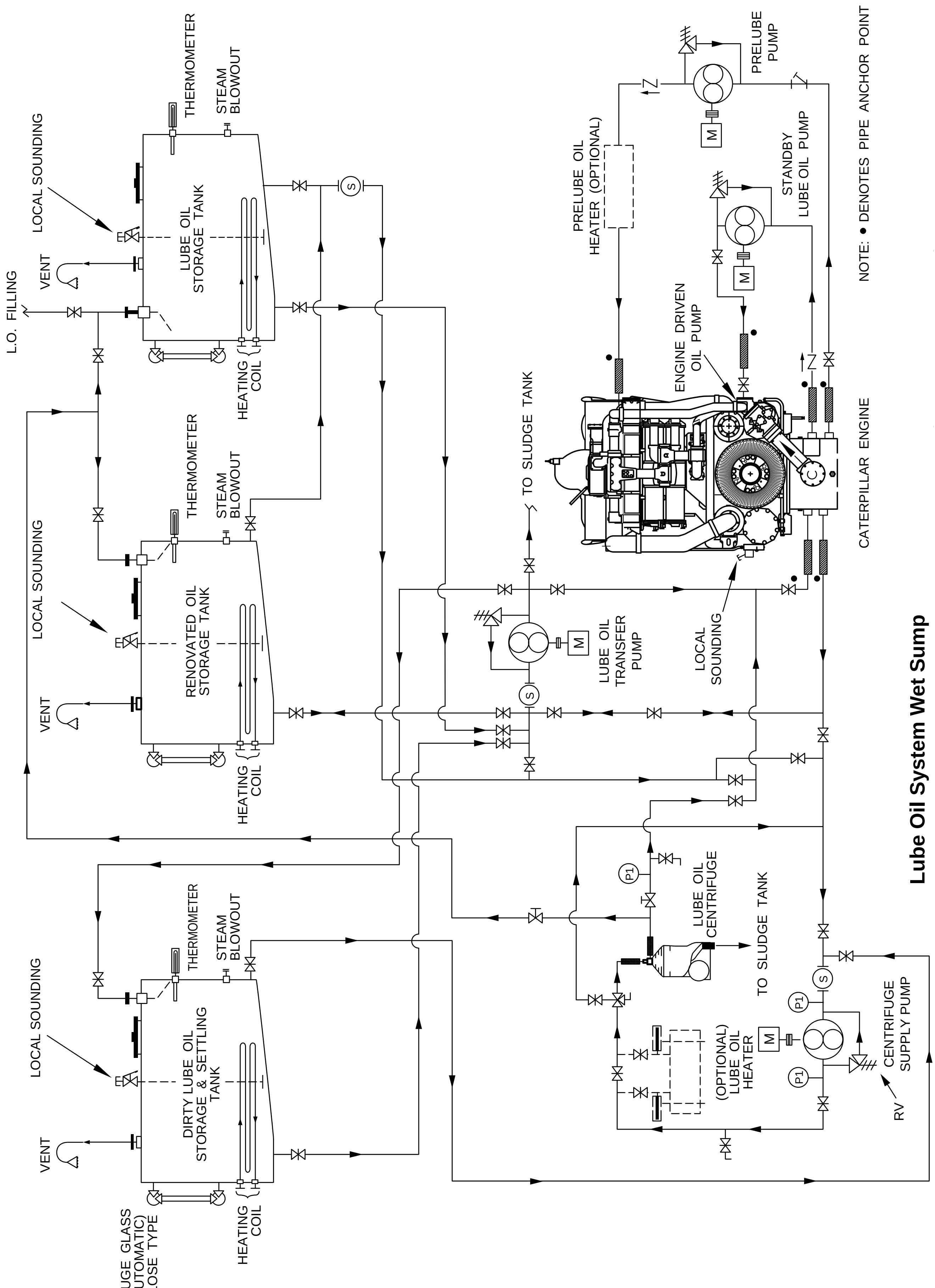

CHECK VALVE
TO ENGINE DRIVEN LUBE OIL PUMP
SUCTION STRAINER
SLOPED TANK
APPROX. 150 mm (6 in)
TANK TOP
OIL LEVEL
SHELL
COLLECTING SUMP
ENGINE
SHELL
COFFERDAM
PRELUBE PUMP SUCTION
RETURN FROM L.O. CENTRIFUGE
VENT
SUMP OIL OUTLET
VENT
L.O. TRANSFER PUMP SUCTION
SUCTION TO L.O. CENTRIFUGE
SOUNDING PIPE
SUCTION PIPE TO ELECTRIC MOTOR DRIVEN STANDBY PUMP
Remote Lube Oil Sump
ENGINE SUMP
FLEX CONNECTIONS
150 mm (6 in) PIPE
Typical Sump Oil Drain Connections

Figure 9



Remote Dry Sump System

Figure 10



Lube Oil System Wet Sump
LUBE OIL STORAGE TANK
RENOVATED OIL STORAGE TANK
DIRTY LUBE OIL STORAGE & SETTLING TANK
L.O. FILLING
VENT
LOCAL SOUNDING
THERMOMETER
STEAM BLOWOUT
HEATING COIL
GAUGE GLASS (AUTOMATIC) CLOSE TYPE
TO SLUDGE TANK
LUBE OIL TRANSFER PUMP
LUBE OIL CENTRIFUGE
(OPTIONAL) LUBE OIL HEATER
CENTRIFUGE SUPPLY PUMP
RV
CATERPILLAR ENGINE
ENGINE DRIVEN OIL PUMP
PRELUBE OIL HEATER (OPTIONAL)
PRELUBE PUMP
STANDBY LUBE OIL PUMP
NOTE: • DENOTES PIPE ANCHOR POINT

Figure 12

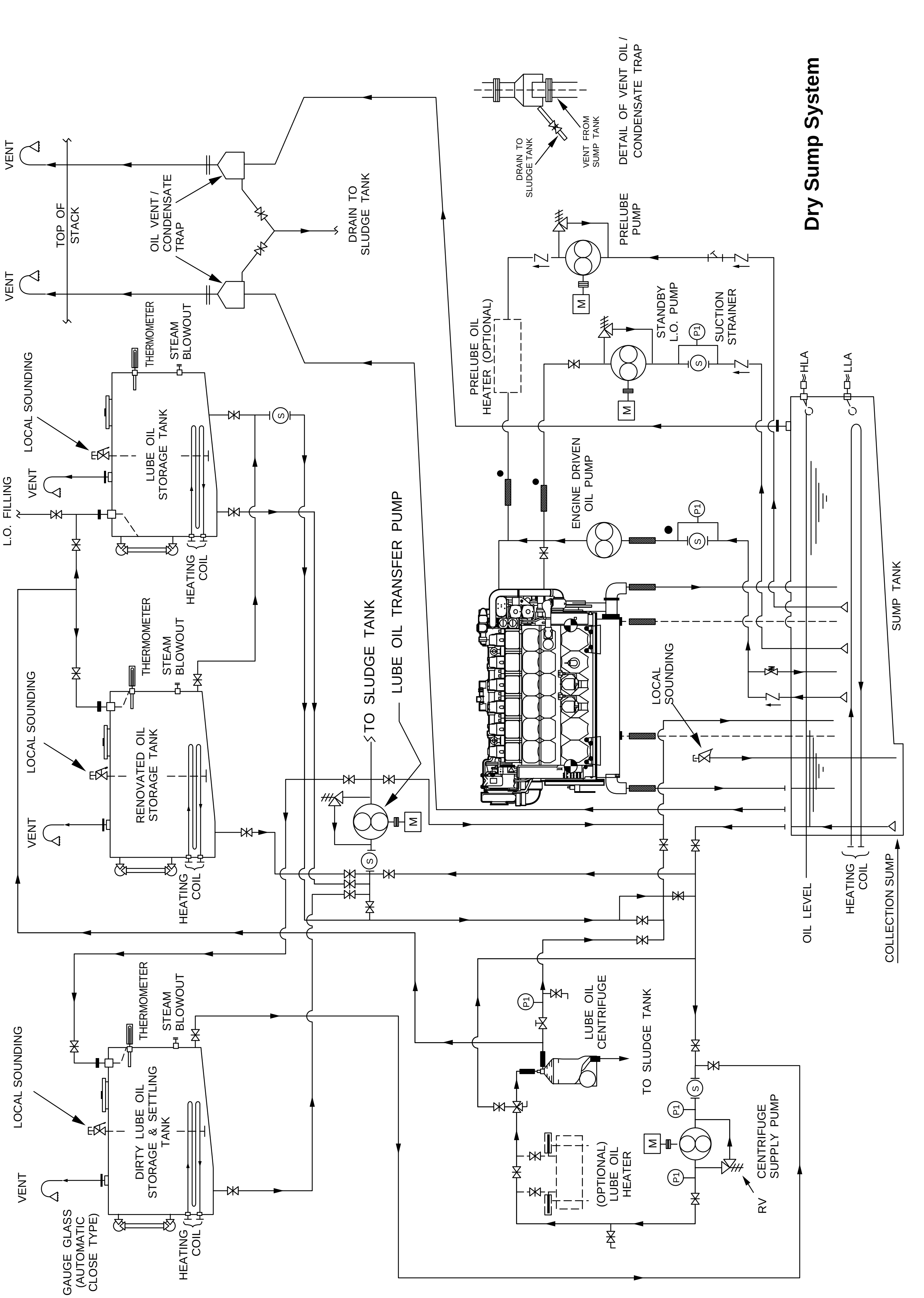

Dry Sump System
VENT
VENT
TOP OF STACK
OIL VENT / CONDENSATE TRAP
DRAIN TO SLUDGE TANK
DETAIL OF VENT OIL / CONDENSATE TRAP
DRAIN TO SLUDGE TANK
VENT FROM SUMP TANK
PRELUBE PUMP
PRELUBE OIL HEATER (OPTIONAL)
M
STANDBY L.O. PUMP
P1
S
SUCTION STRAINER
HLA
LLA
ENGINE DRIVEN OIL PUMP
SUMP TANK
LOCAL SOUNDING
OIL LEVEL
HEATING COIL
COLLECTION SUMP
L.O. FILLING
VENT
LOCAL SOUNDING
THERMOMETER
STEAM BLOWOUT
LUBE OIL STORAGE TANK
HEATING COIL
LOCAL SOUNDING
VENT
THERMOMETER
STEAM BLOWOUT
RENOVATED OIL STORAGE TANK
HEATING COIL
TO SLUDGE TANK
LUBE OIL TRANSFER PUMP
LOCAL SOUNDING
VENT
THERMOMETER
STEAM BLOWOUT
DIRTY LUBE OIL STORAGE & SETTLING TANK
GAUGE GLASS (AUTOMATIC CLOSE TYPE)
HEATING COIL
LUBE OIL CENTRIFUGE
TO SLUDGE TANK
(OPTIONAL) LUBE OIL HEATER
CENTRIFUGE SUPPLY PUMP
RV

Figure 13

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- Fresh Water Cooling
- Sea Water Cooling

LEKM8465 8-98

CATERPILLAR®

Diesel Engine Systems - Fresh Water Cooling

Operating Parameters

Basic operating parameters for the fresh water closed circuit engine cooling system are:

- 32°C (90°F) nominal water temperature to the aftercooler and oil cooler when using distillate or heavy fuel.
- 90°C (194°F) nominal water temperature to the cylinder block circuit on distillate and 93°C (199°F) on heavy fuel.
- 85°C (185°F) nominal oil to bearing temperature.

Marine engine ratings are based on 32°C (90°F) water to the aftercooler and 25°C (77°F) air to the turbocharger.

Marine engines which must operate in sea water temperatures greater than 26°C (79°F) will be allowed to operate without any power deration with water to the aftercooler and oil cooler of 38°C (100°F) maximum. Larger heat exchangers will be required to attain 38°C (100°F) aftercooler/oil cooler water temperatures when sea water temperatures exceed 26°C (79°F), but the benefits will be longer valve, exhaust manifold, and turbocharger life.

Consult the dealer or factory project engineer in those cases where aftercooler/oil cooler water temperatures are expected to exceed the 38°C (100°F) limit.

Basic System Configurations

Two basic closed circuit fresh water cooling systems are used — combined circuit and separate circuit.

The *combined circuit* configuration is also referred to as the single circuit fresh water system. It is typically used for marine and heavy fuel applications where a single heat exchanger is preferred. The aftercooler and oil cooler circuit is externally regulated (fluid inlet temperature control) to *32°C (90°F).* The system uses the aftercooler/oil cooler outlet water to cool a portion of the high temperature outlet water. The block coolant is contained on the engine. Only the water returning to the aftercooler/oil cooler pump requires a cooling source. This results in simple coolant piping installation. Refer to Figure 1 for a typical combined circuit flow diagram. An in-line engine is shown in Figure 2 and a vee engine in Figure 3. Figure 4 is a piping schematic for the combined circuit system. *(Refer to pages 33 through 36 for illustrations.)*

Figure 5, page 37, is a diagram for a two step inlet air temperature control system for continuous heavy fuel applications. See the *Heavy Fuel* section for further details.

The *separate circuit* cooling system shown in Figures 6, 7, and 8 is available for marine applications. It is normally used for keel cooled or radiator cooled installations to reduce the external cooling package size. *(Refer to pages 38-40 for illustrations.)*

Engine Coolant Flow Control

The correct coolant flows are provided by factory installed orifices combined with external circuit resistance (set at each site). The orifices are sized to provide proper flow splits and pressure levels to engine components (aftercooler, oil cooler, cylinder block, cylinder heads, and turbochargers). The external resistance setting is critical. It establishes total circuit flow by balancing total circuit losses with pump performance curves. Set it with an adjustable, lockable valve or orifice in customer piping. Measure external circuit resistance with blocked open regulators to assure all flow is passing through the external circuit. *The valve used to set the resistance must not use elastomer seat material.*

Typical factory and customer orifice locations are shown in Figure 1 for a combined system and Figure 6 for a separate circuit system.

Temperature Regulation

Inlet control temperature regulators are used on the jacket water and aftercooler/oil cooler (AC/OC) coolant and lube oil circuits. The standard regulator characteristics are shown below. Some marine societies require coolant temperature regulators to have a manual override capability. In these cases the standard Caterpillar regulator is not acceptable and another supplier must be used.

	Start-Open Temp °C (°F)	Full-Open Temp °C (°F)	Nominal Temp °C (°F)
AC/OC Circuit*:			
Distillate and Heavy Fuel	27 (81)	37 (99)	32 (90)
Two Step Control	(at low load)		75 (167)
JW Circuit**:			
Distillate Fuel	85 (185)	95 (203)	90 (194)
Heavy Fuel	88 (190)	98 (208)	93 (199)
Lube Oil Circuit:	76 (169)	89 (192)	83 (181)

* Dual temperature control may be required on heavy fuel applications. See “Heavy Fuel” in the “Engine Systems” section of this guide.
** Minimum allowable inlet water temperature is 83°C (181°F) on distillate fuel and 85°C (185°F) on heavy fuel.

Heat recovery circuits usually require an external regulator to prevent over-cooling the engine. If the heat recovery circuit uses less than 30% of the available jacket water heat load, then an external regulator is not required. If used, the heat recovery regulator must have a start-to-open temperature 5°C (9°F) lower than the jacket water circuit regulator. See *Heat Recovery* within this section.

Regulator mounting location depends on the cooling system type and engine package configuration. If an expansion tank is mounted on an accessory module in front of the engine, the regulator may be mounted on the tank. See the table below for typical Caterpillar regulator mounting locations. Regulators supplied by other suppliers are usually mounted in the shipyard piping.

Water Pumps

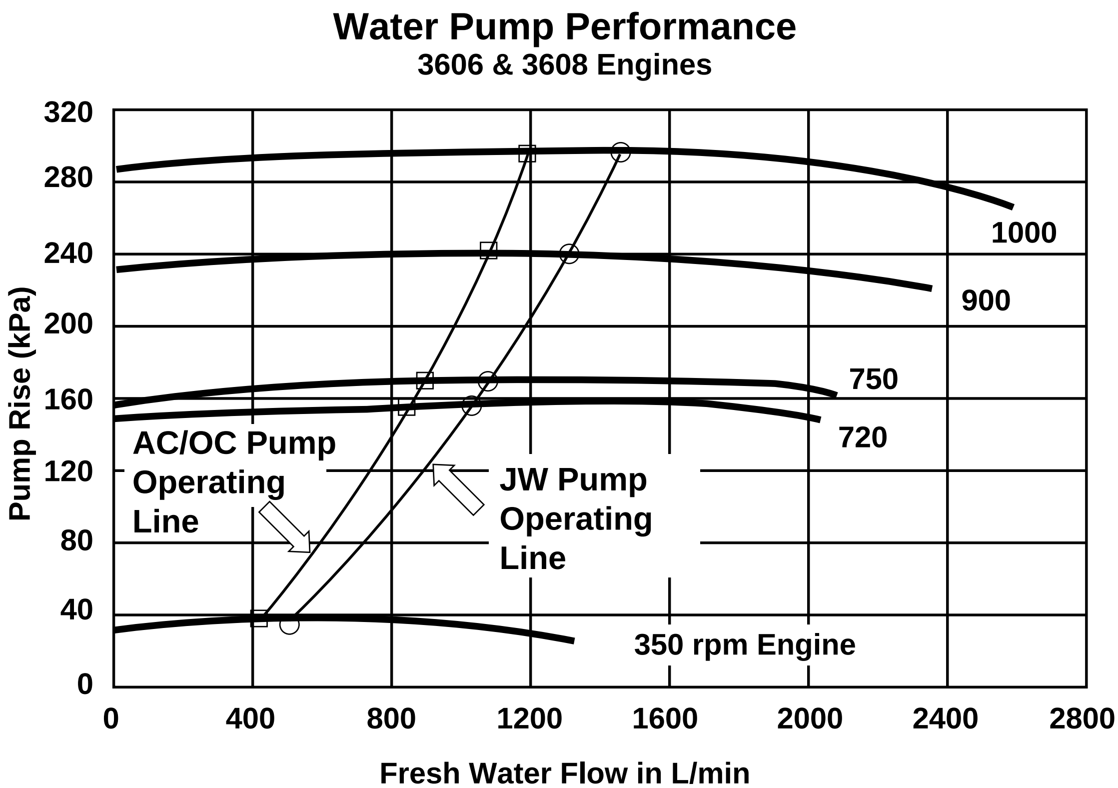
All engines have two engine driven fresh water pumps mounted on the front engine housing. The right hand pump (viewed from the flywheel end) supplies coolant to the cylinder block, cylinder heads, and turbocharger. The left hand pump supplies coolant to the aftercooler and oil coolers. Complete pump performance curves at various pressure heads are shown in Figure 9. An engine driven raw water pump is available and is gear driven off the front of the engine. See Figure 46 in the *Engine Performance* section for raw water pump power requirements.

Some applications will require standby pumps. Electrically driven standby pumps are shown in Figures 4 and 5 and are also included in the following description.

Standby Pumps

Typically an electric standby pump is required to parallel each engine driven pump for single engine marine propulsion applications to meet marine society requirements. Two fresh water pumps are required for standby, or emergency, service. One parallels the engine driven high temperature jacket water circuit. The other parallels the engine driven low temperature AC/OC circuit. Each external circuit must be isolated from the engine by check or shutoff valves.

Cooling System	Expansion Tank Location	JW Regulator Location	AC/OC Regulator Location	Oil Regulator Location
Combined	Module	Engine	Exp. Tank	Engine
Combined	Remote	Engine	Exp. Tank or Remote	Engine
Sep. Circuit	Module	Exp. Tank	Remote (in piping)	Engine
Sep. Circuit	Remote	Remote	Remote (in piping)	Engine


Water Pump Performance
3606 & 3608 Engines
320
280
240
200
160
120
80
40
0
Pump Rise (kPa)
0
400
800
1200
1600
2000
2400
2800
Fresh Water Flow in L/min
1000
900
750
720
AC/OC Pump Operating Line
JW Pump Operating Line
350 rpm Engine

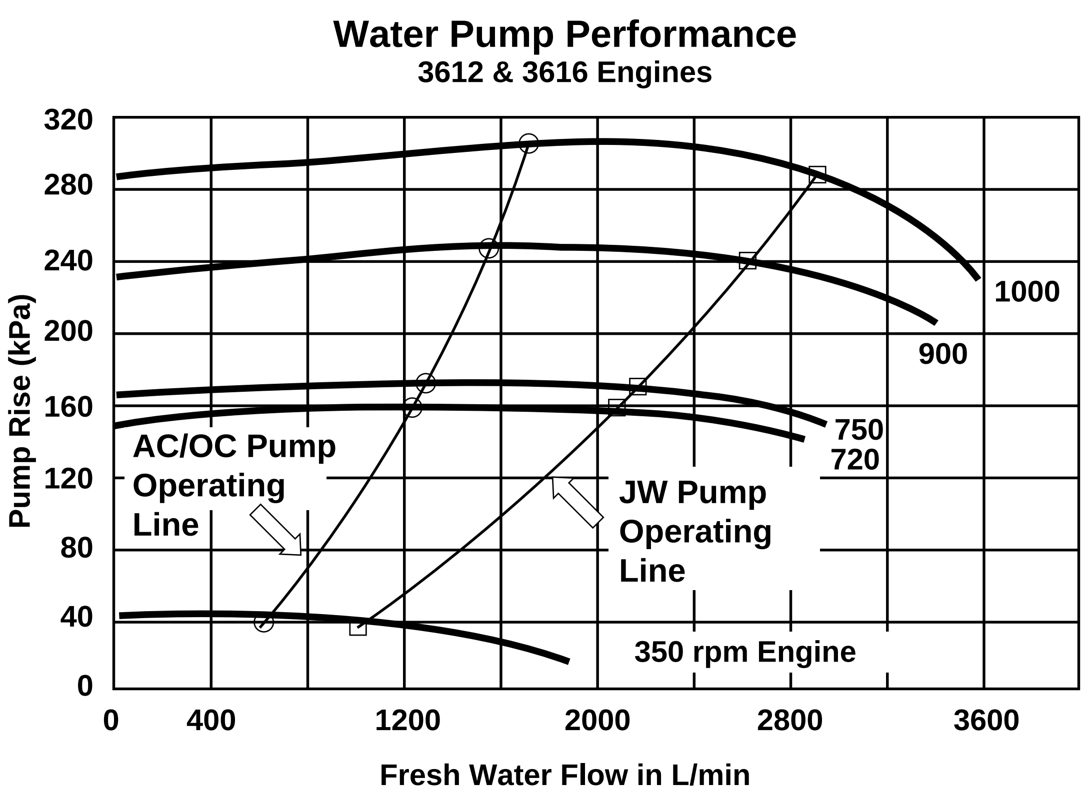

Water Pump Performance
3612 & 3616 Engines
320
280
240
200
160
120
80
40
0
Pump Rise (kPa)
0
400
1200
2000
2800
3600
Fresh Water Flow in L/min
1000
900
750
720
AC/OC Pump Operating Line
JW Pump Operating Line
350 rpm Engine

Figure 9

Install a water pressure low alarm contactor at the discharge of the engine driven pump to control the operation of the standby motor driven pump. The standby pump should start automatically if the engine driven pump discharge pressure falls below 120 kPa (17.4 psi). The control configuration should be arranged to operate only when the engine is running. Additionally, the contactor should be tied into the oil step function of the speed switch so that the standby pump can only operate above 75% of rated speed. This is because the engine driven pump pressure may be lower than the alarm set point at low engine speeds, but the pump pressure is still sufficient to cool the engine and the standby pump is not required.

Flow Requirements

Standby pump flow requirements must match the engine driven pump it is to replace. See the following table for pump requirements.

Watercooled manifolds are not used and there is no direct heat rejection from exhaust manifolds to the coolant. Jacket water heat rejection on 3600 Engines always refers to the sum of the block, head, and turbocharger.

Nominal values for heat rejection, coolant flows, and temperatures are shown in the *Engine Data* section. For the most current data always consult the TMI System.

Aftercooler Correction Factors

Heat rejection correction factors for the aftercooler can be calculated for various ambient air and cooling water temperatures (see Figure 10). A typical correction factor for 45°C ambient air and 32°C water to the aftercooler would be approximately 1.2 times the nominal aftercooler heat rejection valve in the Engine Data section of this guide.

Heat Rejection Tolerances

Coolant Flow = ±10%
Heat Rejection = ±10%

	AC/OC Pump @ 32°C				JW Pump @ 90°C			
	Flow L/min	gpm	Rise kPa	psi	Flow L/min	gpm	Rise kPa	psi
3606/3608:								
1000 rpm	1200	317	295	42.8	1460	385	295	42.8
900 rpm	1080	285	240	34.8	1315	347	240	34.8
750 rpm	900	238	170	24.7	1095	289	170	24.7
720 rpm	860	227	160	23.2	1050	277	160	23.2
3612/3616:								
1000 rpm	1730	457	305	44.3	2920	771	290	42.1
900 rpm	1560	412	245	35.6	2630	694	240	34.8
750 rpm	1300	343	170	24.7	2190	578	170	24.7
720 rpm	1250	330	160	23.2	2100	554	155	22.5

The recommended materials for the standby pumps are:
- Casing — Cast Iron
- Impeller — Bronze
- Shaft — Stainless Steel
- Seal — Mechanical

For emergency pump connection locations and sizes see Figure 4 (combined circuit).

Heat Rejection

Heat rejection to engine coolant comes from the cylinder block, cylinder heads, watercooled turbocharger turbine housing, aftercooler, and oil cooler.

The tolerances account for engine-to-engine variation, test data accuracy, repeatability, and scatter. The heat rejection tolerance band does *not* account for on-site conditions such as ambient air temperature. Tolerance guidelines are as follows:

Heat Exchanger Tolerances

Base heat rejection capacity on the high side of the tolerance band, i.e., +8% to +10%. This tends to assure normal engine operating temperatures and compensates for unexpected fouling situations.

AfterCooler Heat Rejection
Correction Factors for Water and Ambient Air Temperature

NOTE: Applicable At or Near Rated Load Only.

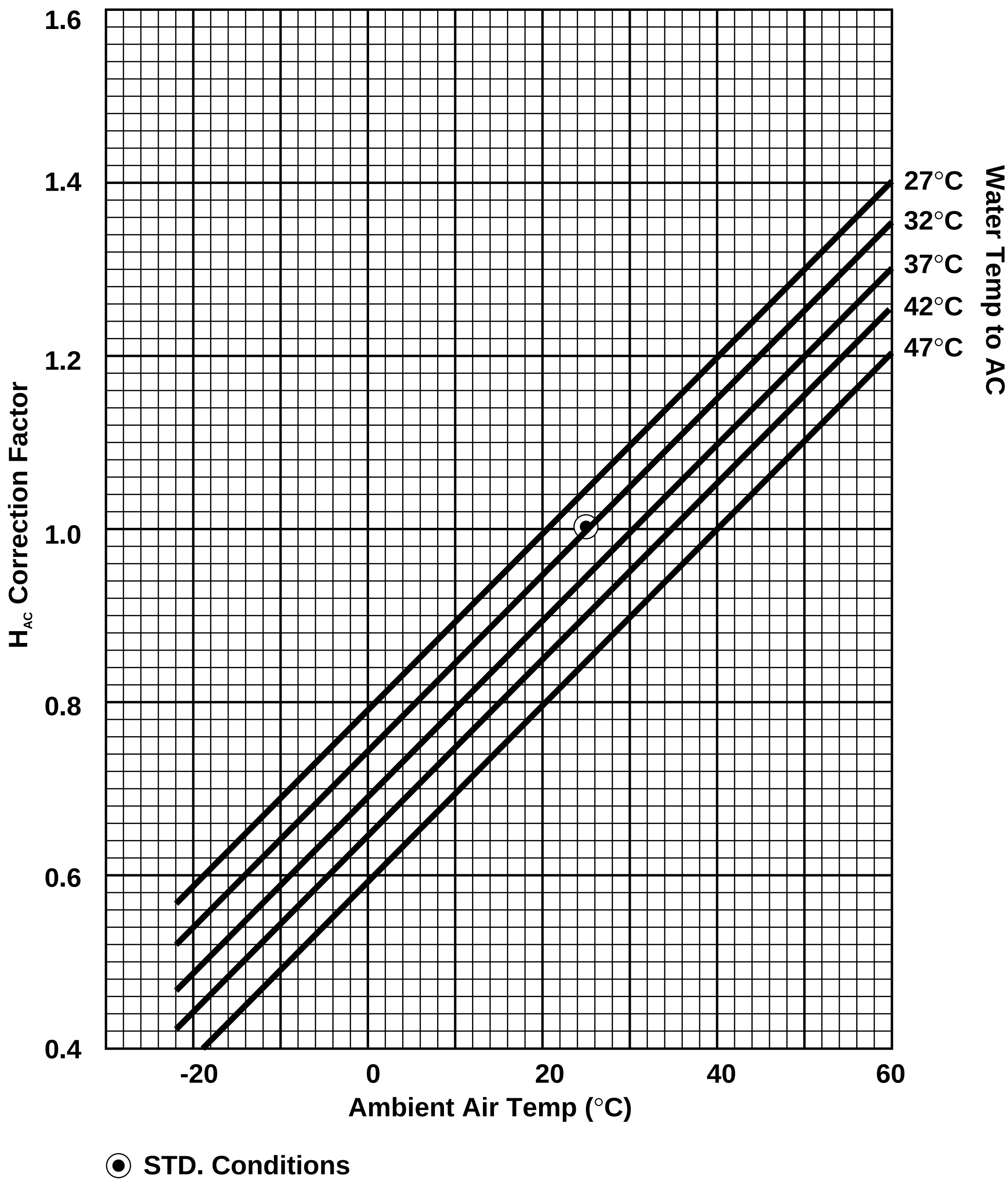


Figure 10

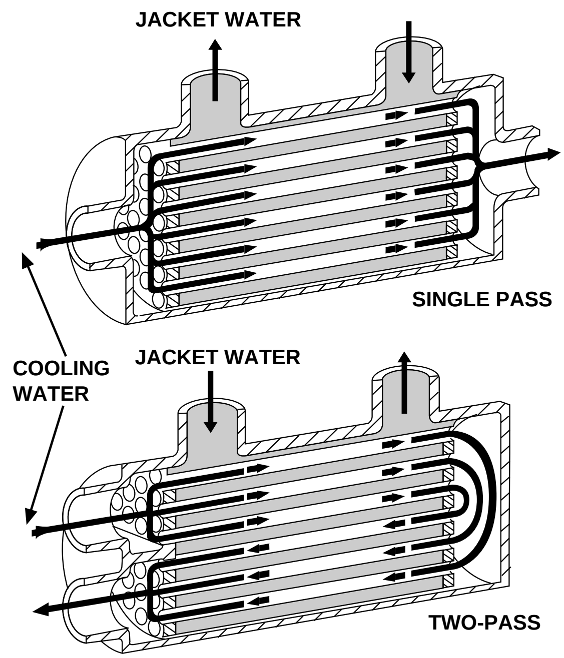
Heat Recovery Unit Tolerances
Assume recoverable heat available is at the lower end of the tolerance zone, i.e., -8% to -10%. This adjusts for the regulator control system characteristics and convection/radiation losses from the piping. See *Heat Recovery* in this section of the guide.

Heat Exchanger

The Caterpillar shell and tube type heat exchangers provide compact, reliable, and cost effective cooling. Since heat exchanger tubes can be cleaned easily, raw water is usually routed through tubes and engine coolant through the shell. The flow in the raw water section is either single-pass or two-pass (see Figure 11). A two-pass type flows raw water twice through the exchanger; single-pass types use raw water only once. To provide maximum temperature differential and heat transfer in single-pass exchangers, the raw water flows opposite to coolant flow. The direction of flow is not important in two-pass exchangers.

If the raw water contains debris, use strainers to prevent tube plugging. In cases of extreme silt contamination or abrasive materials, consider a back-flush filter. Some raw water sources contain high levels of impurities or hardness which accelerate heat exchanger fouling. More frequent heat exchanger cleaning will be required if treatment is not practical.

Heat exchanger performance depends on raw water flow and temperature differential. Orifices or fixed valves must be used to limit raw water velocity and avoid tube erosion. Do not use temperature regulators in the raw water circuit. Engine jacket water is thermostatically controlled and additional controls add expense, cause restriction, and decrease reliability.



Heat Exchanger Types

Figure 11

Heat Exchanger Sizing
Combined Circuit:
The heat exchanger should be sized using a maximum coolant temperature at the AC/OC pump inlet of 38°C (100°F) for all Marine engines. The heat exchanger sizing must also consider the maximum expected ambient air temperature, maximum engine power (rack stop power), maximum expected raw water temperature, and 10% margin for a fouling and safety factor. Consult a project engineer if the vessel will operate in sea water temperatures greater than 32°C (90°F). It is impractical to purchase heat exchangers which are sized for less than a 6°C (11°F) differential between sea water and AC/OC water.

Separate Circuit:
There are two heat exchangers required for separate circuit cooling systems, one for the engine jacket water circuit and one for the AC/OC water circuit. The jacket water heat exchanger should be sized using a maximum coolant temperature at the jacket water pump inlet of 93°C (199°F) for heavy fuel engines, and 90°C (194°F) for distillate fuel engines. The jacket water heat exchanger sizing must also consider maximum engine power (rack stop power), maximum expected raw water temperature, and 10% margin for a fouling and safety factor.

The AC/OC heat exchanger should be sized using a maximum coolant temperature at the AC/OC pump inlet of 38°C (100°F) for all marine engines. The AC/OC heat exchanger sizing must also consider the maximum expected ambient air temperature, maximum engine power (rack stop power), maximum expected raw water temperature, and 10% margin for a fouling and safety factor. See the previous note on combined circuit heat exchanger sizing if sea water temperature is greater than 32°C (90°F).

Separate circuit cooling systems are most commonly used in applications where keel coolers or radiators are used as the heat exchangers, to keep the equipment size to a minimum.

Expansion Tanks

Caterpillar expansion tanks provide:
- Expansion volume for coolant
- Coolant level alarm
- Single filling location
- Pressure cap & vent
- Coolant sight gauge
- Deaeration chamber
- Thermostat mounting
- Drain
- Positive pump inlet pressure

Caterpillar offers two expansion tanks. The smaller tank has an expansion volume of 75 L (20 gal) and the larger tank has 245 L (65 gal). Calculations can determine if an auxiliary expansion tank is required.

Two tank arrangements can be provided by Caterpillar as follows:

Standard Volume Tank - For use with cooling systems whose total volume is up to 1500 L (400 gal), assuming a 4.4°C (40°F) fill water temperature.

High Volume Tank - For use with cooling systems whose total volume is up to 5700 L (1500 gal), assuming a 4.4°C (40°F) fill water temperature.

Figures 12 and 13 on page 13 show the two Caterpillar expansion tanks that are available.

Two possible methods of arranging the expansion tank in the cooling system are the full flow system and shunt type system. The most important point with either system is to ensure that air entrained in the coolant is removed to prevent pump cavitation and cavitation erosion of internal engine components. Deaeration of the coolant requires a low velocity area. In either case, locate the expansion tank to prevent vacuum formation. *The water level in the tank should be the highest point in the cooling circuit at any ship attitude.*

With the full flow system, the entire flow of coolant passes through the expansion tank via a regulator mounted on the tank. This allows air to be removed from the coolant because the tank has internal baffles that slow the water flow down to 0.6 m/sec (2 ft/sec). The full flow system provides a single fill point in both the combined and separate circuit systems. A make-up line between the two circuits is required on the separate circuit system (see Figure 6). The full flow system is usually used when the expansion tank is located near the front of the engine.

With the shunt type system, the expansion tank is connected to the cooling system by one smaller pipe that maintains a static head on the cooling system. Separate vent lines must be run from each system high point to the expansion tank to remove entrained air from the coolant. A deaerator chamber must also be installed at the coolant outlet from the engine. The deaerator removes entrained air from the coolant and a port in the top of the chamber is used to connect to the expansion tank. Figure 5 shows a shunt type cooling system used in a heavy fuel engine two step cooling system.

The shunt type system is used in applications where the expansion tank cannot be located near the front of the engine. In this case the expansion tank is mounted remotely (usually on the next deck up from the engine level), and only a few small connection lines to the tank are required for vents and the static head connection. This prevents the need for running large coolant pipes over long distances through the engine room. The coolant regulator is mounted separately from the expansion tank in a place convenient for the builder.

Expansion Tank Volume

Expansion tanks must provide adequate volume for coolant expansion plus reserve. Total cooling system volume must be known to determine the minimum acceptable expansion tank size. The total volume is the engine coolant volume plus the volume of all external (customer supplied) circuits. Volume data is shown in Figures 12 and 13 for the engine, full Caterpillar standard and high volume expansion tanks, tank piping and the Caterpillar supplied shell and tube heat exchanger.

The required expansion volume is calculated as follows:

Required Expansion Volume =
(Total System Volume) x
(Expansion Rate)

The expansion rate depends on the coolant mixture being used, and can be determined from the curves shown in Figure 14 on page 14.

Some installations will use the Caterpillar supplied heat exchanger and factory piping. In those cases, the volume of all external piping must be calculated. The minimum reserve capacity is determined from the following table:

	Total External Circuit Volume	Minimum Reserve Capacity
≤	50% of Engine Coolant Volume	10% of Total System Volume
	60% of Engine Coolant Volume	9% of Total System Volume
	70% of Engine Coolant Volume	8% of Total System Volume
	80% of Engine Coolant Volume	7% of Total System Volume
	90% of Engine Coolant Volume	6% of Total System Volume
≥	100% of Engine Coolant Volume	5% of Total System Volume

The minimum acceptable expansion tank volume is:
Minimum Tank Volume = (Expansion Volume) + (Minimum Reserve Capacity)

Expansion Tank Standard Volume 75 L (20 gal)

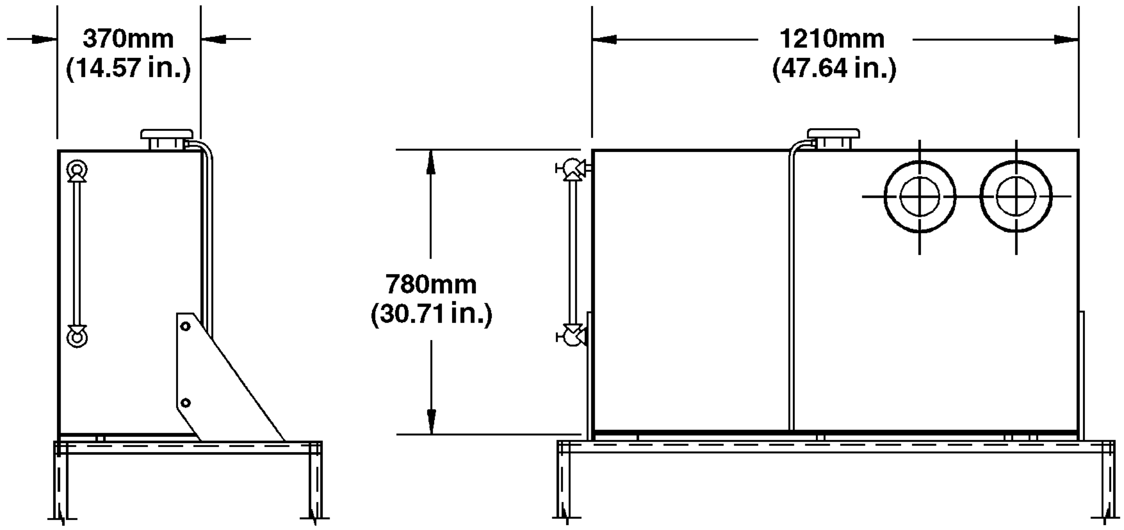


Figure 12

Expansion Tank High Volume 245 L (65 gal)

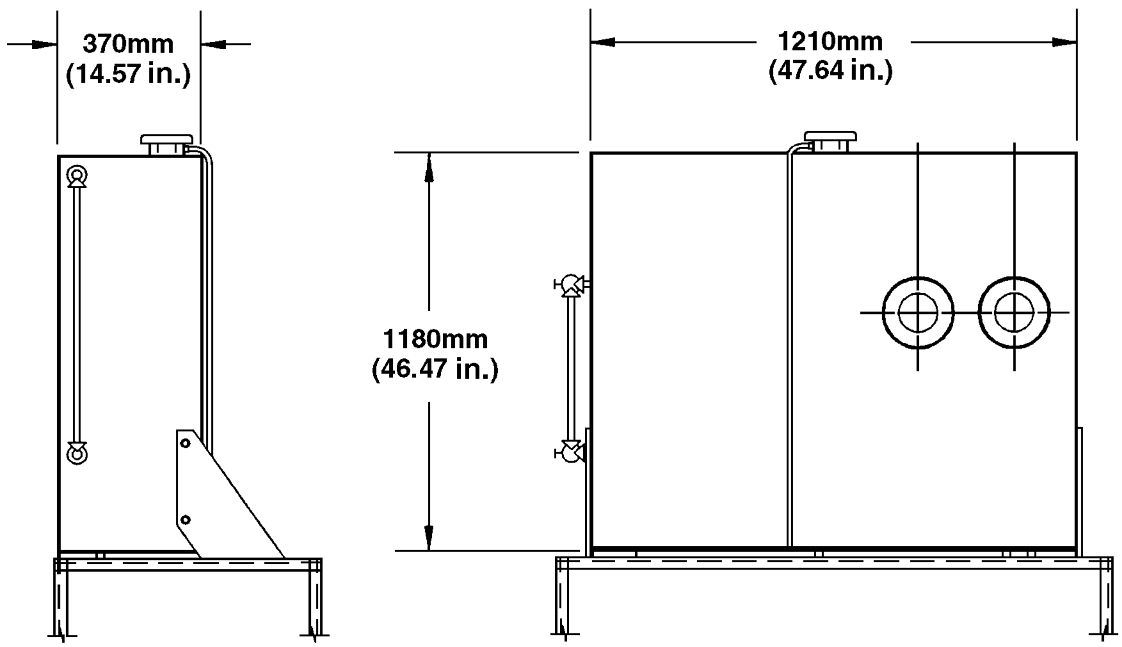


Figure 13

Engine	Engine Coolant Volume	Expansion Tank Standard Capacity	Expansion Tank Increased Capacity	Expansion Tank Piping	Heat Exchanger
		Liters (kg)			
3606	400 (400)	300 (300)	475 (475)	150 (150)	50 (50)
3608	530 (530)	300 (300)	475 (475)	150 (150)	50 (50)
3612	800 (800)	300 (300)	475 (475)	200 (200)	100 (100)
3616	1060 (1060)	300 (300)	475 (475)	200 (200)	100 (100)
Engine		U.S. Gallons (lb)			
3606	105 (875)	80 (667)	125 (1042)	40 (333)	15 (125)
3608	140 (1167)	80 (667)	125 (1042)	40 (333)	15 (125)
3612	210 (1751)	80 (667)	125 (1042)	55 (333)	30 (250)
3616	280 (2334)	80 (667)	125 (1042)	55 (333)	30 (250)

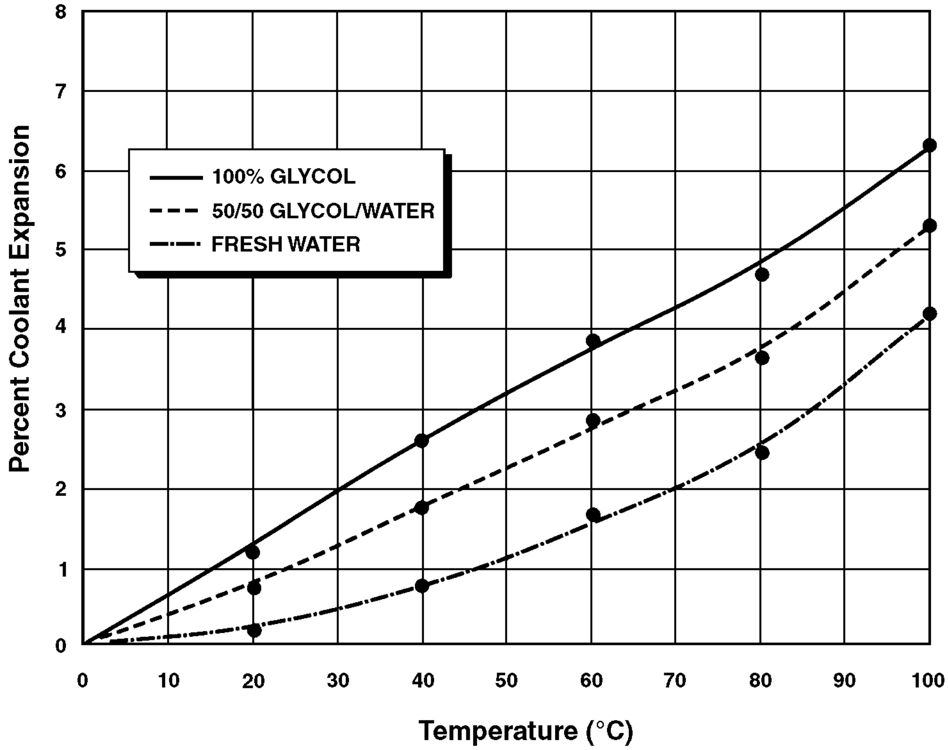


Figure 14

System Pressures

The following pressure limits apply to all 3600 Diesel Engines:

Water Pump Pressures:

Maximum Allowable Static Head ....145 kPa (15 m H_20)

Minimum AC/OC Pump Inlet (Dynamic).......................-5 kPa (-0.5 m H_20)

Minimum JW Pump Inlet (Dynamic)* ....30 kPa (3.0 m H_20)

Minimum Raw Water Pump Inlet (Dynamic) ....-5 kPa (-0.5 m H_20)

Maximum Operating Pressures:

Engine Cooling Circuits........500 kPa (51 m H_20)

Caterpillar Expansion Tanks....................................150 kPa (15.3 m H_20)

Caterpillar Heat Exchangers...............1000 kPa (102 m H_20)

Radiators/Non-Cat Heat Exchangers ....(Contact Supplier)

* Acceptable jacket water pump inlet pressures are achieved on combined cooling systems by maintaining the correct external circuit resistance.

External Circuit Resistance

The method used to set external circuit resistance depends on cooling system geometry.

Method No. 1: Used when the cooling circuit includes the Caterpillar expansion tank and regulators mounted on the front module assembly (full flow system). External pressure drop is measured from the engine outlet to the cold flow entrance at the regulator housing. Measure both pressures as close to the same elevation as possible (see Figure 15 and table at right).

Method No. 2: Used when the cooling circuit includes a remote-mounted expansion tank and remote regulators (shunt type system). External pressure drop is measured from the engine outlet to the pump inlet. Make pressure measurements at the corresponding outlet and inlet elevations (see Figure 16).

rpm	ΔP (P_1-P_2) kPa (psi)
1000	90 (13)
900	73 (11)
750	51 (7.5)
720	47 (7)
Tolerance:	±10%

The above external resistance settings must be made with blocked-open regulators to assure full heat exchanger flow. Refer to Engine Data Sheet 50.5, "Cooling System Field Test".

A lockable plug valve is preferred for setting external resistance. A plate type orifice or other adjustable valve may be used, but it must not include an elastomer seal element.

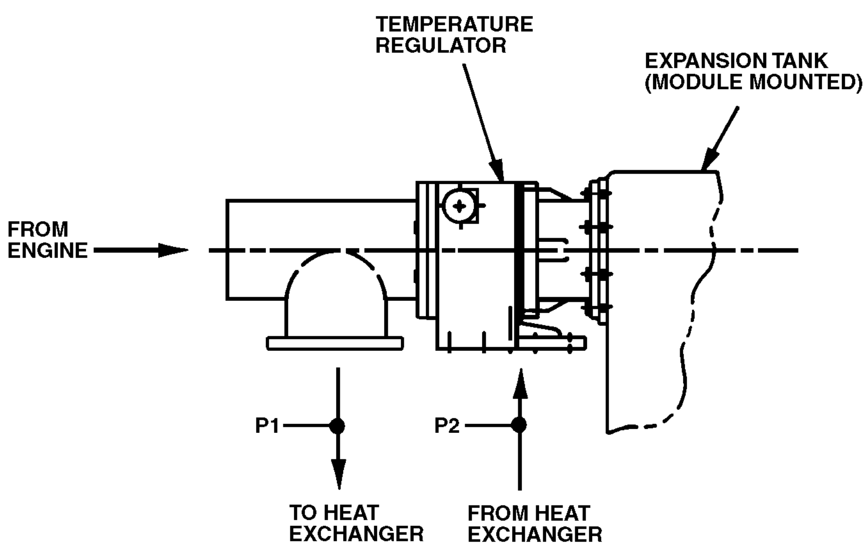
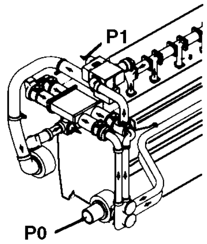


Figure 15

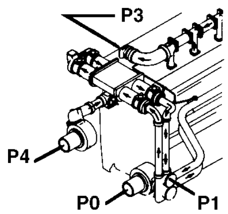
3606 and 3608 Combined Circuit

External Circuit Resistance, kPa (psi)



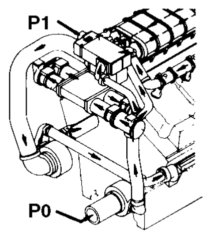
Engine Speed rpm	Low Temperature Circuit ∆ P (P1-P2)	High Temperature Circuit ∆ P (P3-P4)
1000	91 (13)	—
900	71 (10)	—
750	45 (6.5)	—
720	40 (5.8)	—
Tolerance:	± 10%	—

3606 and 3608 Separate Circuit



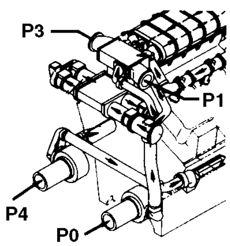
1000	104 (15)	99 (14)
900	84(12)	77 (11)
750	58 (8)	50 (7)
720	52 (7.5)	44 (6)
Tolerance:	± 10%	± 10%

3612 and 3616 Combined Circuit



1000	85 (12)	—
900	66 (9.6)	—
750	42 (6)	—
720	38 (5.5)	—
Tolerance:	± 10%	—

3612 and 3616 Separate Circuit



1000	85 (12)	103 (15)
900	66 (9.6)	81 (12)
750	42 (6)	52 (7.5)
720	38 (5.5)	47 (7)
Tolerance:	± 10%	± 10%

Figure 16

The correct circuit restriction must also be maintained for bypass flow. Systems including the module mounted expansion tank with Caterpillar regulators contain factory installed orifices to control bypass flow. For remote systems, set the external bypass restriction to 130% ±10% of the corresponding external restriction value for full heat exchanger flow. The restriction must be set before the circuit reaches regulator start-to-open temperature.

Keel Coolers

A keel cooler is an outboard heat exchanger attached to the submerged portion of a ship's hull. They are typically used in applications encountering muddy or silty cooling water.

Fabricated keel coolers use many shapes (pipe, tubing, channel, etc.). Material choice depends on the cooling water encountered. It must be compatible with the ship's hull materials to prevent galvanic corrosion.

Fabricated Cooler Performance and Sizing

This guide section may be used to determine keel cooler performance characteristics, including sizing, for 3600 Engines. Careful identification of application type, operating conditions, coolant temperature specifications, and acceptance limits must be emphasized for accurate analysis.

Application

The data may be used for the following:

- Determine keel cooler size (surface area) required for either a combined or separate circuit cooling system.

- Determine the performance capability, including the return to engine coolant temperature, for an existing keel cooler configuration.

- Predict *regulated* coolant temperatures at any engine operating conditions for a specific keel cooler configuration. This is an iterative process and requires temperature regulator characteristic curves (temperature vs stroke and flow split vs stroke) for the thermostats being used. Contact a Caterpillar Application Engineer for this analysis.

The general technique for analyzing keel cooler performance is based on establishing a unit heat rejection capacity factor in terms of kW/m^2 of surface area per °C temperature difference between coolant-to-engine and the raw water. This is determined from the curves in Figure 17 for a nominal (typical) set of conditions, and is referred to as the *baseline* performance. The baseline capacity is then adjusted for actual operating conditions using a set of correction factors. The corrections take into account fouling factors (raw water and coolant), use of antifreeze (% glycol) if applicable, and actual steel thickness of the heat transfer surface. Materials other than structural (mild) steel are not considered in this analysis.

For keel cooler sizing, the heat rejection capacity factor is used to calculate the total surface area required. This is based on acceptance criteria for the specific engine and application. Acceptance is normally based on coolant-to-engine temperature limits specified in the beginning of this *Cooling* section. After determining the required surface area, the structural members can be selected based on space limitations, availability, and total coolant flow. The cross sections selected (angle irons, channels, etc.) must provide flow conditions (velocity and turbulence) used in the capacity calculations and analysis. Flow losses (pressure drop) through the cooler must also be calculated to confirm an acceptable external circuit resistance.

To evaluate an existing keel cooler configuration (vessel repower, etc.), the heat rejection capacity factor is used to calculate the coolant-to-engine temperature. This calculation should be done assuming full keel cooler flow (thermostats fully open). If the resulting coolant temperature is *below* the maximum allowable limit, the keel cooler design is acceptable relative to heat rejection. Pressure drop through the cooler must also be calculated to determine if external circuit resistance is acceptable.

The curves and techniques in this section can also be applied to predict engine cooling system temperatures for specific operating conditions. This analysis procedure requires the determination of the equilibrium point at which the system flows — temperatures, engine heat rejection, keel cooler capacity, and thermostat temperature/flow characteristics are all balanced. Refer this iterative process to a Caterpillar Application Engineer.

Performance and Sizing Criteria

Keel cooler sizing must be based on the most critical set of operating conditions.

- For marine propulsion engines operating in a consistent type of raw water, the critical case will most likely be maximum engine power at rated vessel speed at maximum expected raw-water temperature. Examples would include ocean going ships, vessels limited to the Great Lakes, or large river tugs.

- For propulsion engines operating in multiple raw-water types, several cases may have to be evaluated to identify the critical situation. An example is an ocean-going vessel entering inland harbors via rivers, channels, etc.

- For marine auxiliary engines, the critical condition will most likely be maximum load, still water (ship anchored), and maximum raw-water temperature. If load demand varies significantly between anchored and *under-way* operation, both conditions must be evaluated.

The keel cooler design must meet the following criteria:

- Structural (mild) steel welded to ship's hull. *If raw water temperature exceeds 30°C, particularly in salt water, the use of packaged coolers made of corrosion resistant materials is recommended.*

- Engine coolant flowing from rear to front of the vessel (counter-flow). If this is not possible due to the hull design and piping limitations, or if an existing cooler with split flow types is being analyzed, contact a Caterpillar Application Engineer.

- No paint or protective coatings applied to heat transfer surfaces.

The engine coolant must meet the following:

- Water used must meet Caterpillar specifications.

- Conditioner must be used and maintained at proper concentration levels.

- Use of antifreeze (glycol) is acceptable.

Engine coolant flow through the cooler must meet the following:

- Flow velocity:

Maximum	2.5 m/sec	(8.2 ft/sec)
Minimum	0.5 m/sec	(1.65 ft/sec)
Design Point**	1.5 m/sec	(4.92 ft/sec)

- Turbulent flow (natural or induced)

** Rated engine speed with full flow through cooler (thermostats fully open)

Baseline Performance Conditions

The baseline performance curves in Figure 17 are for the following conditions:

Engine Coolant:
Treated Fresh Water (no glycol)

Engine Coolant Fouling Factor:
0.0010 (no excessive hardness)

Raw Water Fouling Factor:
0.0030 (typical river water)

Steel Thickness:
6.35 mm (0.25 in)

Correction Factors

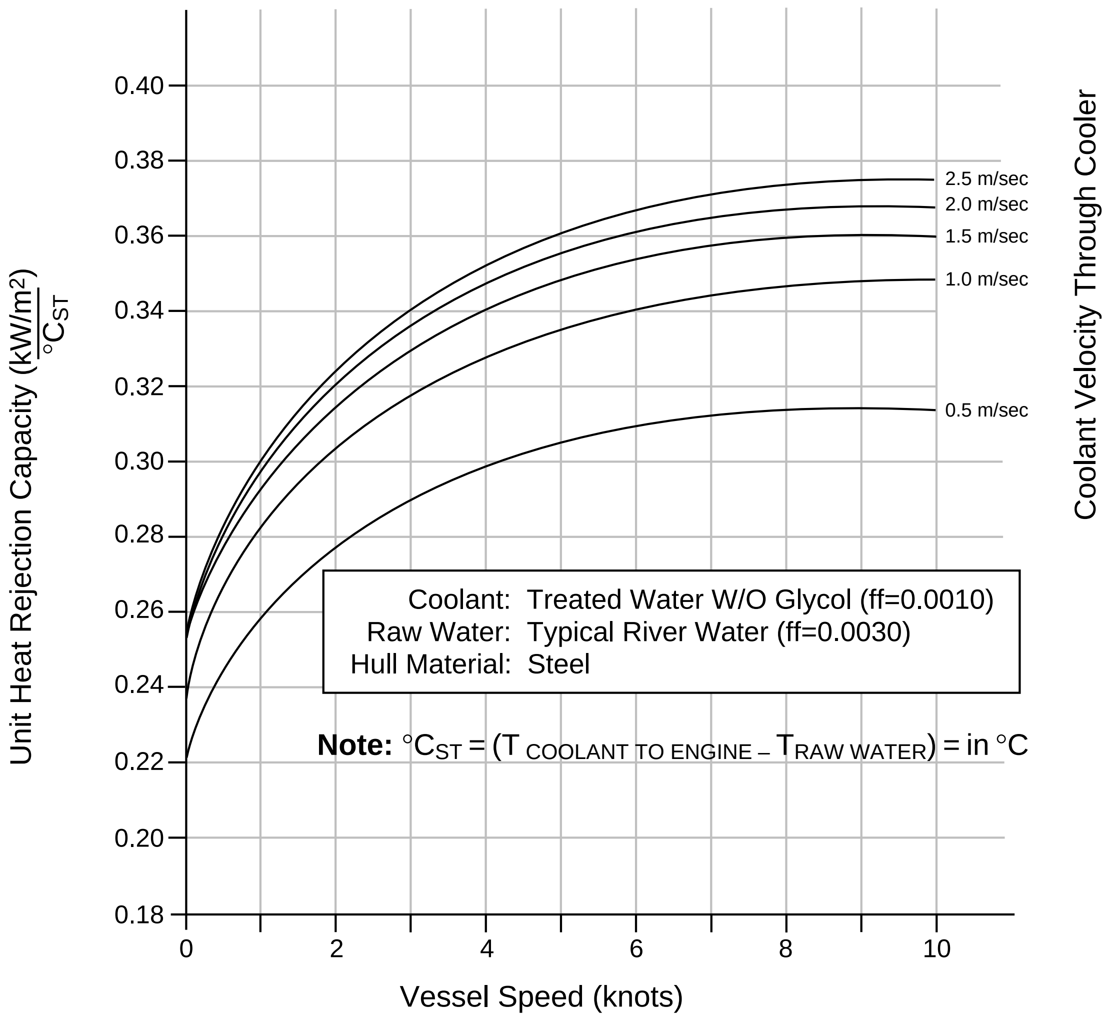
The *baseline* keel cooler performance (unit heat rejection capacity) obtained from Figure 17 must be adjusted to account for actual conditions. Correction factors (multipliers) required are shown in Figures 18 and 19.

Use of extremely hard water
Figure 18

Use of antifreeze (glycol)
Figure 18

Raw water fouling factors
Figure 18

Steel thickness (heat transfer surface)
Figure 19



Keel Cooler Performance & Sizing
Baseline Heat Rejection Capacity

Figure 17

Keel Cooler Performance Correction Factors

Correction Factors for Cooling System Water:

Water meets Caterpillar specifications	(baseline)1.00
Extremely hard water (>15 grains/gal)	0.90

Correction Factors for Antifreeze:

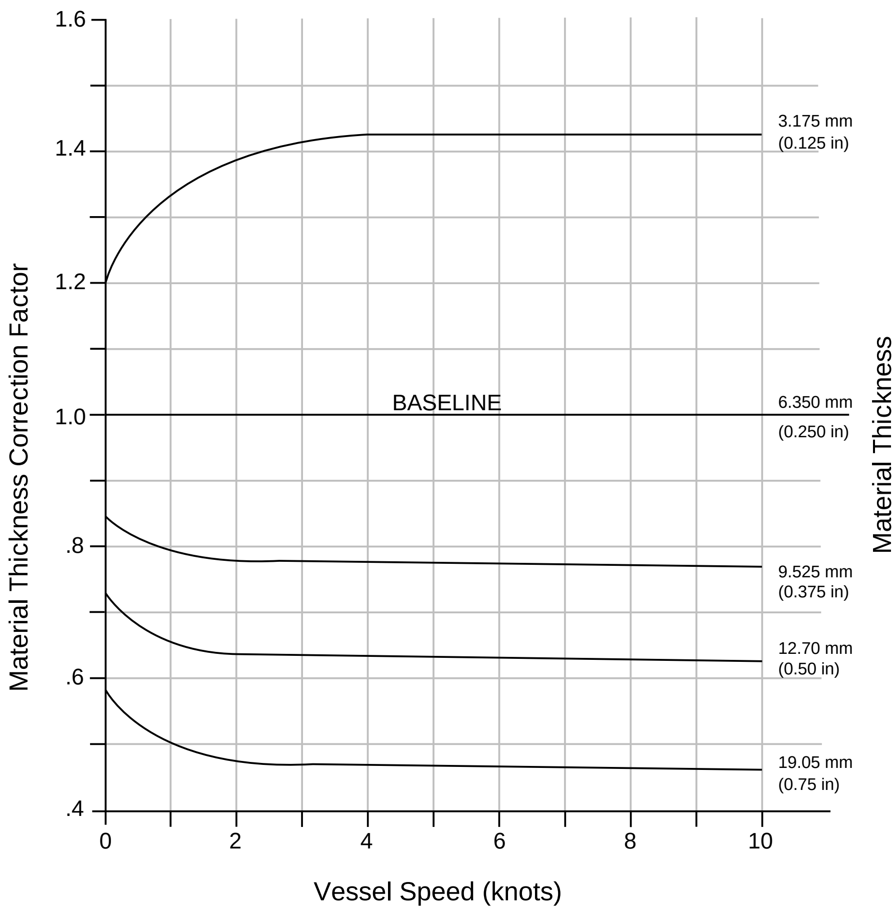
0% glycol	(baseline)1.00
10% glycol	0.97
20% glycol	0.94
30% glycol	0.91
40% glycol	0.88
50% glycol	0.85

Correction Factors for Raw-Water Type

Raw-Water Description	*Fouling Factor	Correction Factors @ Vessel Speed <2 knots	Correction Factors @ Vessel Speed >2 knots
River water (baseline)	0.0030	1.00	1.00
Open sea (ocean water)	0.0007	1.11	1.16
Great Lakes	0.0010	1.10	1.13
Chicago Canal	0.0060	0.88	0.85

* Fouling factor is shown here for reference only and is used to calculate the vessel speed correction factor.

Figure 18



Keel Cooler Performance & Sizing
Capacity Corrections for Material Thickness
(Structural Steel)

Figure 19

Worksheet
A worksheet for calculating keel cooler size (surface area) is shown on page 22. This worksheet applies to combined and separate circuit systems. A separate circuit system requires two worksheets: one for the low-temperature (aftercooler/ oil cooler) circuit, and one for the high temperature (jacket water) circuit.

Design/Installation Considerations
Large cross-sectional channels are often used for keel cooler passages. This can result in water velocities that are too slow for effective heat transfer. Inserts can be installed to create localized high water velocity or turbulence. An effective design for keel cooler inserts is a *ladder-like* device inserted through the full length of the keel cooler passages.

Construct the ladder using rods [6 mm (1/4 in.) diameter] and flat bar (approximately the same shape, but 70% of the cross sectional area of the keel cooler flow passages). Use the same metal alloy as the hull and keel cooler. The flat bar cross pieces must not restrict flow. They should redirect the flow to avoid the laminar flow due to slow average velocity. Insert the ladder into the keel cooler flow passages and weld on end inlet and outlet manifolds.

Bypass Filters
Welded structural steel cooler systems require strainers between the cooler and the pump inlet. Material such as weld slag and corrosion products must be removed from the system to prevent wear and plugging of cooling system components. Use a continuous bypass filter used to remove smaller particles and sediment. The element size of the continuous bypass filter should be 20 to 50 microns (0.000787 to 0.000197 in.). Water flow through the bypass filter must not exceed 19 L/min (5 gal/min).

Strainers
Full flow strainers are desirable. Size the strainer screens no larger than 1.6 mm (.063 in.) mesh. Connections must be no smaller than the recommended line size. A differential pressure gauge across the duplex strainer can be used to determine service periods.

Pressure drop across a strainer at maximum water flow must be considered as part of the system's external resistance. The strainer should have no more than 1 m (3 ft) H_2O restriction in clean condition.

Packaged Keel Coolers
Packaged keel coolers are purchased and bolted to the outside of a ship's hull. They are normally copper-nickel alloy and are initially toxic to marine growth, one of the more important advantages over fabricated keel coolers. The toxicity will decline with time, but the keel cooler can be partially restored by cleaning the heat transfer surfaces with a vinegar-salt solution. Another advantage of packaged keel coolers is their compactness and light weight compared to fabricated keel coolers. They can have less than 20% of the heat transfer surface of a fabricated cooler. Manufacturers publish sizing guidelines for specific conditions.

Never paint packaged keel coolers. Paint greatly reduces heat transfer.

Packaged keel coolers are rarely the same material as the ship's hull.*

If the piping is not the same material as the cooler, it must be electrically isolated from the hull metal and the ship's piping.

Keel Cooler Location
Locate the cooler in a protected area and low on the hull. The area immediately forward of the propellers is a region of high water velocity. It is high enough on the hull to be protected from grounding damage. The effects of sandblasting the cooler (from the propellers) during astern maneuvers must be considered.

*Coolers of aluminum alloy reduce the galvanic corrosion problems associated with dissimilar metals submerged in salt water, ie. aluminum and copper nickel.

KEEL COOLER SIZING WORKSHEET

GENERAL INFORMATION:

Project ________________________________ Engine ____________

Application ________________________________

Fuel Type ________________________________

Rated Power ____________________ bkW Rated Speed __________ rpm

Cooling System Type (Combined or Separate) ________________________

DESIGN-POINT CONDITIONS:

Engine Power	____________	bkW
Engine Speed	____________	rpm
Heat Rejection Data (from TMI):		
Jacket Water	____________	kW
Oil Cooler	____________	kW
Aftercooler	____________	kW
Vessel Speed	____________	knots
Maximum Expected Raw Water Temperature	____________	°C
Raw Water Type / Description	______________________	

CIRCUIT ANALYSIS INFORMATION:

Circuit Being Analyzed	______________________	
Total Circuit Heat Rejection	____________	kW
Max Allowable Coolant-to-Engine Temp	____________	°C
Regulator (Thermostat) Part Number	________________	
Start-to-Open Temperature	____________	°C
Full-Open Temperature	____________	°C
Total Circuit Flow	____________	L/min
Coolant Velocity thru Keel Cooler	____________	m/sec
Max Allowable Circuit Resistance	____________	kPa
Coolant Water Type	________________	
Antifreeze Content (glycol)	____________	%
Steel Thickness of Heat Transfer Surface	____________	mm

CIRCUIT ANALYSIS INFORMATION:

Baseline Unit Heat Rejection Capacity (Figure 17) = ____________ (kW/sq m) / ° C

Total Correction Factor (see Figures 18 and 19):

Water Factor		Glycol Factor		Raw-Water Factor		Thickness Factor		
(______)	x	(______)	x	(______)	x	(______)	=	____________

Corrected Unit Heat Rejection Capacity:

Baseline Capacity		Total Correction Factor			
(________)	x	(________)	=	____________	(kW/sq m) / °C

Temperature Difference Calculation:

Coolant-to-Engine Temperature		Raw Water Temperature			
(_______) °C	-	(_______) °C	=	____________	°C

Unit Heat Rejection Capacity @ Design Temperatures:

Corrected Unit Capacity		Temperature Difference			
(________)	x	(________)	=	____________	kW/sq m

Total Surface Area Required:

Total Circuit Heat Rejection		Unit Capacity @ Design Temps			
(________)	/	(________)	=	____________	sq m

Keel Cooler Circuit Pumps
The engine driven water pump will normally circulate engine fresh water through the cooler. If the total external resistance cannot be held within limits, an auxiliary pump will be required.

Keel Cooler Venting
Proper venting of fabricated keel cooler channels is critical for good cooling system operation. Both ends of each channel section should have manual or automatic vent valves to remove air during initial system filling. This is important because the ship's trim can vary from vessel to vessel and air can be trapped if the channels are vented at only one end. If air gets trapped in the channel sections during initial fill, the expansion tank volume will drop dramatically when the engine is running because that air will be compressed by the pump pressure and coolant will take its place. This trapped air can also cause the external circuit resistance to be set improperly, which may result in poor coolant flow to the engine. Pump cavitation may also result from air trapped in the keel cooler.

Marine Gear Heat Rejection

Marine gears have an efficiency of about 97%. Approximate heat rejection to the marine gear cooling system is:

H = P x F

Where:

- H = Marine Gear Heat Rejection, (kW)
- P = Engine Power, (kW)
- F = Gear Efficiency Loss, (0.03)

H = P x F x 42.41

Where:

- H = Marine Gear Heat Rejection, (Btu/min)
- P = Engine Power, (hp)
- F = Gear Efficiency Loss, (0.03)

The gear manufacturer can supply actual heat rejection values as well as required cooling temperatures. Use the graphs previously presented to calculate the additional cooling area required for the marine gear.

Piping

Use black seamless pipe with connections fitted in the flow direction to minimize turbulence. *Do not use galvanized pipe.*

Cleanliness

All external pipe and water passages must be cleaned before initial engine operation. *Strainers are available from Caterpillar to be installed in pipes leading to externally added equipment.* They are available for 100 mm, 127 mm, and 152 mm (4 in., 5 in., and 6 in.) pipe sizes and all have 1.6 mm (1/16 in.) mesh size. *Install them on site prior to startup and remove after commissioning.*

Venting

Proper venting is required for all applications. Route vent lines to the expansion tank at an upward slope without dips. Avoid traps in customer supplied piping, but if this is not possible they must be vented. When it is not practical to route vent lines to a common point, use automatic air-release valves. The valves are suited for low velocity coolant areas such as expansion tanks. They may also be adapted to deaeration chambers. Locations must be selected to collect entrained air. Automatic air release valves are available in several styles. The heavy duty (cast iron body) style is recommended. In addition to the automatic venting feature, the valves usually have a *fast-vent* port available. Typically it is a pipe plug which can be removed or replaced by a ball valve, allowing venting during initial system fill.

Line Sizing

Water velocity guidelines are:

	Maximum Velocity m/sec	ft/sec
Pressurized Lines	4.5	15
Pressurized Thin-Wall Tubes	2.0-2.5	6.5-8
Suction Lines (Pump Inlet)	1.5	5
Low Velocity Deaeration Line	0.6	2

Connections

Cooling system weld flanges for customer connections are shown in Figures 20, 21, 22, and 23. *(Refer to pages 41-44 for illustrations.)*

Caterpillar flexible joint assemblies are available in the three pipe sizes used on cooling systems: 100 mm, 127 mm, and 152 mm (4 in., 5 in., and 6 in.).

Use flexible joints for all connections to the engine, but *do not use rubber hoses*. Minimize the length and weight of piping mounted on the engine. Place the flexible connection as close to the engine connection as possible, preferably right at the engine connection. This minimizes the stresses on the water pump housings caused by piping weight. Provide adequate pipe support on the hull side of system piping to minimize pipe movement and flex connection loading. Arrange flexible connections, check valves and shutoff valves as shown in Figure 4 when emergency cooling connections are used so that the engine can continue to operate with the standby pump. This is particularly important in single engine propulsion applications.

Orient the flex connector to take maximum advantage of its flexibility. Consider normal and maximum expected movement ranges when selecting connectors. Material compatibility must also be evaluated. The internal surface must be compatible with the coolant used over the anticipated operating temperature and pressure ranges. The liner material must also be compatible with potential coolant contaminants such as lube oil, fuel, and system cleaning solutions. The outer cover must be compatible with its environment — temperature extremes, ozone, grease, oil, paint, etc.

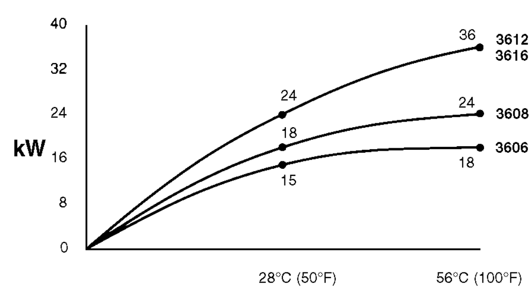
Jacket Water Heating System

Jacket water heating systems allow starting at ambient temperatures below 0°C (32°F). Heated water must enter the top of the cylinder block and exit from the bottom. This maintains a positive water pressure to the heater pump and avoids priming and cavitation problems. The jacket water heater and pump should automatically turn on when the engine is shutdown and automatically stop when the engine is started.

The Caterpillar system is a prepackaged shipped loose unit including:

- Circulating pump
- Electric water heater
- Control panel including controls for starting/stopping pump, high temperature shutdown, no flow shutdown, etc.
- Piping, valves and fittings are on the unit -- the customer must plumb the unit to the engine

A typical jacket water heating package is shown in Figure 24. *(Refer to page 45 for illustration).* The heating requirements for each engine is shown in Figure 25.



Coolant Temperature — Above Ambient

Figure 25

Water Treatment

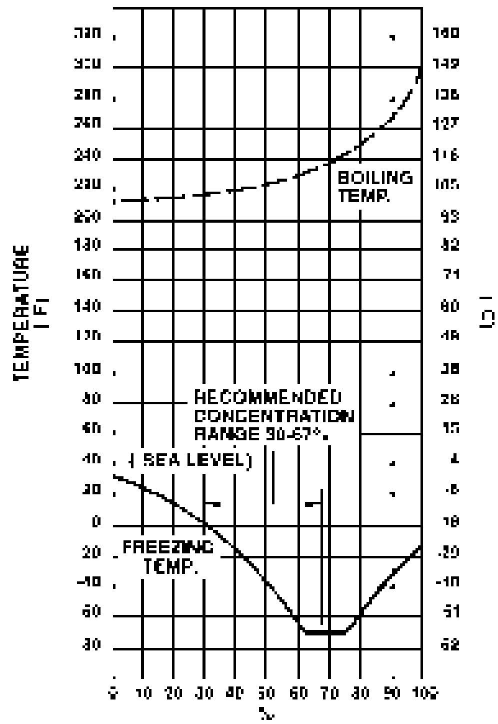
Caterpillar's water quality recommendations must be followed, particularly in closed cooling systems. Excessive *hardness* will cause deposits, fouling, and reduced cooling system component effectiveness. Water hardness is described in grains per gallon, one grain being equal to 17.1 parts per million (ppm) or mg/L, both expressed as calcium carbonate. Water containing up to 3.5 grains per gal (60 ppm) is considered soft and causes few deposits. Cooling system water must meet the following criteria:

Chloride (CL).......2.4 g/gal (40 ppm) max.
Sulfate (SO4).....5.9 g/gal (100 ppm) max.
Total
Hardness ....10.0 g/gal (170 ppm) max.
Total Solids......20.0 g/gal (340 ppm) max.
pH ....5.5 - 9.0

Water softened by removal of calcium and magnesium is acceptable. Corrosion inhibitors added to water maintain cleanliness, reduce scale and foaming, and provide pH control. With the addition of an inhibitor, maintain a pH of 8.5 to 10.

Exposing engine coolant to freezing ambient temperatures requires the use of antifreeze. Ethylene glycol is most common. The concentration required can be determined from Figure 26. Also refer to Form No. SEBD0970-01, *Coolant and Your Engine.*

Caterpillar recommends using a 50/50 mixture of glycol/water. Concentrations less than 30% require the addition of corrosion inhibitors to maintain cleanliness, reduce scale and foaming, and provide acidity and alkalinity (pH) control. The rust inhibitor must be compatible with the glycol mixture and not damage flexible connections, seals, or gaskets. Avoid sudden changes in coolant composition to minimize adverse effects on nonmetallic components.



COOLANT FREEZING AND BOILING TEMPERATURES
VS. ETHYLENE GLYCOL CONCENTRATION

Figure 26

Note: *Caterpillar antifreeze contains the proper amount of coolant conditioner. Do not use coolant conditioner elements or liquid coolant conditioners with Dowtherm 209 Full-Fill Coolant. Caterpillar inhibitors are compatible with ethylene glycol base antifreeze. Soluble oil or chromate solutions must not be used.*

Note*: Water treatment may be regulated by local codes when cooling water contacts domestic water supplies.*

Caterpillar's coolant additive is available in 19 L (5 gal) and 208 L (55 gal) containers: Part No's. 8C3680 and 5P2907 respectively. Caterpillar does not recommend additives from other suppliers. Caterpillar antifreeze is available in 3.8 L (1 gal) and 208 L (55 gal) containers: Part No's. 8C3684 and 8C3686 respectively.

System Monitoring

Make provisions for pressure and temperature differential measurements across major components. This allows accurate setup and performance documentation of the cooling system during the commissioning procedure. Future system problems or component deterioration (such as fouling) are easier to identify if basic data is available. It also provides information for relating *on-site* conditions to the original factory test.

Temperature and pressure measurement locations should give an accurate reading of fluid stream conditions. Preferred locations are in straight lengths of piping reasonably close to each system component. Avoid pressure measurements in bends, piping transition pieces, or turbulent regions. Self-sealing probe adapters are available in several sizes of male pipe threads and straight threads for O-ring ports. The adapters use a rubber seal allowing temperature or pressure to be measured without leakage. Probe diameters up to 3.2 mm (0.125 in.) may be used. The straight-threaded adapters are used on the engines with available ports. Pipe threaded adapters are more easily incorporated in the external customer supplied system. The adapters are an excellent alternative to permanently installed thermometers, thermocouples, and pressure gauges. They are not subject to breakage, fatigue failures, and gauge-to-gauge reading variations.

Serviceability

Access to heat exchangers is required for tube *rodding* (cleaning) or removal of the tube-bundle assembly. Engine water pumps should also be easy to remove. Remote water temperature regulators must be accessible, and appropriate isolation valves provided. Apply similar guidelines to heat recovery units, deaeration chambers, and other components requiring service.

System Design: Engine Data, Criteria and Guidelines

Design Forms:

Included in this section are forms for recording design input for both the combined (page 27) and separate circuit systems (page 28). See the *Engine Data* section of this guide for heat rejection and coolant flow values for both distillate and heavy fuel engines. Use Figure 10 to correct the AC/OC water and ambient air temperatures when different from standard conditions.

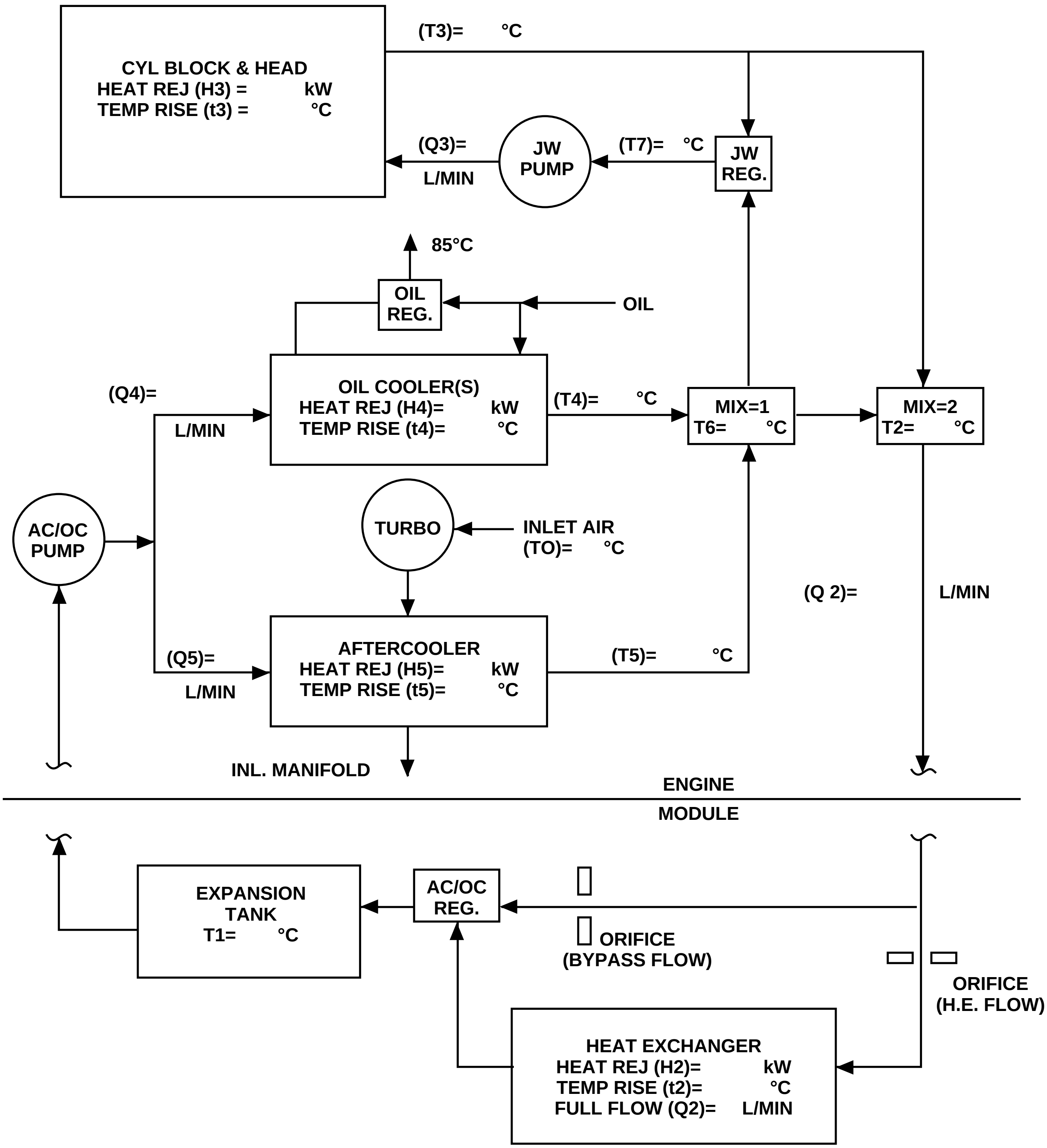
3600 Combined Cooling System

PROJECT: ______________________________ DATE: ____________

ENGINE: ______________________________ SPEED: ____________ (RPM)

APPLICATION: ______________________________ POWER: ____________ (BKW)

ALTITUDE: ____________ (M) COOLANT: ______________________________



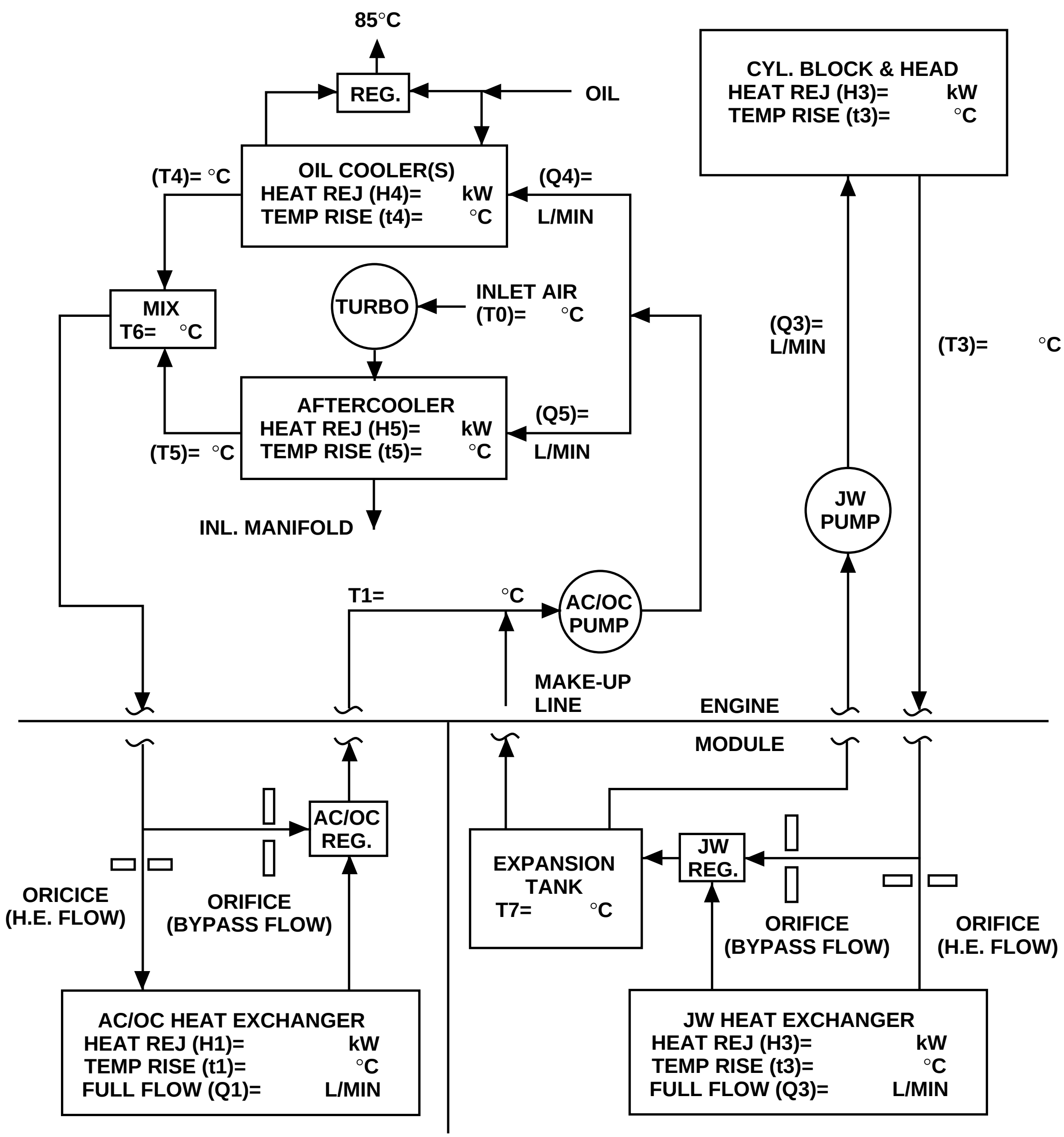
3600 Separate Circuit System

PROJECT: ______________________________ DATE: ____________

ENGINE: ______________________ SPEED: ____________ (RPM)

APPLICATION: ____________________ POWER: ____________ (BKW)

ALTITUDE: __________ (M) COOLANT: ____________________



Heat Recovery

The 3600 Engines convert about 44% of their input fuel energy into mechanical power compared to 33% on older engines. The remaining input fuel energy transforms into heat from friction and combustion. It is carried from the engine by jacket water (including turbocharger cooling water), oil cooler water, aftercooler water, exhaust, surface radiation, and convection.

Heat recovery is a viable option with the 3600 Engine, but because of high overall thermal efficiency it must be given more deliberate consideration. Older engines have traditionally higher percentages of heat rejected to the exhaust and cooling systems, making heat recovery more desirable.

Heat recovery design best suited for any installation depends on many technical and economic considerations. However, the primary function of any design is to cool the engines. Engines must be adequately cooled even when heat recovery demand is low.

Due to the wide variety of uses for the heat recovered from a diesel engine, it is impractical to discuss specific systems in detail. Utilize design consultants or factory assistance when considering heat recovery.

The typical heat balance of 3600 Engines is shown in Figure 27.

Typical 3600 Heat Balance
ISO Conditions

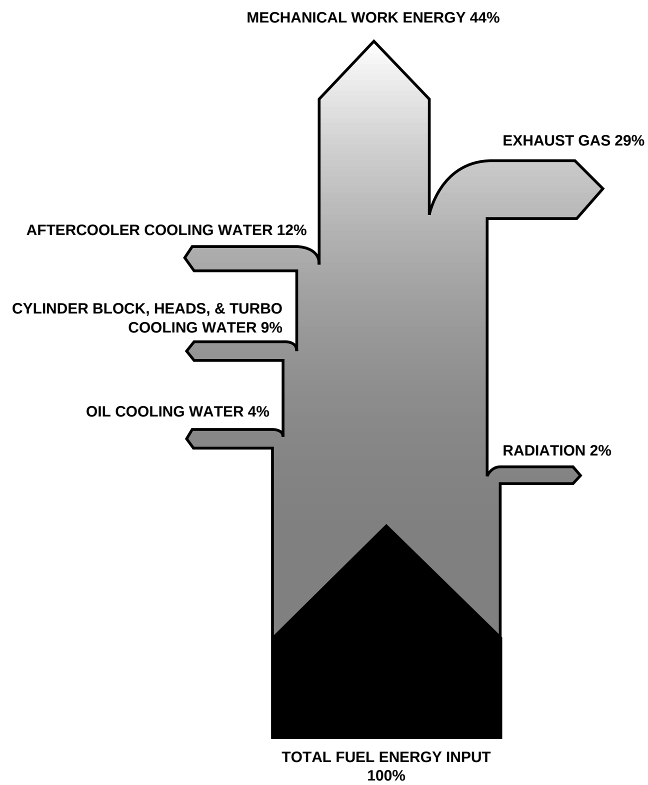


Figure 27

Heat rejection values for marine propulsion engines are included in the *Engine Data* section of this guide. The following data is included for all four engines at 750, 800, 900 and 1000 rpm.

- Jacket water heat rejection (includes turbo)
- Oil cooler heat rejection
- Aftercooler heat rejection
- Exhaust gas heat rejection using the lower fuel heating value
- Exhaust stack gas temperature
- Volume flow of the exhaust gas
- Coolant flow — jacket water and AC/OC water

Heat rejection for marine auxiliary engines is given in Form No. LEKX6559, the *Technical Data* section of the EPG A&I Guide.

When considering heat recovery for 3600 Engines review the cooling system parameters. The two cooling systems available are the combined circuit and separate circuit, and either system can use the high temperature jacket water circuit for heat recovery. Figure 28 shows a combined circuit cooling system and Figure 29 shows a separate circuit cooling system, both with heat recovery from the high temperature jacket water circuit. The flow restriction in the heat recovery circuit is critical because all of the cylinder block flow is directed to the heat recovery unit. Pressure measuring locations at the inlet and outlet connections of the engine are provided, but a factory project engineer should be consulted to determine the permissible pressure differential of the heat recovery system. Exhaust gas heat recovery is also available in either arrangement but details are not shown. If the heat recovery circuit uses less than 30% of the available jacket water heat load, then an external temperature regulator is not required. If a regulator is used it must be set 5°C (9°F) lower than the jacket water circuit regulator to prevent overcooling the engine. Install a full flow bypass valve to isolate the heat recovery circuit when not in use. A heat recovery unit bypass line may be required if the heat recovery unit cannot use the full amount of coolant flow.

Heat Balance

Typical heat balance calculations are illustrated in the following information. These are typical numbers only, meant to illustrate the calculations required. Values selected are from the Engine Data section of this guide. For the latest data use the TMI System.

Heat Balance Example

Use a 3606 Engine with a single circuit cooling system rated at 1730 kW (2320 bhp) at 900 rpm (using distillate fuel) as an example.

Heat Rejection Available
See *Technical Data* within the *Engine Data* section of this guide.

	kW	Btu/min
Block, head and turbocharger	373	21,212
Oil cooler water	185	10,521
Aftercooler water	402	22,877
Total water heat rejection at approx. 45°C (113°F)	**960**	**54,610**
Exhaust heat rejection	**1256**	**71,475**

$$\text{Total Fuel Energy Input} = \frac{\text{BSFC x kW x Qc}}{(1000\text{ g/kg})(60\text{ min/hr})(60\text{ sec/min})}$$

Where Qc = LHV of Fuel = 42,780 kJ/kg (18,390 Btu/lb)

$$= \frac{195.5 \times 1730 \times 42{,}780}{3{,}600{,}000}$$

= 4,019 kW (228,710 Btu/min)

Practical Exhaust Heat Recovery, assuming 177°C (350°F) gas temperature after heat exchanger

$$Q\text{ (available)} = \dot{m} c_p \Delta T$$

Where: $\dot{m}$ = mass flow rate, kg/hr

c_p = specific heat of exhaust gas = 0.018 $\frac{\text{kW - min}}{\text{kg - °C}}$

ΔT = exhaust temp drop through heat recovery, °C

The exhaust gas mass flow rate is obtained by multiplying the volumetric flow rate (372.1 m^3/min in this example) by the density. See the conversion formula in the *Exhaust* section.

Q (available) = .018 x 11,439 x (403-177) x 1/60
Q (available) = 776 kW (44,160 Btu/min)

Note: This example does not consider the heat of vaporization of water, a product of combustion and not usually retrievable.

$$n = \text{Thermal efficiency} = \frac{\text{Brake kW}}{\text{Fuel kW}} = \frac{1730}{4019} = 43.0\%$$

$$\text{Jacket Rejection} = \frac{373}{4019} = 9.3\%$$

Heat Balance (continued)

Oil Cooler = $\frac{185}{4019}$ = 4.6%

Aftercooler = $\frac{402}{4019}$ = 10.0%

Exhaust = $\frac{1256}{4019}$ = 31.3%

Radiation = $\frac{73}{4019}$ = 1.8%

100%

Available Heat Recovery

Using high temperature jacket water circuit and exhaust gas

$Q = Q_j + Q_{ex}$

Q (Available) = 373 + 776

Q (Available) = 1149 kW (65,386 Btu/min)

n (Available) = $.43 + \frac{1149}{4019}$

n (Available) = 71.6%

3600 Combined Circuit Cooling
Typical System Schematic

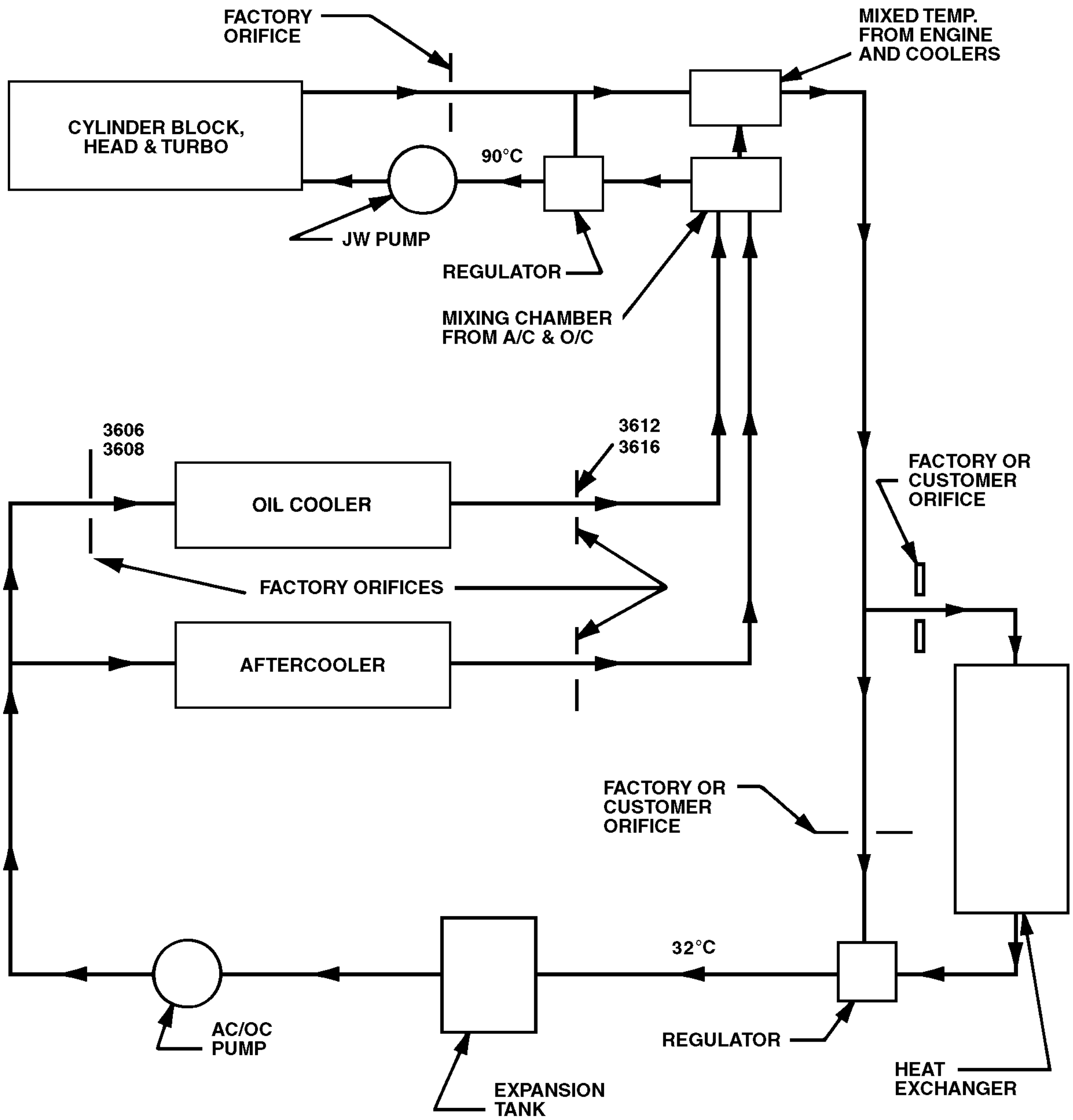
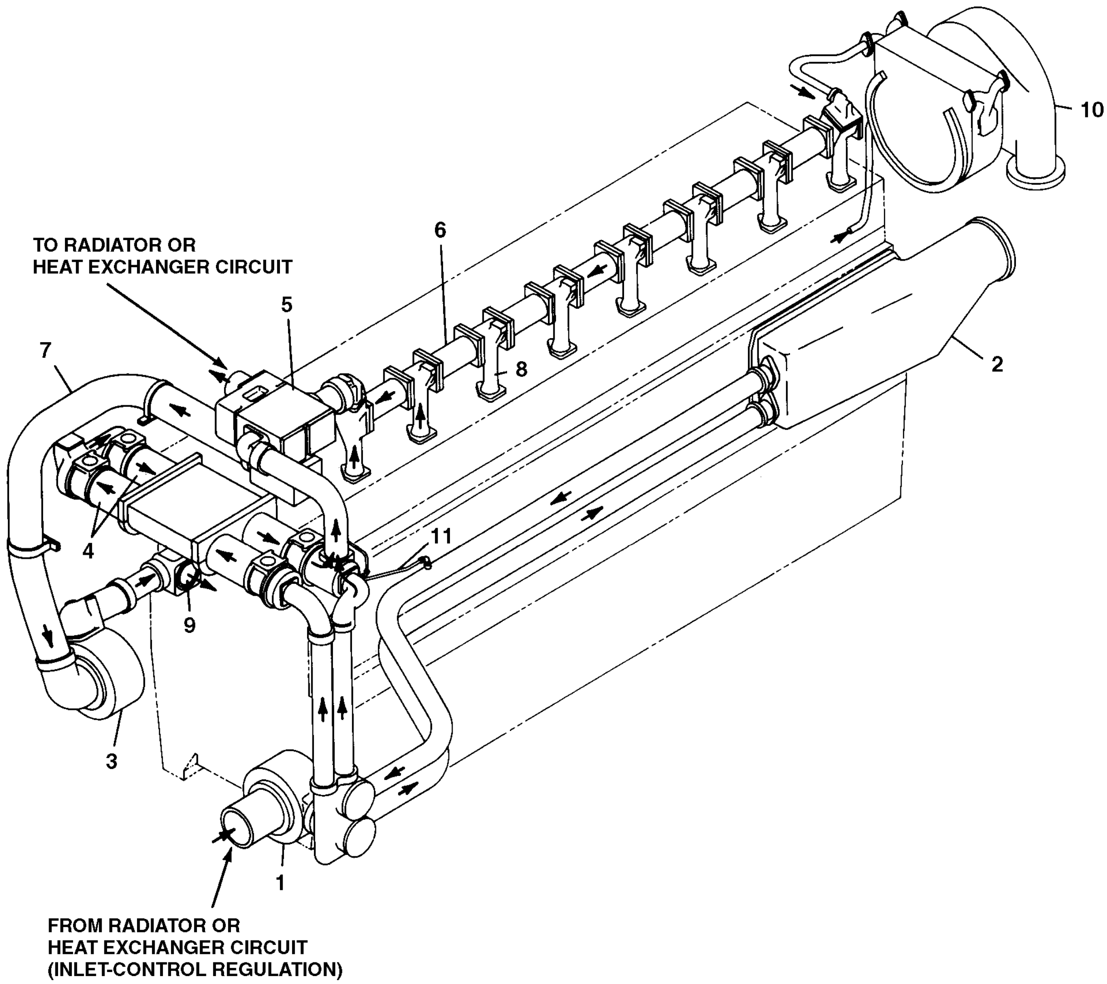
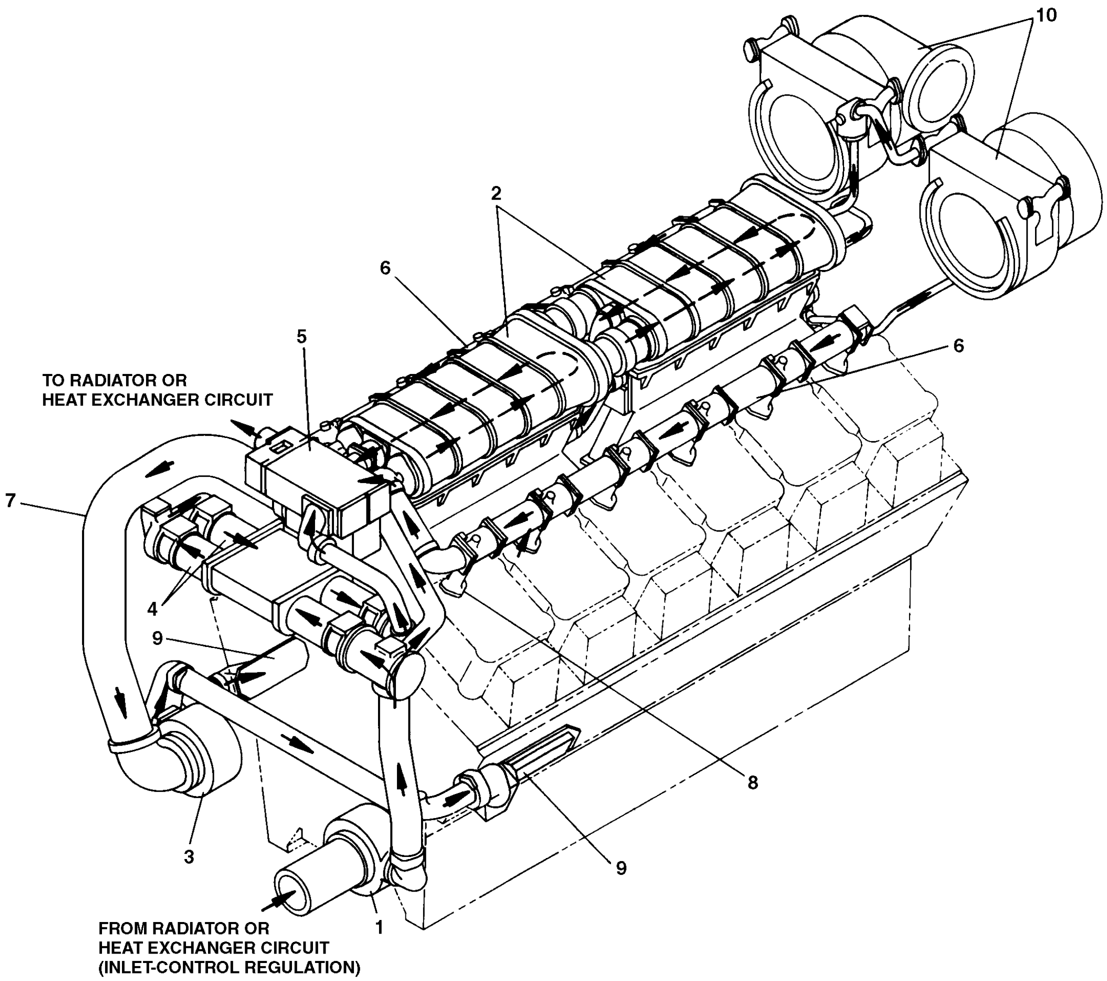


Figure 1



Typical 3606 and 3608 Combined Cooling Schematic	
1. Aftercooler/Oil Cooler Pump	7. Jacket Water Pump Suction LIne
2. Aftercooler	8. Water From Heads
3. Jacket Water Pump	9. Water To Block
4. Oil Coolers	10. Turbocharger
5. Thermostat Housing (JW circuit)	11. Vent Line
6. Water Manifold	

Figure 2

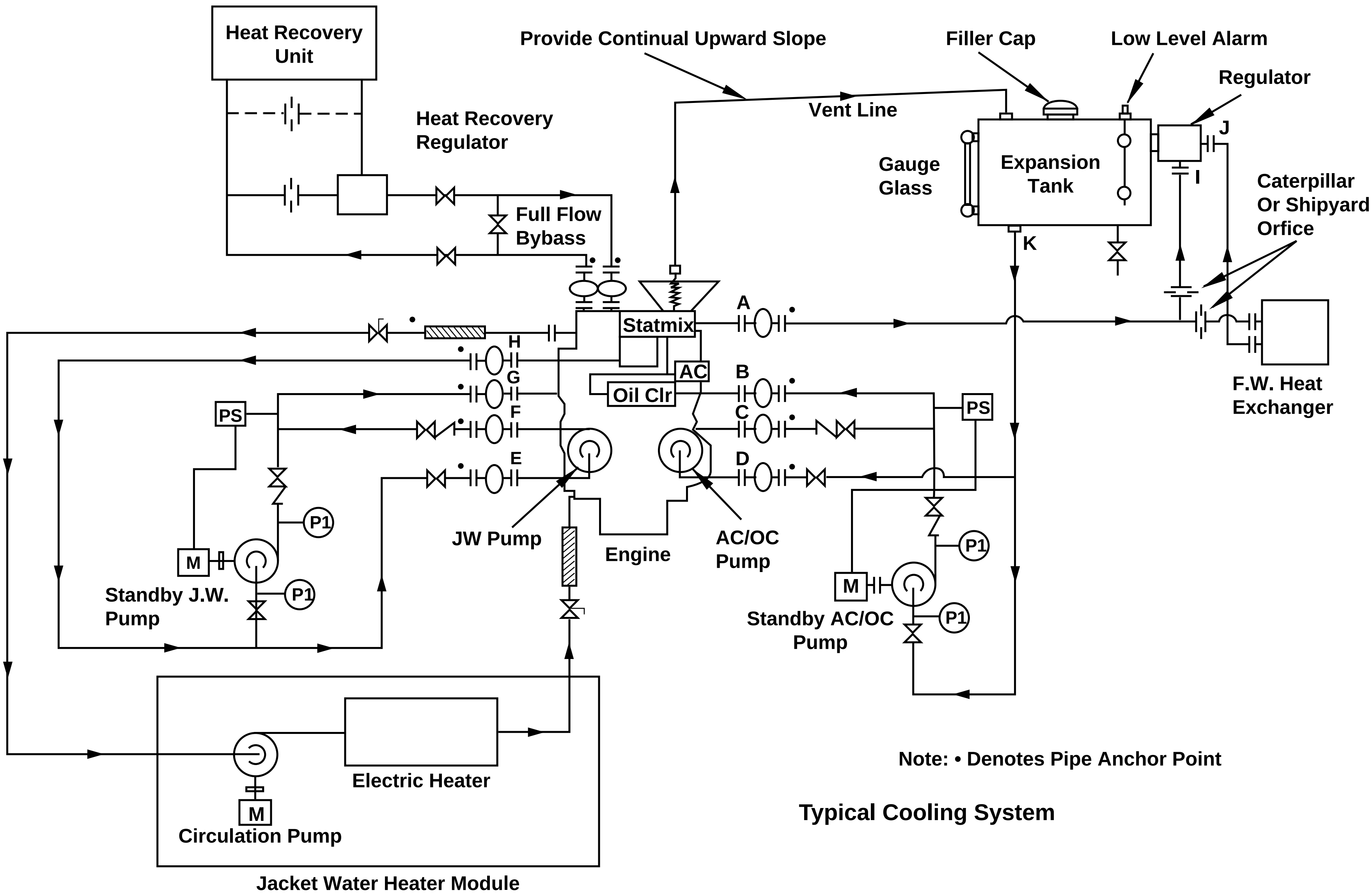


Typical 3612 and 3616
Combined Cooling Schematic

1. Aftercooler/Oil Cooler Pump
2. Aftercoolers
3. Jacket Water Pump
4. Oil Coolers (2) *
5. Thermostat Housing (JW circuit)
6. Water Manifold
7. Jacket Water Pump Suction Line
8. Water From Heads
9. Water To Block
10. Turbochargers

* Three Coolers Required On Some Applications.

Figure 3



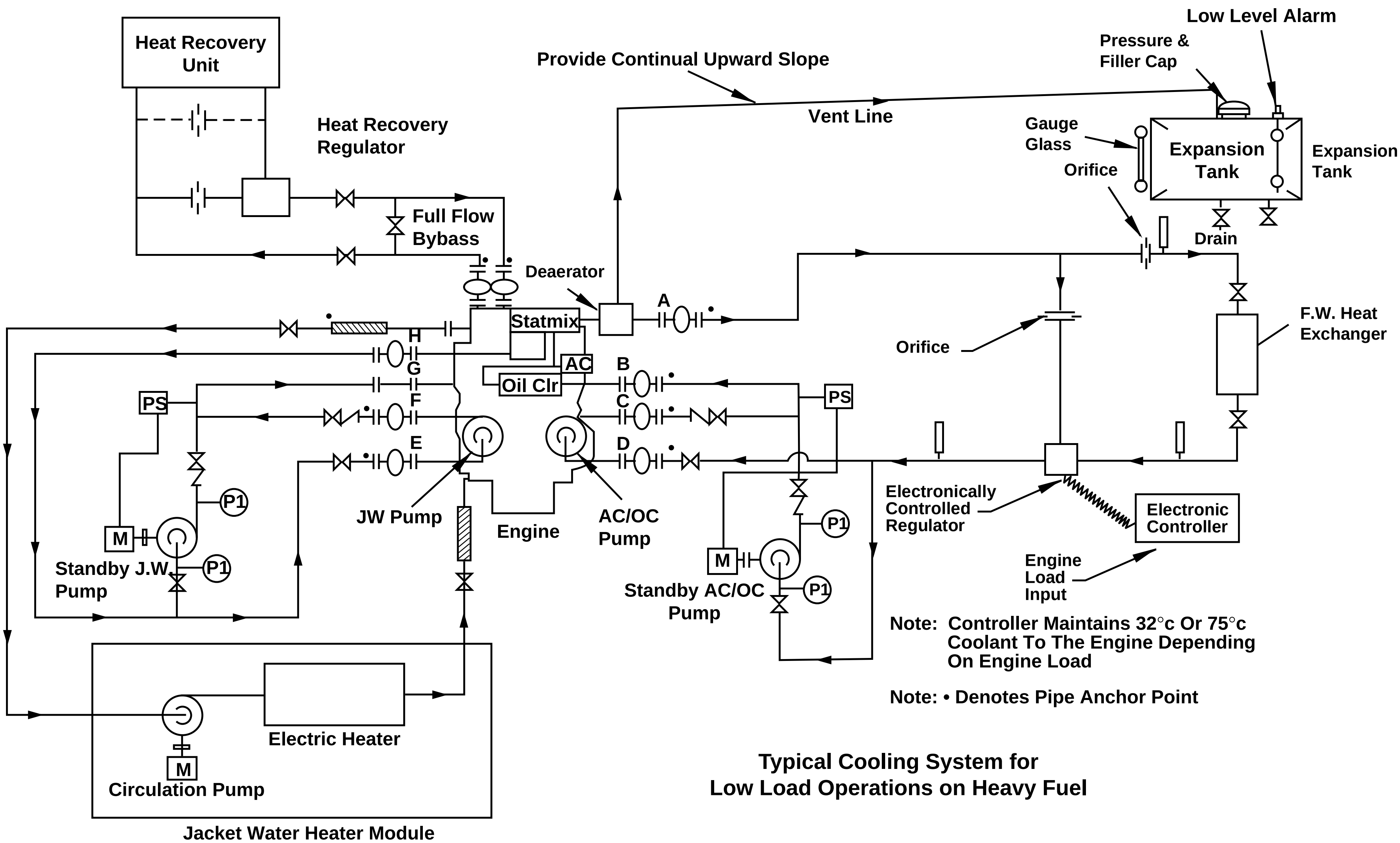
Note: • Denotes Pipe Anchor Point

Typical Cooling System

FLANGE TABLE

WELD FLANGE I.D. - mm (in.)											
ENGINE	A	B	C	D	E	F	G	H	I	J	K
3606	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33)	110 (4.33)	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)
3608	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33)	110 (4.33)	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)
3612	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)
3616	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)

Figure 4



Note: Controller Maintains 32°c Or 75°c Coolant To The Engine Depending On Engine Load

Note: • Denotes Pipe Anchor Point

Typical Cooling System for Low Load Operations on Heavy Fuel

FLANGE TABLE

WELD FLANGE I.D. - MM (IN.)								
ENGINE	A	B	C	D	E	F	G	H
3606	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33)	110 (4.33)	143 (5.63)
3608	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33	110 (4.33)	143 (5.63)
3612	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)
3616	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)

Figure 5

3600 Separate Circuit Cooling
Typical System Schematic

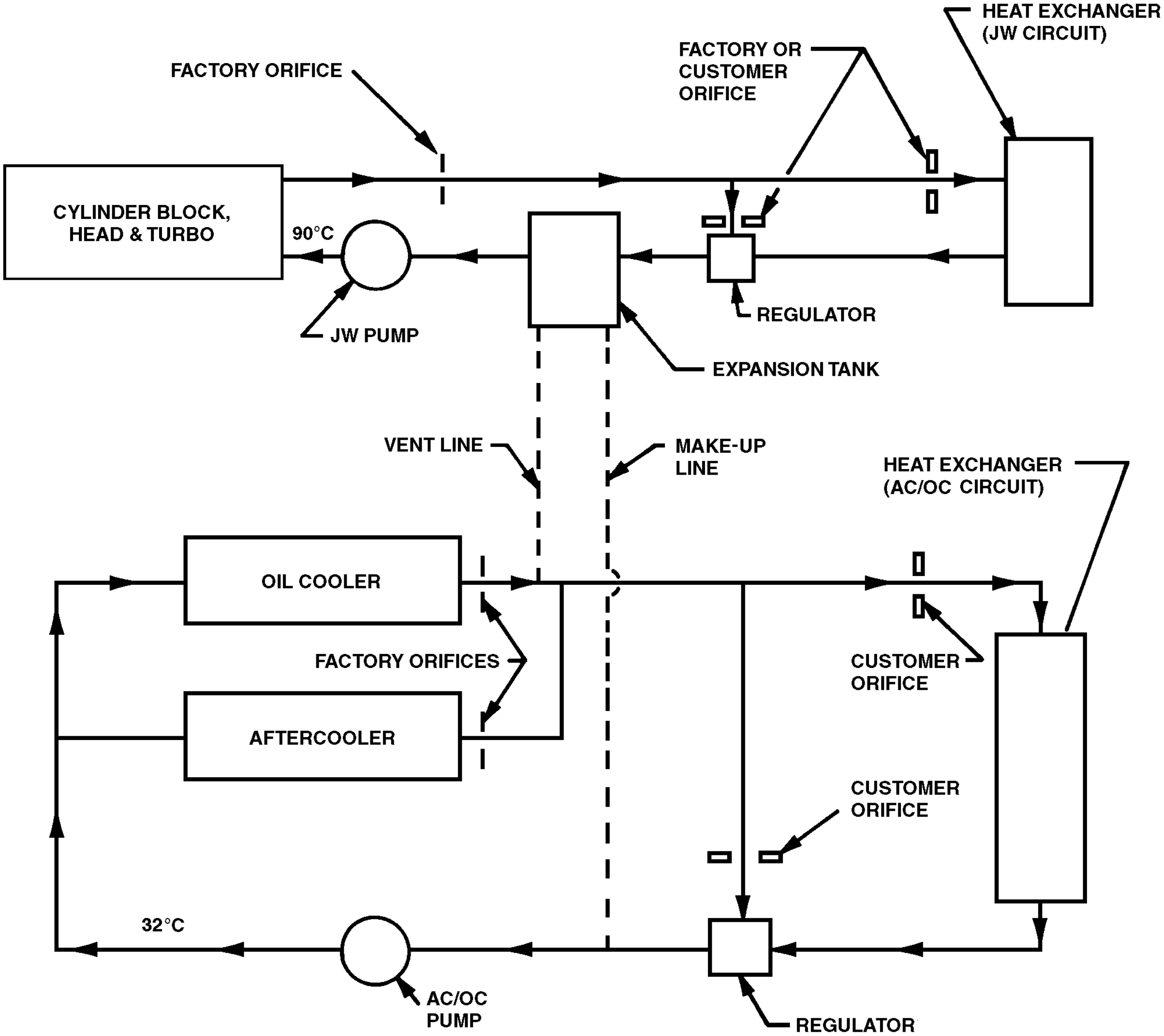
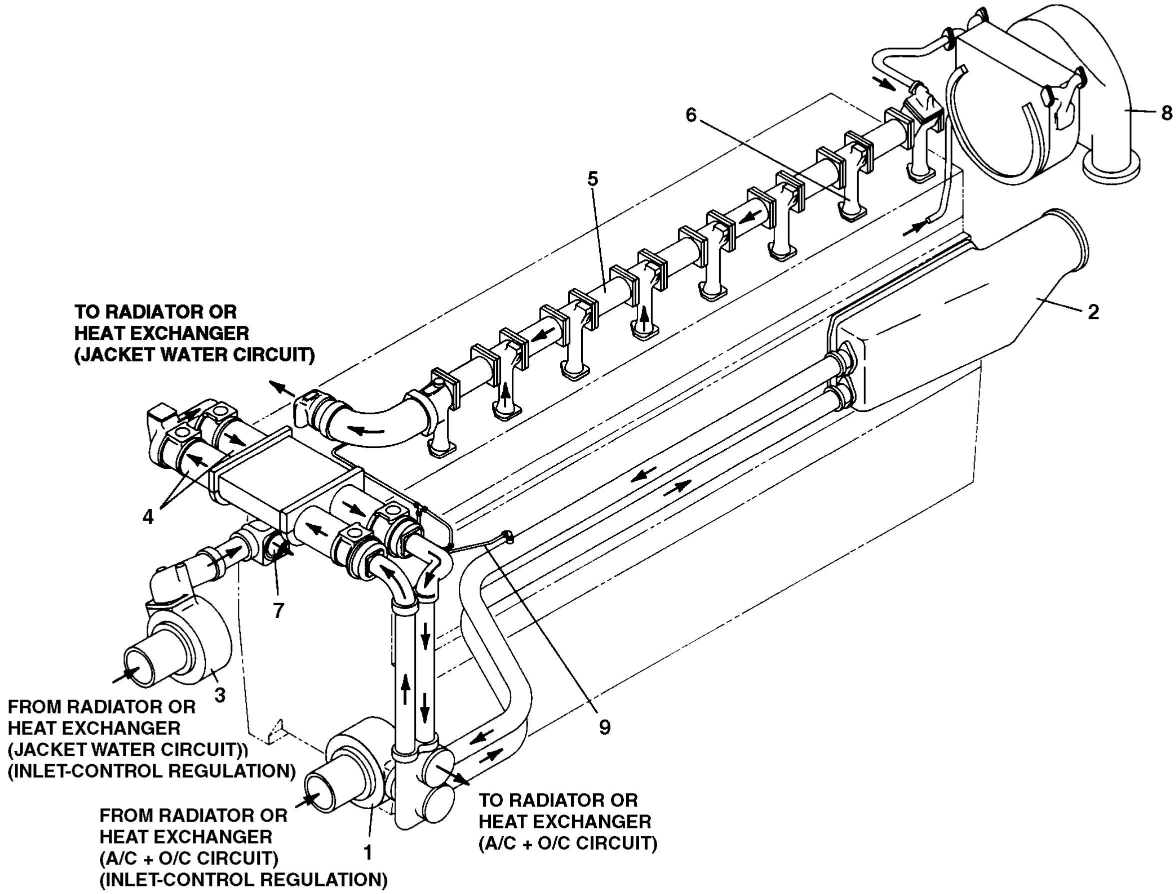
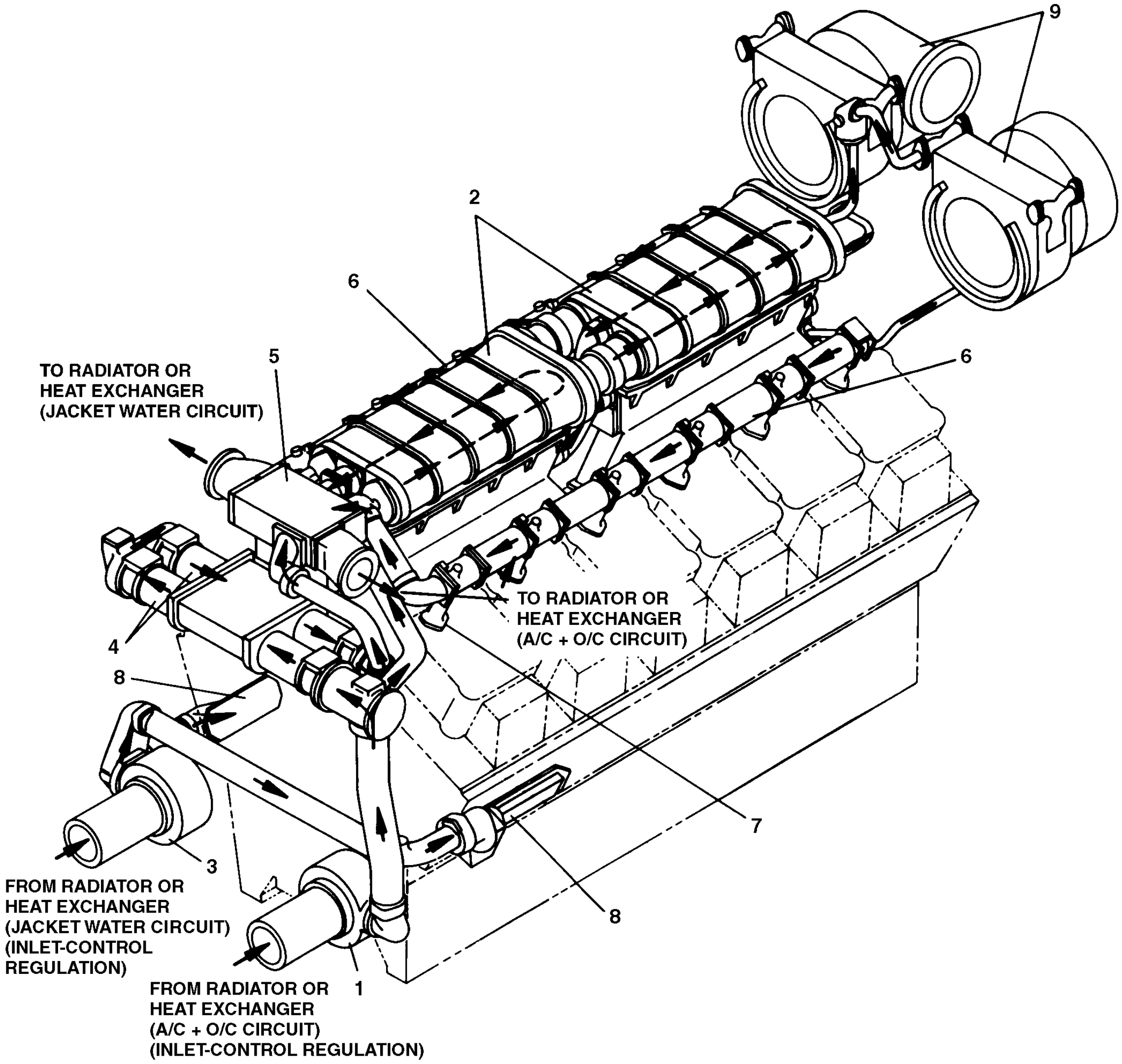


Figure 6



Typical 3606 and 3608 Separate Circuit Cooling Schematic	
1. Aftercooler/Oil Cooler Pump	6. Water From Heads
2. Aftercooler	7. Water To Block
3. Jacket Water Pump	8. Turbocharger
4. Oil Coolers	9. Vent Line
5. Water Manifold	

Figure 7



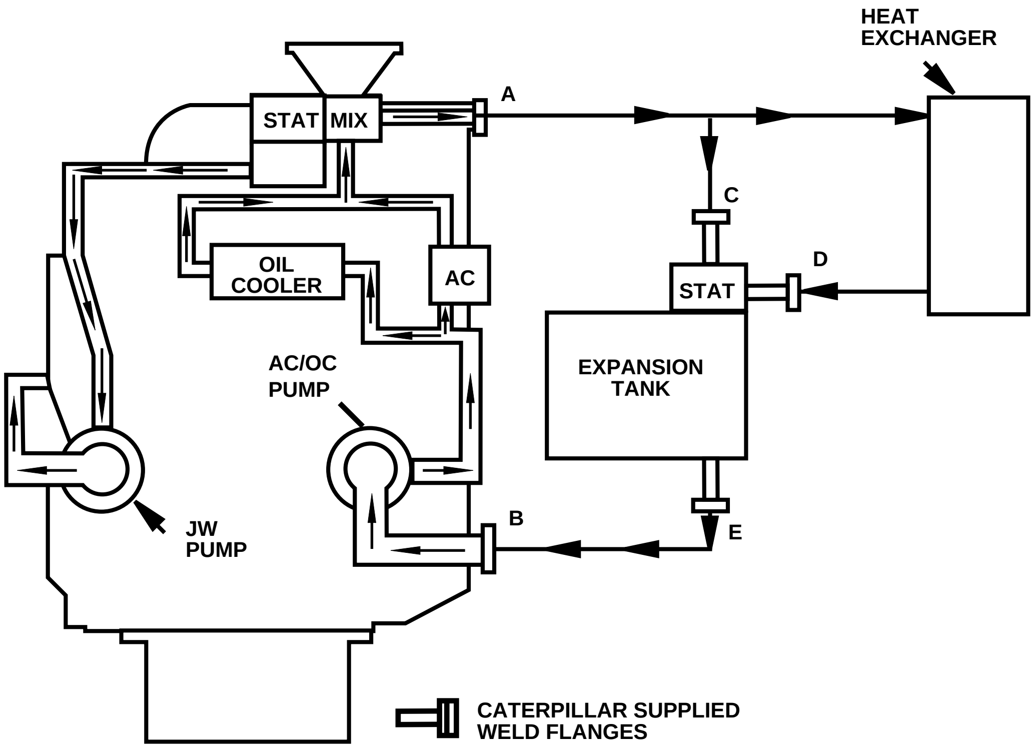
Typical 3612 and 3616
Separate Circuit Cooling Schematic

1. Aftercooler/Oil Cooler Pump
2. Aftercoolers
3. Jacket Water Pump
4. Oil Coolers (2) *
5. Outlet Housing
6. Water Manifold
7. Water From Heads
8. Water To Block
9. Turbochargers

* Three Coolers Required On Some Applications.

Figure 8

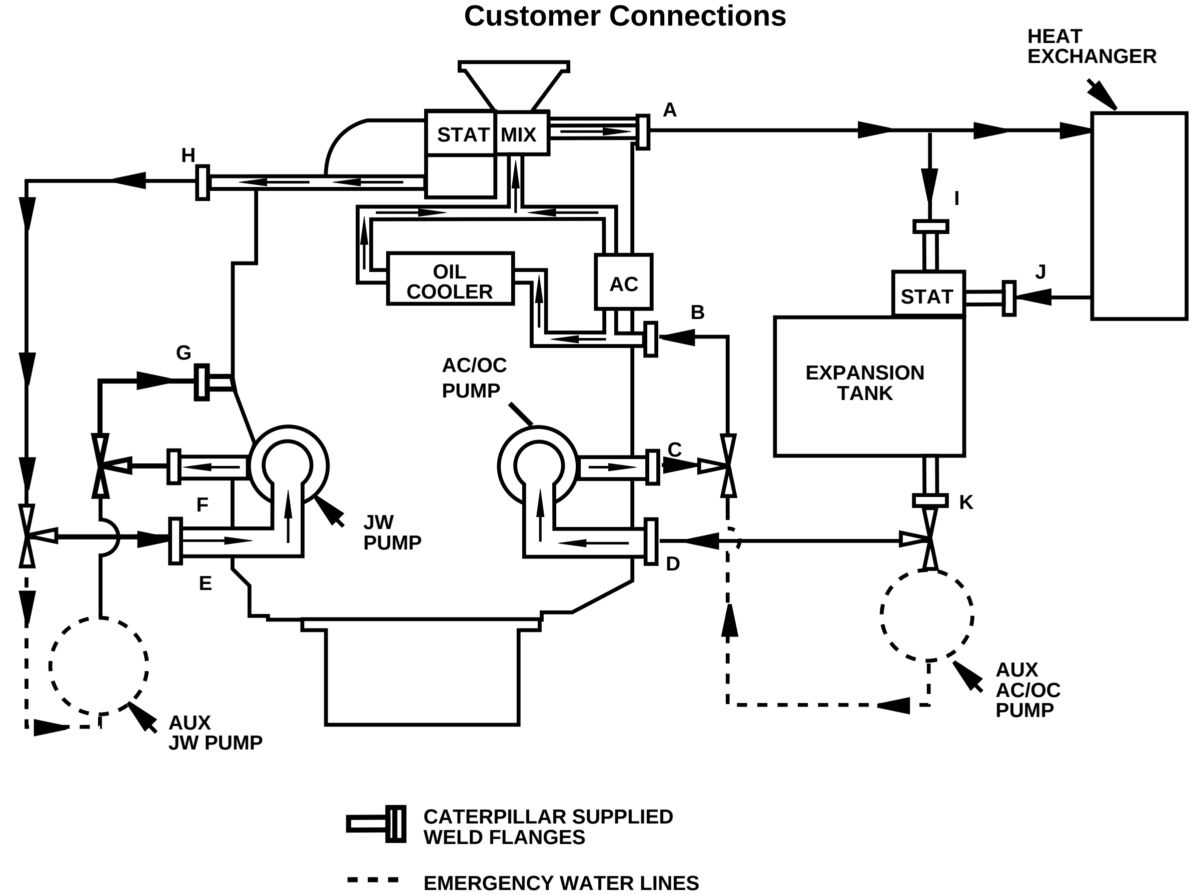
3600 Combined Circuit — Treated Water Cooling System
Customer Connections



Weld Flange ID — mm					
ENGINE	A	B	C	D	E
3606	143	171	143	143	171
3608	143	171	143	143	171
3612	143	171	143	143	171
3616	143	171	143	143	171

Figure 20

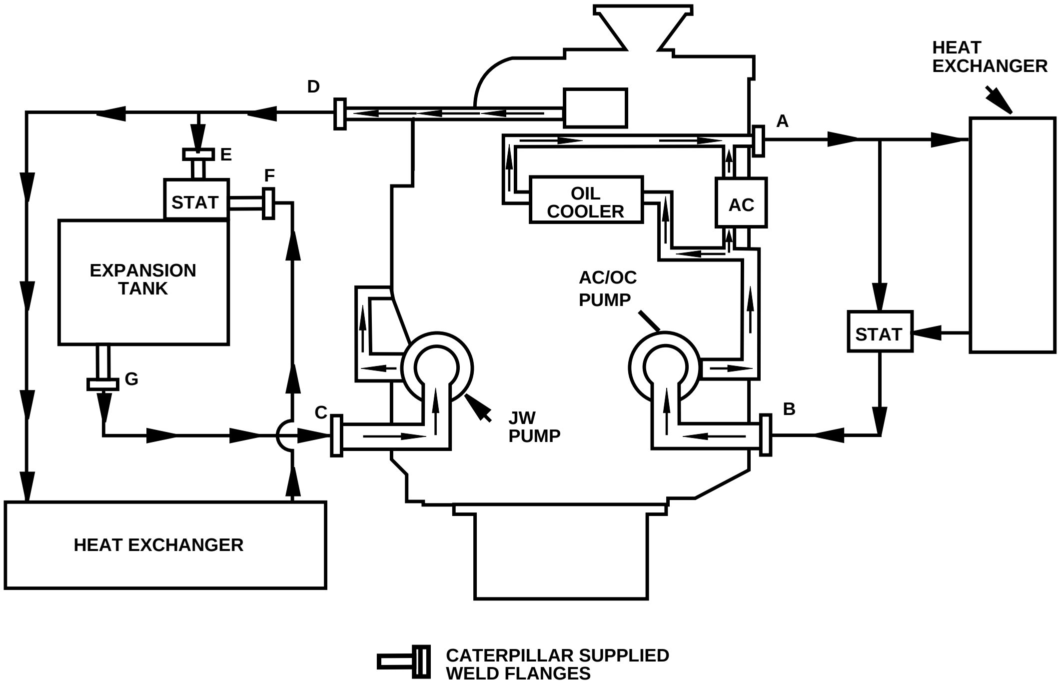
3600 Combined Circuit — Treated Water Cooling System with Auxiliary Pumps Customer Connections



Weld Flange ID — mm											
ENGINE	A	B	C	D	E	F	G	H	I	J	K
3606	143	110	110	171	171	110	110	143	143	143	171
3608	143	110	110	171	171	110	110	143	143	143	171
3612	143	143	143	171	171	143	143	171	143	143	171
3616	143	143	143	171	171	143	143	171	143	143	171

Figure 21

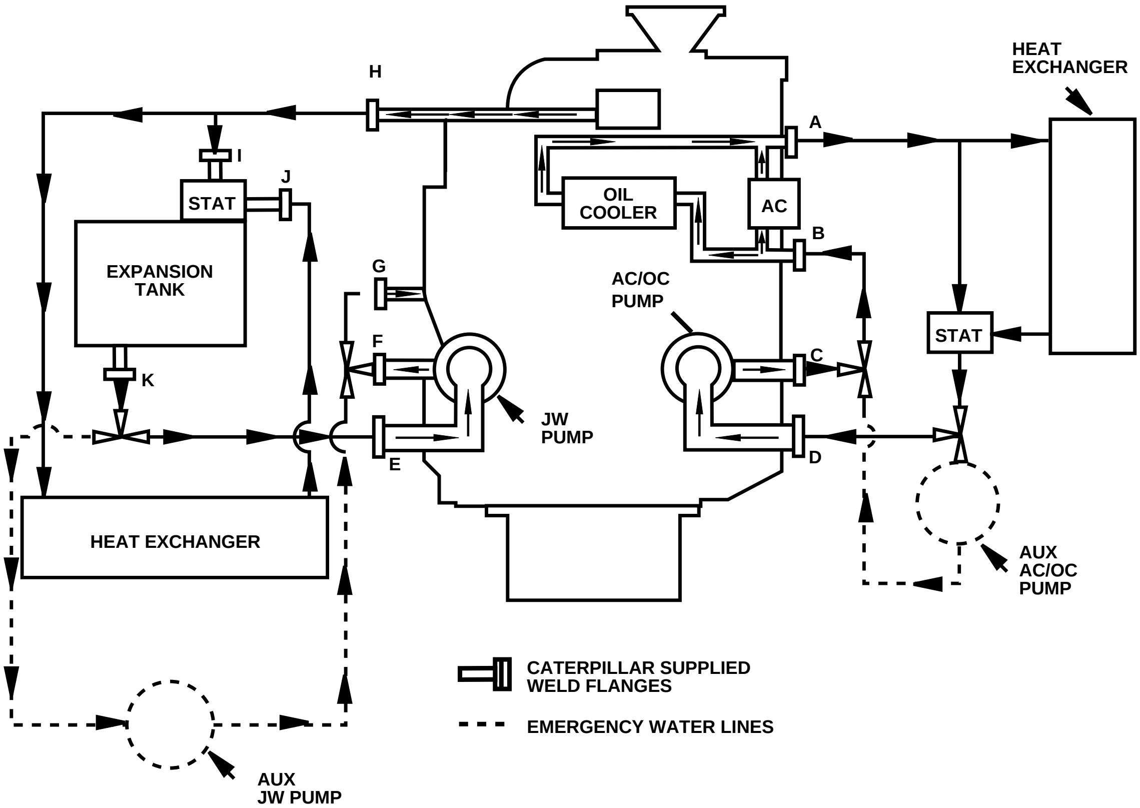
3600 Separate Circuit — Treated Water Cooling System
Customer Connections



Weld Flange - mm							
Engine	A	B	C	D	E	F	G
3606	110	171	171	171	143	143	171
3608	110	171	171	171	143	143	171
3612	143	171	171	171	143	143	171
3616	143	171	171	171	143	143	171

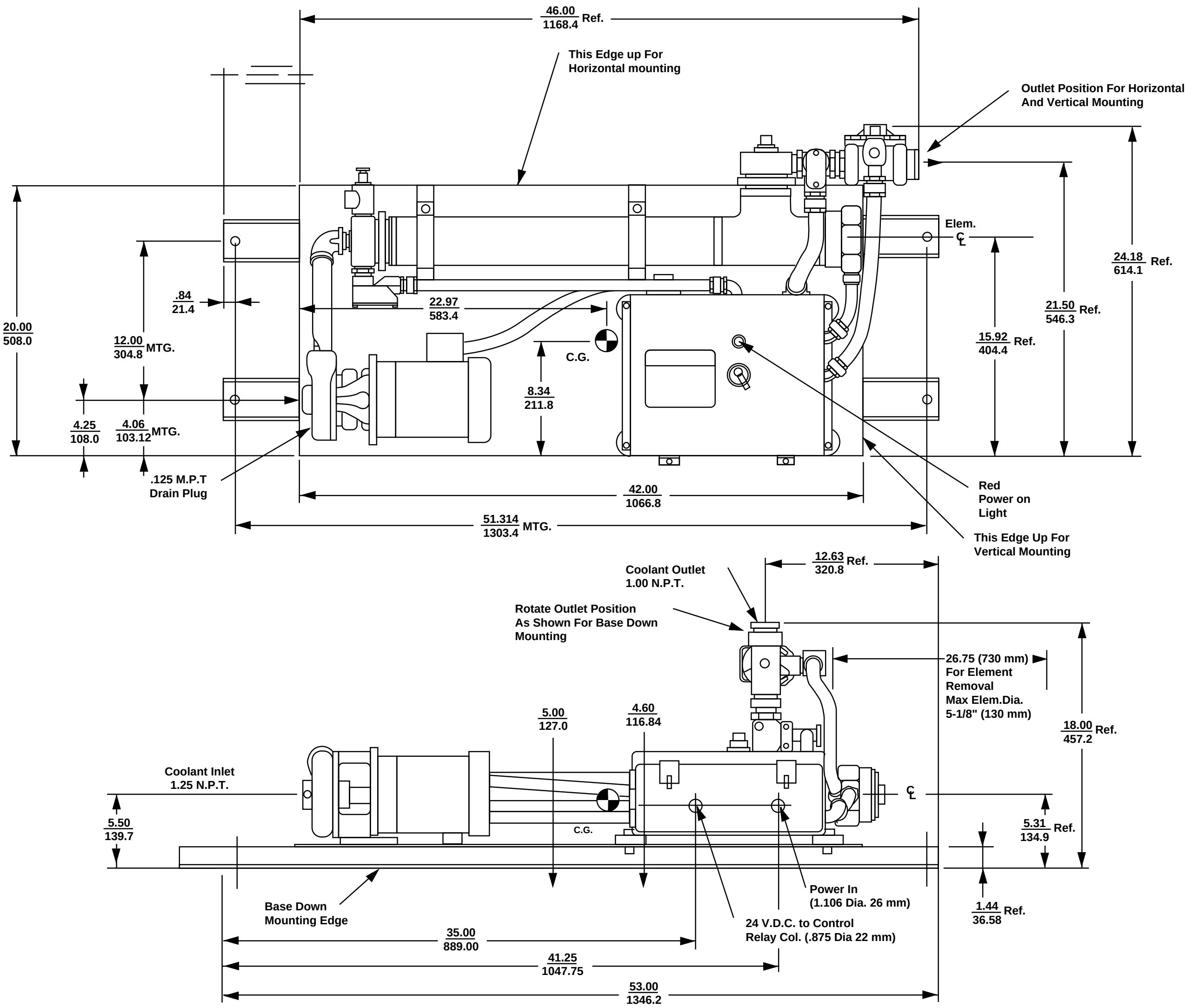
Figure 22

3600 Separate Circuit — Treated Water Cooling System With Auxiliary Pumps Customer Connections



Weld Flange ID - mm											
Engine	A	B	C	D	E	F	G	H	I	J	K
3606	110	110	110	171	171	110	110	143	143	143	171
3608	110	110	110	171	171	110	110	143	143	143	171
3612	143	143	143	171	171	143	143	143	143	143	171
3616	143	143	143	171	171	143	143	143	143	143	171

Figure 23



Sample Model No. CL 3 180 4 — 5 — CAT

Large Coolant Heating System — CL
1 - 1 Phase
3 - 3 Phase
120 - 12000 Watts
150 - 15000 Watts
180 - 18000 Watts
240 - 24000 Watts
(Incoloy Sheath Elements)

Main Power:
2 - 220/230v.
3 - 380v.
4 - 480v.
5 - 575v.

Hertz 5 - 50Hz
Blank - 80 Hz

CAT — Designed to Caterpillar Specifications

NOTES:

1. THE HEATING SYSTEM MUST BE MOUNTED IN THE PROPER POSITION TO ENSURE COMPLETE FILLING OF THE HEATING TANK. THE OUTLET MUST ALWAYS BE AT THE HIGHEST POINT OF THE INSTALLED SYSTEM. IF THE HEATING TANK IS NOT COMPLETELY FULL, PREMATURE ELEMENT FAILURE MAY RESULT.

2. COOLANT PUMP SUPPLY LINE MUST BE 1.25 NPT MIN.

PUMPING SPECIFICATIONS:

WARM WATER	LP.M. (GPM)	(HEAD IN METERS (FT))
15.6°C (50°F) 62M (25') SUCTION LIFT	0 (0)	195.7 (60)
26.6°C (80°F) 65.6M (20') SUCTION LIFT	37.8 (10)	180 (55)
37.8°C (100°F) 52.5M (16') SUCTION LIFT	75.7 (20)	147.5 (45)
48.9°C (120°F) 36.1M (11') SUCTION LIFT	113 (30)	131 (40)
60°C (140°F) 19.7M (6') SUCTION LIFT	151 (40)	98.4 (30)
82.2°C (180°F) 13.1M (4') POSITIVE SUCT.	169 (50)	85.6 (20)

3. THE COOLANT PRESSURE RELIEF VALVE IS ADJUSTABLE FROM 3.6-25.4 kPa COMPLETELY FULL, PREMATURE ELEMENT MAY RESULT. (25-175 P.S.I.) AND IS PRE-SET TO RELIEVE AT 10.9 kPa (75 P.S.I.) AND HAS AN .75 NPT OUTLET.

4. TOTAL SYSTEM WEIGHT 130 Kg (266 LBS.)

5. DIMENSIONS SHOWN AS $\frac{\text{INCHES}}{\text{mm}}$

KIM HOTSTART Mfc. SPOKANE WA.

PROPRIETARY INFORMATION

Typical Jacket Water Heating System

Figure 24

3600 Combined Circuit Heat Recovery System
With Heat Recovery on Jacket Water Circuit

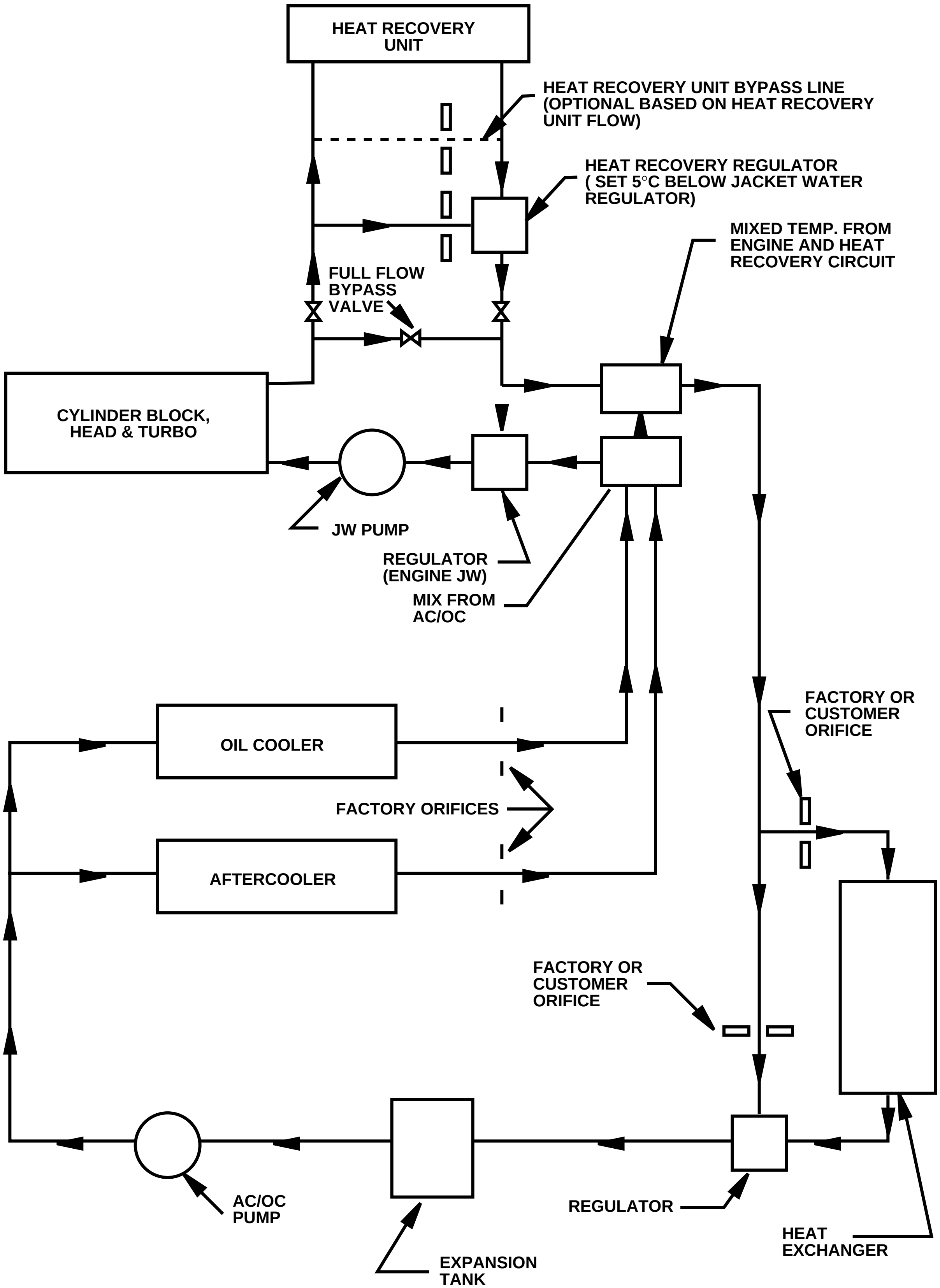


Figure 28

3600 Separate Circuit Heat Recovery System
With Heat Recovery on Jacket Water Circuit

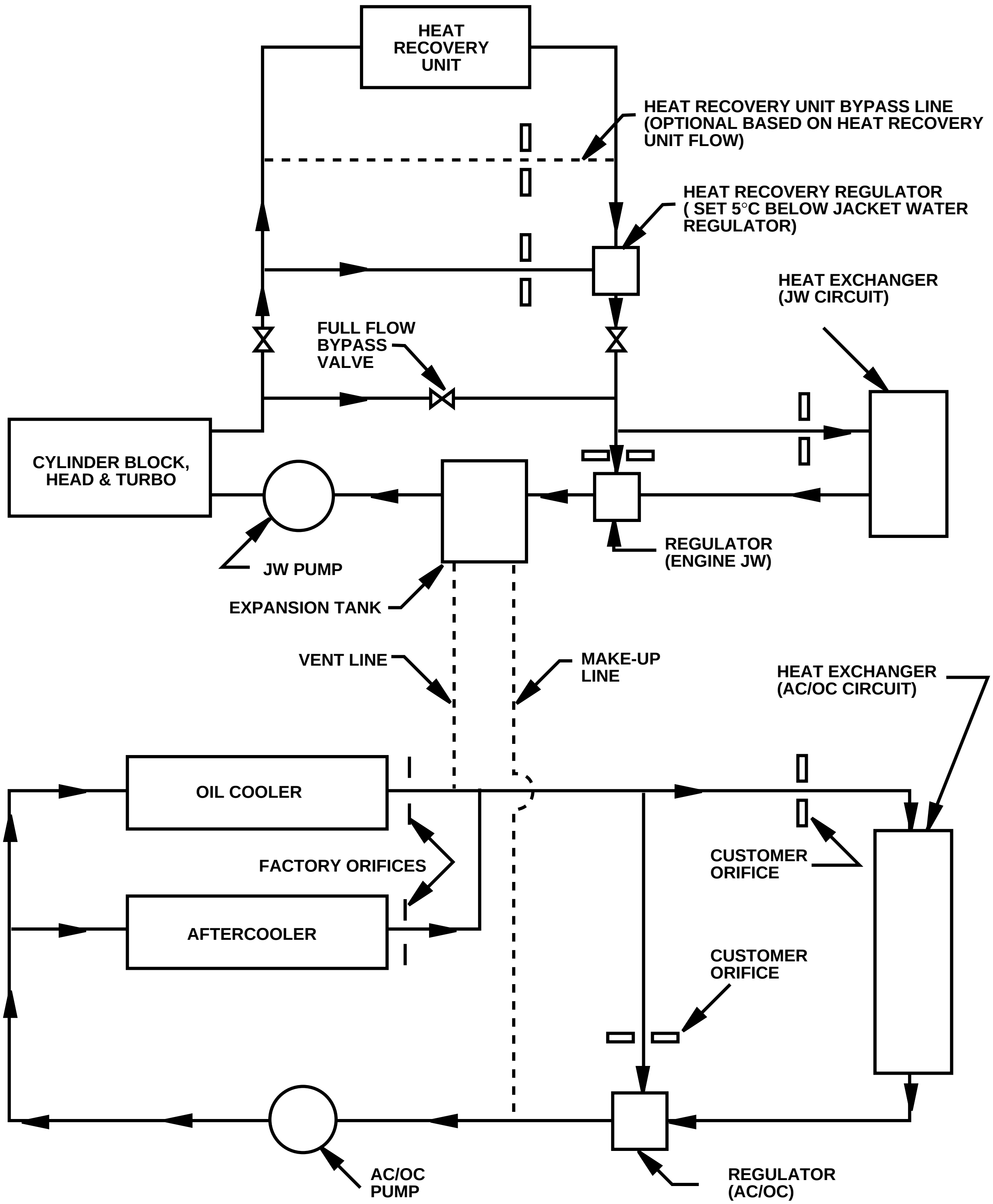


Figure 29

CATERPILLAR®

Diesel Engine Systems - Sea Water Cooling

General

Figure 30 is a typical single circuit sea water cooling system designed for marine applications. The fresh water circuit is cooled with sea water having a maximum temperature of 32°C (90°F). Since the lubricating oil and air aftercooler are cooled directly by water from the fresh water cooling circuit, only one fresh water heat exchanger is required. The aftercooler and oil cooler systems are an integral part of the basic engine design; nothing is required from the shipyard to pipe these systems. The arrangement reduces the sea water piping system and lowers the cost of expensive copper-nickel alloy piping, fittings, and valves. The result is less wear, corrosion problems, and maintenance.

Sea Connections

Locate sea chests to minimize the intake of silt, air, or discharges from overboard ship connections. Locate and design them to minimize entrance losses and suction problems when the ship is underway. Make every effort to minimize the possibility of the sea chests becoming air bound under conditions of roll, pitch, and astern operation. Keep them clear of bilge keels and located to not interfere with docking blocks.

The sea chests should have removable, galvanized, perforated grids located at the shell line. The grid must have a minimum clear area of 1.5 times the area of the inlet sea valve. Use stainless steel bolts and locking wire for grid attachment.

Fit the sea chests with baffle plates to trap entrained air. A vent valve is used between the baffle plate and shell to vent air above the weather deck. Use steam or compressed air to clear the grid.

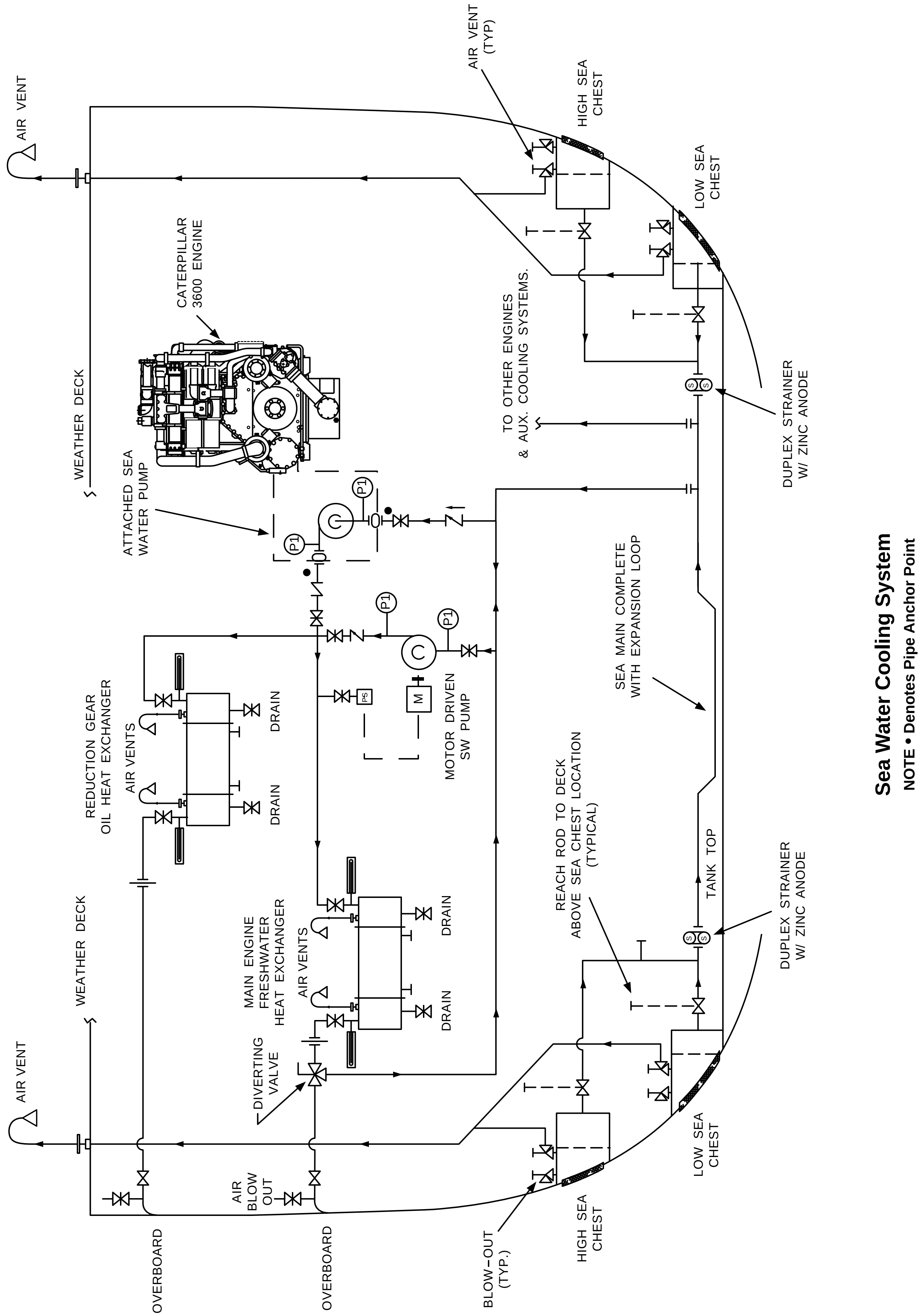
All pipe connections to the sea chest should be as short as possible and made of schedule 80 thickness minimum. When required, use gusset brackets to prevent excessive stresses at welded connections.

Protect the sea chest interior with anti-fouling paint and sacrificial anodes (zinc).

Do not allow overboard connections to discharge in lifeboat (or work boat) launching areas.

Where practical, all sea valves should be flanged gate or globe type. Lug type butterfly valves may also be used. Angle valves can be used where the installation of gate, globe or butterfly valves are impractical. Sea valves should be controllable from a deck above the sea chest. Fit all valves with open/close indicators. The recommended materials for sea chest or overboard discharge valves are cast steel, bronze or nodular iron. Cast iron and malleable iron valves are not recommended. The valve seat, disk, and stem must be made from corrosion resistant material such as monel alloys.

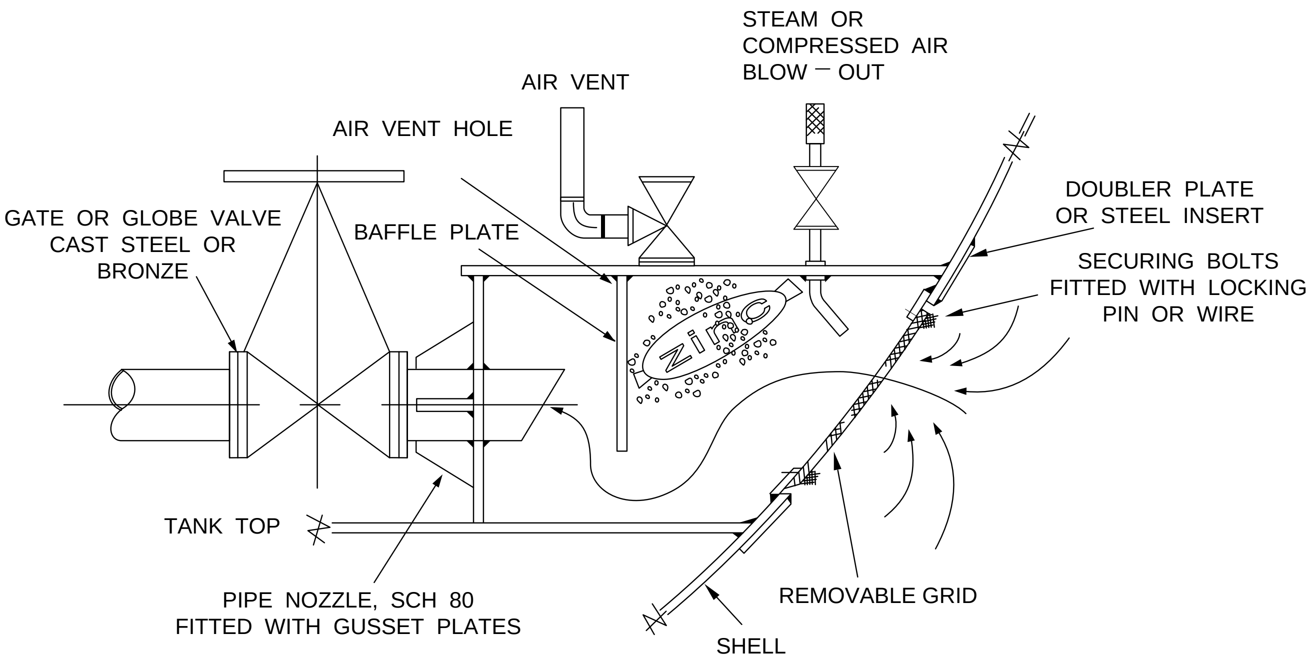
Install the high and low sea chests on the port and starboard sides of the ship. For a typical arrangement including overboard discharge connections, see Figure 31.



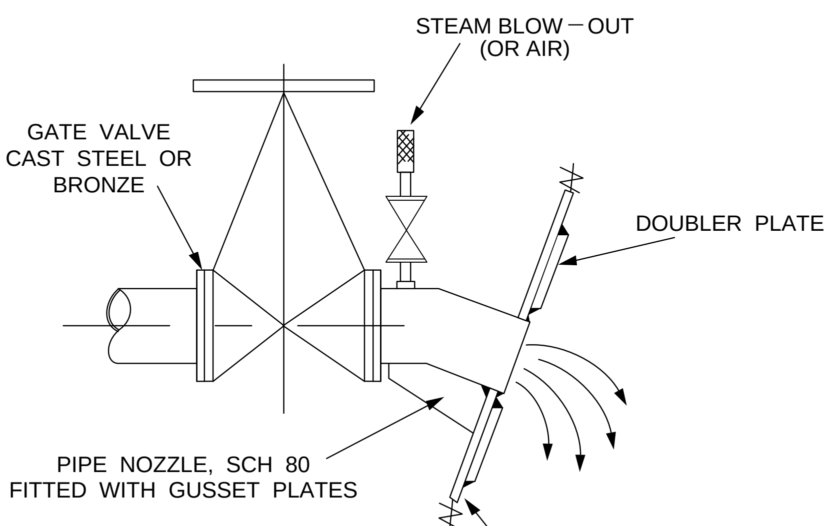
Sea Water Cooling System

NOTE • Denotes Pipe Anchor Point

Figure 30



Typical Sea Chest



Typical Overboard

Figure 31

Sea Water Strainer

Use duplex strainers with changeover valves between the sea chests and the sea water pumps. They must be bronze or galvanized cast iron and have stainless steel baskets with 5 mm (3/16 in.) diameter perforations. The perforation size must be smaller than the tube diameter of the heat exchanger to minimize flow passage fouling. Fit each strainer with a zinc anode. Locate them to allow servicing and cleaning of the baskets. Pressure loss through the strainer when clean and at full flow conditions should be as low as possible, approximately 7 kPa (1 psi). Use a differential pressure gauge or switch for early warning of strainer plugging.

Sea Water Pumps

Two centrifugal sea water pumps are normally used, one engine driven and one electrically driven. The engine driven sea water pump is not self-priming, so it must be located below the light water line of the ship or a priming arrangement must be provided. The pump rise of the engine driven pump versus capacity is shown in Figure 32. The engine power required to drive the Caterpillar supplied pump is shown in the *Engine Performance* section of this guide. The electrically driven sea water pump capacity is determined by the type of cooler used, heat to be dissipated, and the sea water inlet temperature. The heat to be dissipated in the main engine fresh water heat exchanger is listed in the *Engine Data* section of this guide.

In many sea water systems, the pump supplying cooling water to the main engine heat exchanger also supplies cooling water to auxiliary heat exchangers (such as the reduction gear oil cooler). In these arrangements the capacity of the sea water pump must be increased to allow for the additional requirements.

Start and stop control of the electric motor driven pump should be with a pressure switch installed in the common discharge line from the pumps. The switch starts the pump at 35 kPa (5 psi) and stops at 245 kPa (35 psi). The pipes connecting to the individual pumps must be at least equal to the pump suction diameter, to minimize the restrictions in the suction piping.

The suggested material for the pumps is:

- Casing bronze
- Impeller bronze
- Shaft monel
- Seal mechanical

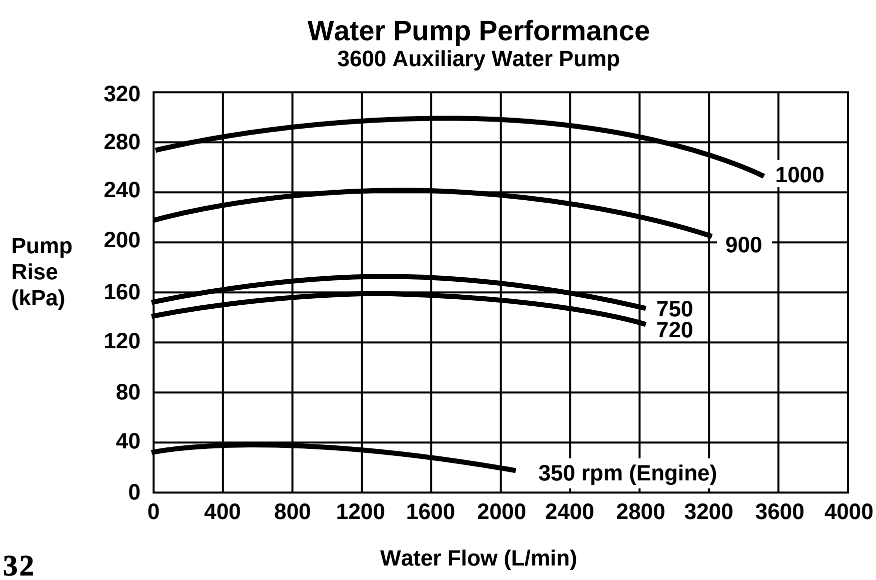


Figure 32

Fresh Water Heat Exchanger

Caterpillar supplies both shell and tube and plate type coolers for the fresh water heat exchanger. Since the heat exchanger tubes can be cleaned easily with a shell and tube type, sea water is usually routed through the tubes and the engine coolant through the shell. The flow in the sea water side of the heat exchanger is either single-pass or two-pass. A two-pass unit flows sea (raw) water twice through the heat exchanger; single-pass units use sea (raw) water only once. To provide maximum temperature differential and heat transfer in single-pass heat exchangers, the sea (raw) water must flow opposite the coolant flow. The direction of the sea (raw) water flow in two-pass heat exchangers is not important.

Heat exchanger performance will depend on the sea water flow and temperature differential. Orifices or fixed valves must be used to limit the sea water velocity to avoid erosion in the heat exchanger tubes. The maximum velocity through the tubes must not exceed 2.5 m/sec (8.2 ft/sec).

Fit each heat exchanger with:
- Drains
- Air vents

The suggested material for the heat exchangers is:

• Shell	Steel
• Heads	Cast Iron
• Tubes	90/10 CuNI
• Tube Sheets	90/10 CuNi
• Baffles	Steel

A plate type heat exchanger can be substituted for the shell and tube type. If installed, the suggested material for the plate heat exchanger is:

• Frame	Mild steel, painted
• Plates (sea water)	Titanium or aluminum brass
• Plates (raw, fresh water)	Stainless steel
• Nozzles (sea water)	Steel, coated
• Nozzles (fresh water)	Steel, coated
• Gaskets	Nitrile

Classification societies may require a spray shroud around the plates to prevent liquid spray on equipment or personnel if a gasket fails.

The *Engine Data* section of this guide has heat rejection to the sea water for the various propulsion engine ratings based on 32°C (90°F) fresh water to the AC/OC circuit. Add a safety margin of 10% to the total heat rejection to allow for heat exchanger fouling.

Marine Gear Oil Cooler

Reduction gear lube oil heat exchangers normally use sea water taken directly from the engine sea water circulating system. The water flow required is obtained from the gear manufacturer.

Fit each cooler with the following:

- Drain
- Air vents
- Zinc anode (fitted in each head)

Sea Water Cooling Temperature

If sea water temperature to the fresh water heat exchanger is too low, it can be raised by installing a three-way valve fitted just inboard of the overboard discharge valve. The valve can either be locally or remote controlled. The valve bypass feeds water directly back to the common suction pipe of the sea water circulating pumps. Pressure drop across the valve would normally be about 35 kPa (5 psi), and must be included in the sea water pump total dynamic head requirements.

Central Cooling System

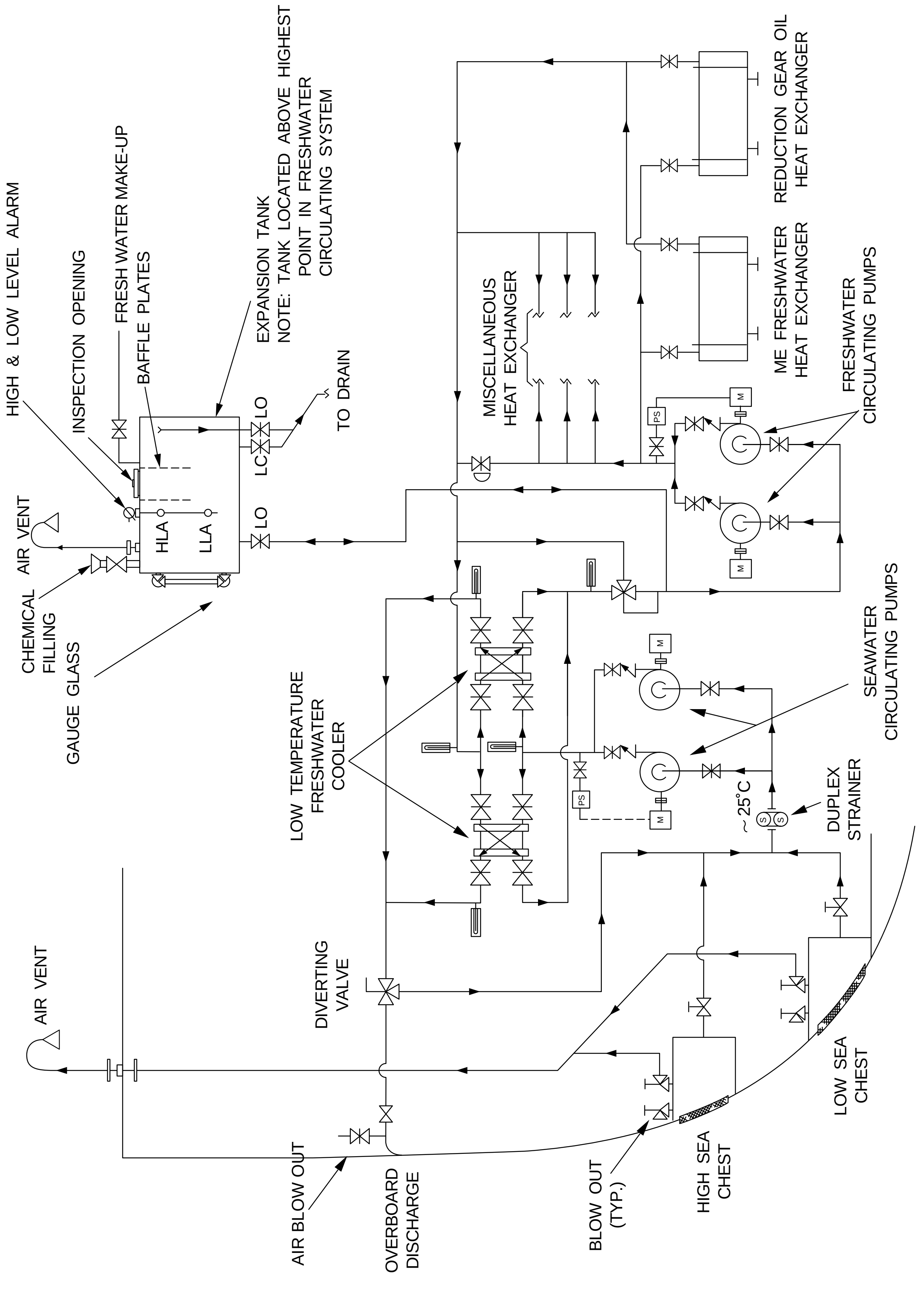
Figure 33 is a guide for a central cooling system for both engine and auxiliary equipment. The fresh water system is a closed circuit with all components connected in parallel with separate fresh water circulating pumps.

The sea water system circulates water from the sea chests through the central fresh water coolers and then overboard.

This arrangement will reduce the extent of the sea water piping system and thereby reduce wear, corrosion, and maintenance. Some disadvantages to this system are the additional electrical loads required for the additional circulating pumps, and a somewhat higher capital and installation cost.

Sea Connections

See section under *Sea Water Cooling System* for a description of sea connections and the suction strainer.



Typical Central Cooling System

Figure 33

Sea Water Pumps

Provide two electrically driven centrifugal sea water pumps with one arranged as a standby. The pumps must be self priming and have the capacity to handle the complete cooling system. Determine the capacity and head characteristics of the pumps from the type of coolers used and the heat rejection. The total dynamic head of the circulating pumps should include friction losses in the piping, pressure loss through the cooler, static discharge head (if any), and velocity head. Add a 10% margin to the calculated head to allow for fouling and aging of the system.

For other characteristics of the sea water pumps, see the pump description in this section.

Low Temperature Fresh Water Pumps

Provide two electrically driven fresh water pumps with one arranged as a standby. The pumps must be centrifugal type and capable of delivering the volume necessary to cool all the auxiliary heat exchangers in the low temperature circuit when circulating fresh water at approximately 26-32°C (79-90°F).

The suggested pump material is:

• Casing	Cast iron
• Impeller	Bronze
• Shaft	Stainless steel
• Seal	Mechanical

Fresh Water Coolers

The fresh water central cooler (or coolers) can be either shell and tube or plate type. The cooler construction should be similar to those outlined in the previous section. Pressure drop across the coolers on the sea water circuit can be obtained from the cooler manufacturer. Install two coolers with each being capable of handling the total heat from the various sources.

Temperature Control Valve

The low temperature fresh water circuit should achieve about 26-32°C (79-90°F) at the discharge to the auxiliary heat exchanger circuits when cooled by seawater at a maximum temperature of about 25°C (77°F). This ensures that the low temperature engine coolant circuit can operate between 32-38°C (90-100°F) with a maximum approach temperature of 6°C (11°F) between the central cooling circuit and engine cooling circuit. The central cooling temperature control valve should be self-contained and fitted with a manual override. The valve must have a cast iron body with bronze internal components.

Expansion Tank

The expansion tank compensates for volume changes in the cooling water circuit, serves as a degassing tank, and provides sufficient static pressure on the cooling system

The following design criteria is provided for guidance:

- Pressure from expansion tank - Locate tank above highest point in fresh water circuit.
- Volume - Approximately 10% of fresh water system volume with a minimum of 160 L (50 gal).

Vent pipes from high points in the system must have separate connections to the expansion tank. The pipes on a continual upward slope will prevent air locks. The connection on the tank must be below the minimum water level in the tank to prevent the entry of air.

Fabricate the tank from mild steel. It must be provided with the following connections: air vent, manhole, local chemical fill, overflow, gauge glass, outlet strainer, drain, vent(s) from engine or equipment, and filling.

See Figure 34 for a typical expansion tank arrangement.

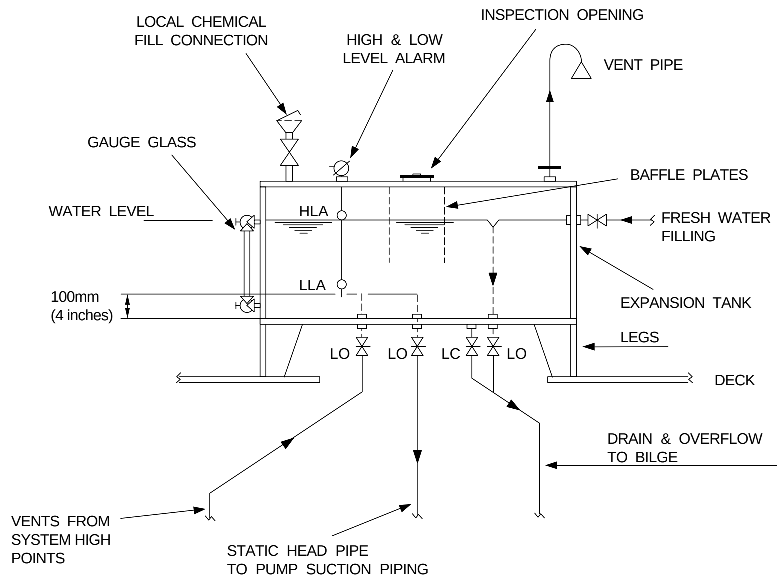


Figure 34 **Fresh Water Expansion Tank**

Pressure Control Valve

A valve is installed to balance the system if one or more of the heat exchangers is shut off. In response to pressure differences across the exchangers, the valve will open or close and try to maintain the pressure at its original setting. As a result, the water flowing through the remaining heat exchangers will remain unchanged, and the temperature relationships will remain constant. Fabricate the valve from cast iron, with bronze internal components, and stainless steel trim.

Galvanic and Electrolytic Corrosion

Electrical current in coolant flowing through different metals can cause galvanic corrosion. The coolant acts as an electrical conductor between metals that are coupled together. An electromotive force or a potential voltage existing between dissimilar metals allows current to flow. Galvanic corrosion occurs on the least resistant (i.e., the least *noble*) metal.

In marine applications where sea water is highly conductive, a sacrificial material is placed in sea water flow passages to act as the anode and absorb current flow. Typically, the sacrificial anodes are zinc rods strategically placed in the piping and near critical components such as heat exchangers, pumps, valves, etc. The shell and tube heat exchangers provided by Caterpillar are manufactured from material which is designed for a sea water environment. Do not install zinc sacrificial anodes in the inlet or outlet bonnet of Caterpillar supplied shell and tube heat exchangers because these increase turbulence in the tubes and can break off and lodge inside the tubes. This further increases turbulence and leads to tube erosion and leakage. Generally black iron piping is used for sea water systems and this provides the best galvanic protection for the heat exchanger. If copper-nickel or stainless steel piping is used, zinc or iron anodes should be provided in the piping to protect the heat exchangers. Rods must be inspected regularly and replaced when necessary. The recommended inspection interval is every 50 hours until a wear rate is established. A listing of zinc rods currently available through the Caterpillar Parts System is shown below in Figure 35. This may be used as a guide in selecting suitable zinc rods for specific applications. Check the status, availability, and possible additional similar parts, prior to making a final selection.

Brass plugs attach the zinc rods to system components. The rods are held in place by straight threads. A typical zinc anode assembly is shown in Figure 36.

Apply sealant only to the shoulder of the zinc rod before assembling to the brass plug. Sealant is *not* to be applied to the straight threaded joint between the rod and plug. Apply thread sealant to the external pipe thread of the plug following normal procedures and specifications as illustrated below in Figure 36.

Brass plugs currently available through the Caterpillar Parts System for use with Caterpillar zinc rods are shown below in Figure 37. Check status and availability prior to final selection. Sacrificial anodes are not provided with the factory supplied heat exchangers. They can be ordered through the Caterpillar parts distribution system.

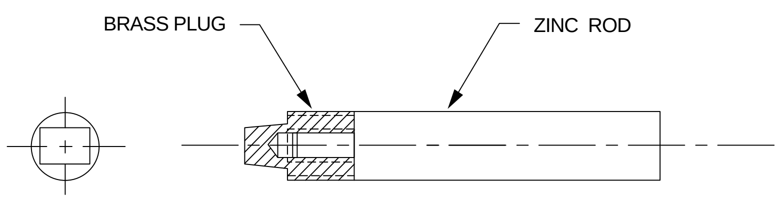
Zinc Anode Summary

Zinc Rod	Straight Thread Size	Rod Length From Shoulder (mm)	(in)	Zinc Rod Diameter (mm)	(in)
6L3104	1/4 - 20	38.1	1.50	9.5	0.38
6L2283	1/4 - 20	57.0	2.25	10.0	0.39
6L2287	3/8 - 16	22.4	0.88	12.7	0.50
6L2281	3/8 - 16	30.2	1.19	12.7	0.50
6L2280	3/8 - 16	41.0	1.62	13.0	0.51
5B9651	3/8 - 16	50.8	2.00	16.0	0.63
6L2288	3/8 - 16	63.5	2.50	16.0	0.63
6L2289	3/8 - 16	76.0	3.00	16.0	0.63
7F9314	3/8 - 16	114.3	4.50	16.0	0.63
6L2016	5/8 - 18	20.5	0.81	22.0	0.87
6L2284	3/4 - 10	53.8	2.12	31.8	1.25
6L2285	3/4 - 10	63.5	2.50	31.8	1.25

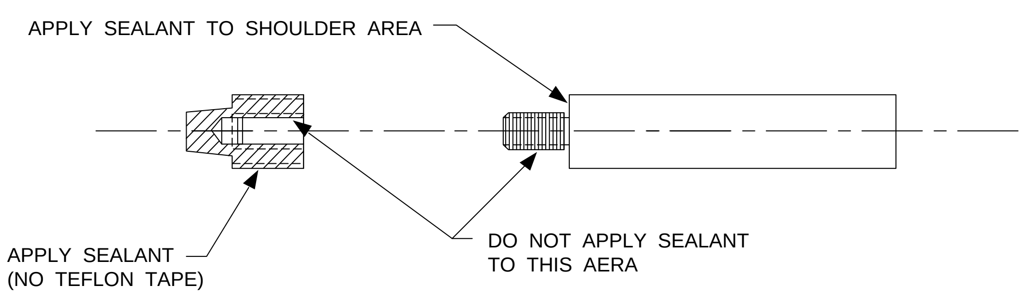
Figure 35

Similar to galvanic corrosion, electrolytic corrosion occurs with an external source of current flow through the coolant. Despite sea water or engine coolant mixture quality, presence of an electrical potential can cause electrolytic corrosion damage to the cooling system materials. Aluminum materials are attacked very rapidly by this type of corrosion. Most materials common to cooling systems, such as copper, brass, bronze, copper-nickel, steel, and cast iron, are susceptible to electrolytic corrosion.

Electrical systems must be designed to eliminate continuous electrical potential on any cooling system component. Electrolytic corrosion is extremely difficult to troubleshoot, since the source of electrical current must be located. A common cause is improper grounding or corroded ground connections. Care must be taken during design, installation, and maintenance phases to assure all grounds are tight and corrosion free.



Typical Zinc Anode



Sealant Application - Zinc Anode

Figure 36

Brass Plug Summary					
		External	Drill	Boss	
Rod Thrd.	Brass Plug	Plug Thread	Dia. (mm)	Min.Dia. (mm)	Min.Thk. (mm)
1/4 - 20	6L2282	1/4 - 18	11.2	28	6
3/8 - 16	6L2279	3/8 - 18	14.5	30	7
3/8 - 16	5B9169	1/2 - 14	18.0	35	8
5/8 - 18	6L2020	3/4 - 14	23.2	40	9
3/4 - 10	6L2286	1-1/4 -11-1/2	38.0	55	11

Figure 37

Marine Growth

Over a period of time, marine growth will adversely impact the efficient operation of heat exchangers. It is necessary to periodically *disassemble* heat exchangers to clean heads and tubes. The use of local thermometers, high temperature alarms, and other instrumentation can warn of gradual loss of sea water flow, and are highly recommended. Periodic chemical treatment will also combat marine growth in sea water systems. The chemical type and concentration must be controlled to prevent deterioration of components in the sea water circulating system, and to minimize environmental impact. Contact a knowledgeable supplier if a chemical treatment system is to be installed. Continuous low concentration chemical treatment via either bulk or self-generating electrical processes are available from various manufacturers.

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- Air Intake
- Exhaust
- Starting Air
- Crankcase Fumes Disposal

LEKM8466 8-98

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Engine Systems - Air Intake

Engine Room

Diesel engine rooms contain many pieces of equipment using combustion and ventilation air. Air requirements other than the engine must be considered.

A method for evaluating both combustion and ventilating air requirements is provided at the end of this section. Classification society and/or regulatory rules should also be reviewed.

The following systems may require engine room combustion and/or ventilation air.

Combustion Air	Ventilation Air/ Heat radiation
Main engines	Main Engines
Ship service generator engines	Ship service generator engines
Boilers	Exhaust piping
	Boilers
	Steam and condensate piping
	Generators
	Electrical equipment including motors
	Hot tanks

Engine room air flow arrangements generally fall into two categories:

- Engine room supplied with filtered air for engine combustion and radiated heat removal. The engine uses combustion air from the engine room using an air intake silencer at the turbo inlet. This system is normally used in vessels operating in clean ambient surroundings.
- Engine room supplied with ventilation air for heat removal and engine combustion air supplied through dedicated air cleaners. The cleaners may be engine room mounted. This arrangement is normally used in inland waterways where the vessel can encounter dirty ambient conditions. The air cleaners for the engine can be part of the Caterpillar engine supply.

Combustion Air

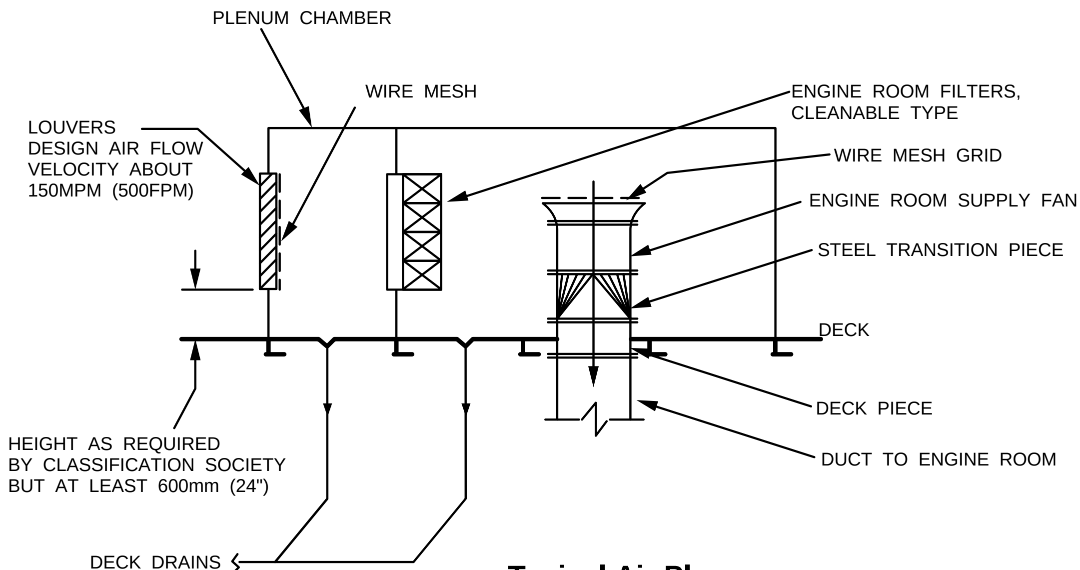
High temperature air supplied to the engine inlet (combustion air) can cause severe engine problems including high exhaust temperatures, piston problems, turbocharger compressor life reduction and turbocharger turbine damage. The maximum air temperature supply to the engine inlet is 45°C (113°F) for standard ratings. This should be the maximum temperature air that the engine receives under the highest ambient temperatures expected. Cooler air in the range of 10° - 30°C (50° - 86°F) is generally desirable.

Temperatures above 45°C (113°F) will usually require a derated condition, even if this occurs for only a short time.

Filtered Air To Engine Room

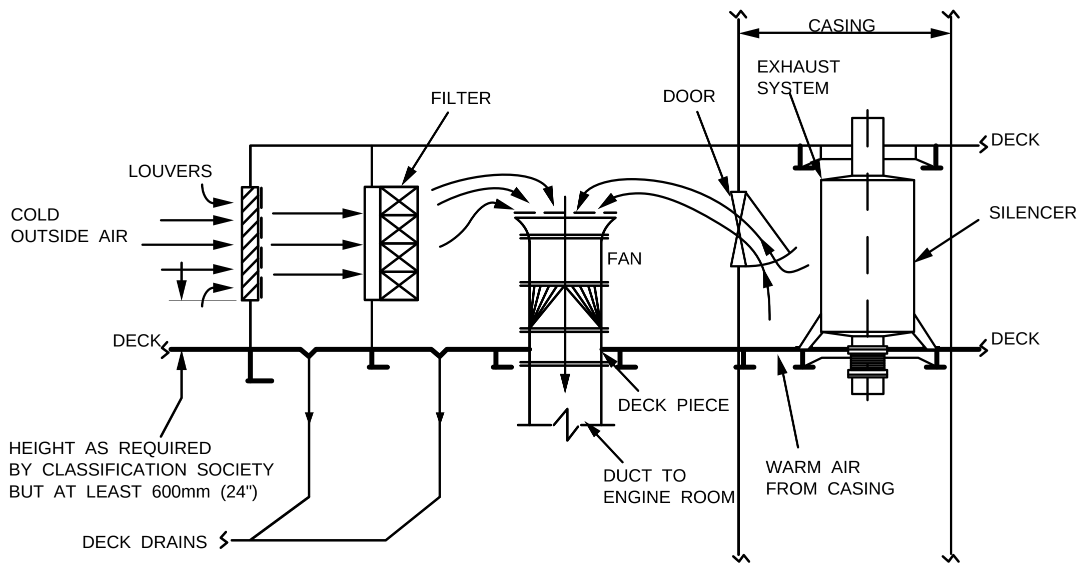
The engine room air must supply engines and boilers with combustion air, remove radiant heat, and provide comfortable engine room working conditions. The following factors must be considered:

- Combustion air must be free from water spray, dust and oil mist.
- Water spray, dust, exhaust gas fumes, oily vapors, etc. must not enter the ventilation fan air inlet plenums. Figure 1 is a suggested plenum arrangement for filtered combustion and ventilation air.



Typical Air Plenum Arrangement

Figure 1



Typical Warm Air Arrangement

Figure 2

- Heated engine room air may be required (for starting purposes only) in applications at very cold ambients (-25°C (-13°F)). This assumes combustion air is being drawn from outside the ship and the engine is preconditioned with preheaters for fuel, water and oil temperatures of 0°C (32°F). In cold weather operations provide a door from the engine room casing into the plenum to warm the cold outside air.

The door would be closed in warm weather. A suggested arrangement is shown in Figure 2. Admitting engine room air must be done without the possibility of allowing dirt or debris in the engine air inlet system. Also, do not recirculate oil laden air or warm engine room air through engine room doors.

- Air cleaner icing can occur in saturated air environments when the ambient air dew point is near freezing temperature. Velocity and pressure changes at the air cleaner inlet reduce the moisture holding capacity of the air, resulting in moisture condensation and ice crystal formation. The ice buildup reduces air flow area and increases the pressure differential across the air cleaner. Eventually a plateau is reached where the pressure differential remains constant even though ice buildup may continue. Power loss and increased fuel consumption will result during these periods.

- Consider two speed engine room supply fans for cold climate operation.

- Engine room air ducting design should consider:
  a) Engine cool air duct discharges should be near and directed at the turbochargers air inlets. This arrangement assumes water free air.
  b) A smaller air flow should evenly distribute ventilation air alongside the engine, coupling, reduction gear, and generator (if fitted) to dissipate radiant heat.
  c) Distribute sufficient air flow throughout the engine room and in areas where work or maintenance take place.

- Engine room supply fans should maintain a slight overpressure in the engine room. This pressure should normally not exceed 0.062 kPa (0.25 in H_2O).

- Exhaust fans may be required if the ventilation air from the engine room cannot be led through a stack with natural ventilation.

- Rooms with fuel oil centrifuges should have separate spark proof exhaust fans discharging to atmosphere. Do not locate the discharge near fresh air inlets.

- Install fire dampers in the ventilation ducting at fans and all exhaust openings.

Outside Air To Engine Air Filters

Air Cleaners Outside The Engine Room

Combustion air should be taken directly from the atmosphere through remote mounted air cleaners in dirty environments, hot climates, and tropical service operations (see Figure 3 on page 23). They are dedicated to engine combustion air and can be Caterpillar supplied. One air cleaner is provided for each turbocharger. Combustion air is ducted from the air cleaner to the turbocharger air inlet. The turbocharger air inlet is provided with a transition piece and flexible connection as shown in Figure 3. The ducting between the air cleaner and the turbocharger should be corrosion resistant material of sufficient thickness and stiffness. The air velocity in the duct should not exceed 25 m/sec (82 ft/sec), and the ducting able to withstand a minimum restriction of 12.5 kPa (50 in. H_2O), which is also the structural capability of the Caterpillar air cleaner.

Air Cleaners In The Engine Room

Locate the air cleaners as close to the turbocharger as possible. Each turbocharger is provided with a separate Caterpillar supplied air cleaner (see Figure 4 on page 24).

Cleanliness

Air intake ducting must be cleaned of all debris. Rivet type fasteners should not be used and welding should be minimized. Remove slag from the ducting interior. Due to the distinct possibility of inlet screen failures and subsequent turbocharger damage, Caterpillar does not provide devices to trap debris ahead of the turbocharger. *Ducting should be made of material durable enough to withstand prolonged operation without debris loosening and entering the turbocharger.*

Install an identifiable blanking plate ahead of the turbocharger to prevent debris from entering during initial engine installation. The plate should have a warning tag indicating it must be removed prior to starting the engine. The Caterpillar supplied shipping cover can be used.

Install takedown flanges in the ducting to allow internal inspection prior to initial startup.

Inlet Restriction

The maximum allowable inlet restriction is 3.7 kPa (15 in. H_2O) with dirty air cleaner elements, and 1.2 kPa (5 in. H_2O) with initially clean elements.

Mass/Volume Flow Conversions

The volumetric air flow found in TMI and in the Engine Data section of this guide are at conditions of 95.9 kPa (28.4 in. hg) inlet pressure and 25°C (77°F) inlet temperature. The flow also simulates the restriction of a clean air cleaner and is applicable for conditions of 100 kPa (29.6 in. Hg) inlet pressure and 25°C (77°F) inlet temperature (which represent SAE J1995 and ISO 3046 conditions).

The corresponding mass air flow ($\dot{M}$) can be calculated using the following relationships:

$$V_{Air}\ (\text{m/min}) = .01486 \times \dot{M}_{Air}\ (\text{kg/hr})$$

$$V_{Air}\ (\text{cfm}) = .2382 \times \dot{M}_{Air}\ (\text{lb/hr})$$

***Note**: Heavy fuel oil burning engines require higher inlet air flow than distillate burning engines. See the Engine Data section of this guide.*

Caterpillar Air Cleaners

Caterpillar air cleaners consist of high efficiency washable paper elements packaged in a low restriction weatherproof housing. They may be bulkhead or deck mounted with the air inlet facing downward. Modification is required for element support if horizontal entry is required. Depending on environmental operating conditions, two housings are available. One housing contains two elements (double) and the other contains three elements (triple). Housings are also available with precleaners (see Figure 5).

Figure 5

	Standard Duty Without Precleaner	Heavy Duty With Precleaner
3606	1-Double Element Housing	1-Triple Element Housing
3608	1-Double Element Housing	1-Triple Element Housing
3612	2-Double Element Housing	2-Triple Element Housing
3616	2-Double Element Housing	2-Triple Element Housing

The cleaners are 99.5 percent efficient for proper turbocharger and aftercooler performance. Use of less efficient elements will result in turbocharger compressor wheel and aftercooler fouling. Dirt on the turbo compressor wheel can cause rotating imbalances leading to turbocharger failure. Fouling of the aftercooler core results in reduced performance and high exhaust temperature problems.

All air cleaner housings are now epoxy coated and can be used for operation in a salt spray environment.

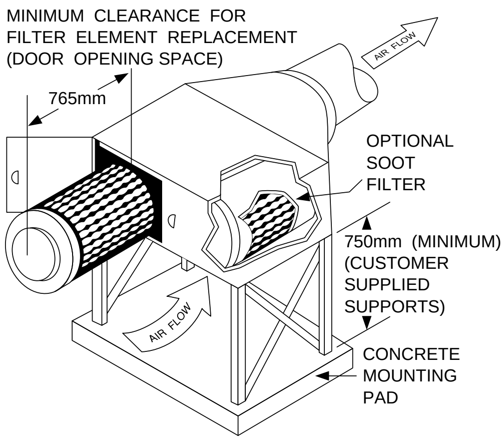


Figure 6

An optional soot filter rated at 70% efficiency is available (Figure 6) to extend element life in applications where exhaust gases can be recirculated.

Consideration should be given to air cleaner element service as a dirty element can weigh 35 kg (78 lb). See Figure 7.

Precleaners

Precleaners adapt to standard air cleaners (Figure 8) producing heavy duty air cleaners which extend filter service periods. *They impose added air restriction and are not recommended for heavy fuel engines.* Precleaners provide 94 percent efficiency in severe dust applications. Heavy duty air cleaners provide the same protection as standard filters, but they allow further extension of filter change periods. Service periods improve six to seven times over that of standard air cleaners.

Air Cleaner Dimensions

See Figure 9 on page 10.

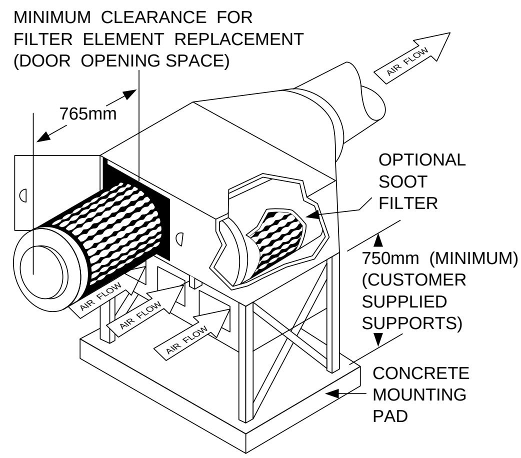


Figure 8

Air Cleaner Restriction

Air cleaner restriction versus engine air flow is shown in Figure 10. Restriction includes the air cleaner housing and elements. The air flows shown are based on the amount of air going through one double or one triple element housing. Total engine air flow for propulsion engines can be found in the *Engine Data* and *Engine Performance* sections of this guide. Heavy fuel engine air flow is in the *Engine Data* section. Also check the TMI System. The air flow entered on the chart is the flow through one air cleaner housing.

Caution*: TMI air flow data is the flow required for an entire engine. As an example, since the vee engines require two air cleaner housings, the air flow taken from TMI for a 3612 or 3616 Engine requires division by 2 before entering the chart.*

The Caterpillar supplied air cleaner housings contain a *pop up* type indicator set for a maximum restriction of 3.7 kPa (15 in. $H_2 0$).

Air Cleaner Specifications - kg (lbs.)

Duty Rating	Element Qty.	Clean Element Weight (ea.)	Dirt Retention Cap. (ea.)	Total Weight (including housing) Clean	Total Weight (including housing) Dirty
Standard	2	16 (35.3)	23 (50.7)	232 (511.5)	278 (612.9)
Heavy	2	16 (35.3)	23 (50.7)	352 (776.0)	435 (959.0)
Heavy	3	16 (35.3)	23 (50.7)	490 (1080.3)	566 (1247.8)

Figure 7

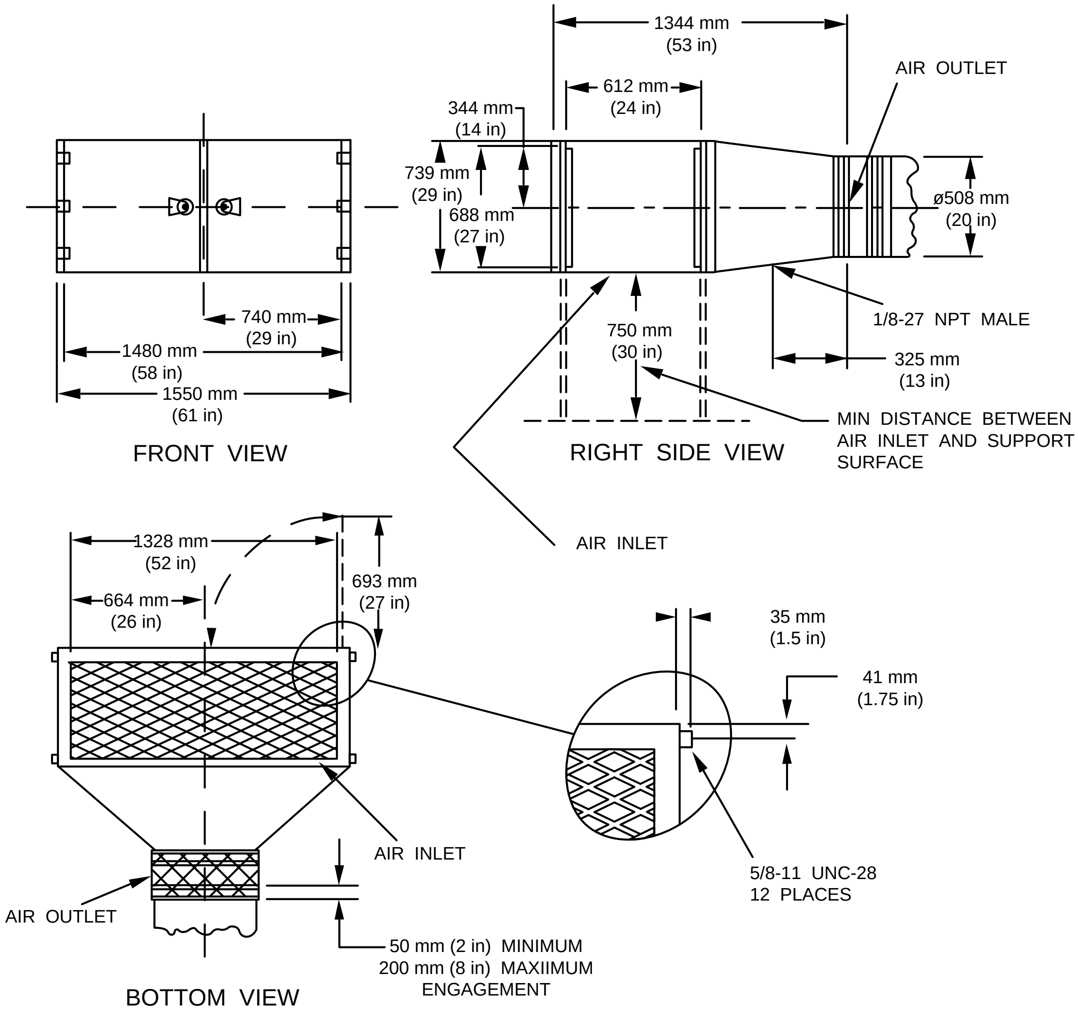


Figure 9

Engine Air Intake Silencer

A Caterpillar air intake silencer can be used in an engine room using filtered air. The silencer can be mounted directly to the turbocharger compressor inlet as shown in Figure 11.

A Caterpillar air intake filter/silencer is also available for use with 3606 and 3612 engines. It cannot be used with 3608 and 3616 engines due to excessive inlet restriction. The filter/silencer provides good air filtration, but it should be used in a clean engine room environment (filtered air). It should be remote mounted from the turbocharger inlet as shown in Figure 11.

Air Inlet Adapters

Caterpillar offers various air inlet adapters for connecting the shipyard furnished ducting to the turbocharger air inlet. They are shown in Figures 12 through 14. They are shipped loose and include gaskets and mounting hardware.

Caution*: Turbocharger performance may be adversely affected if Caterpillar supplied air intake components are not used. They are designed to provide the proper air flow pattern ahead of the turbocharger.*

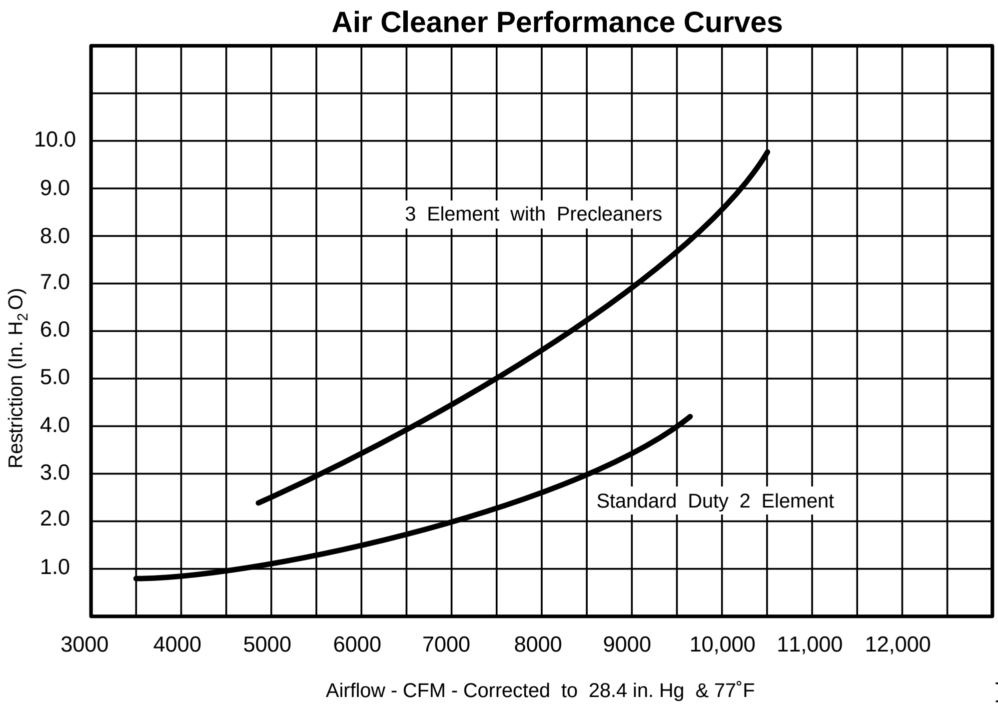
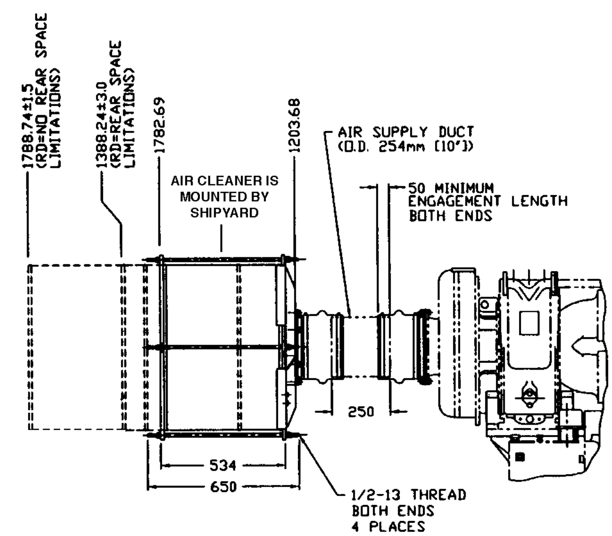


Figure 10



Typical Air Inlet Filter/Silencer
(for 3606 and 3612 engines only)

Figure 11

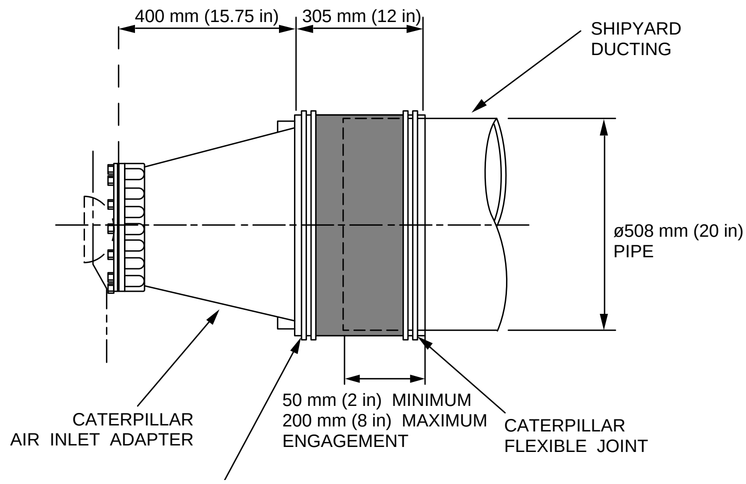


Figure 12

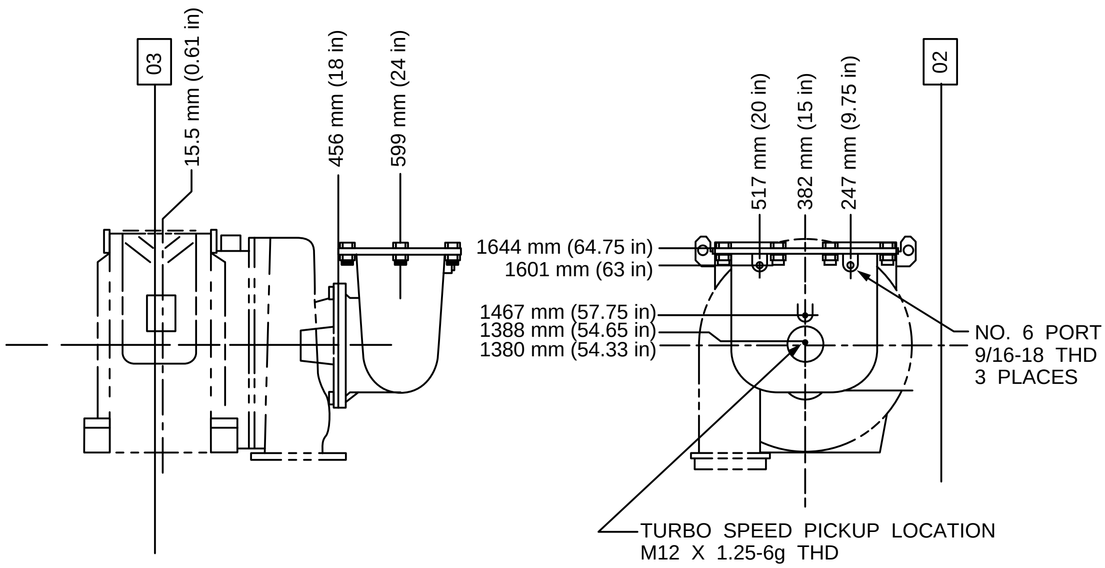
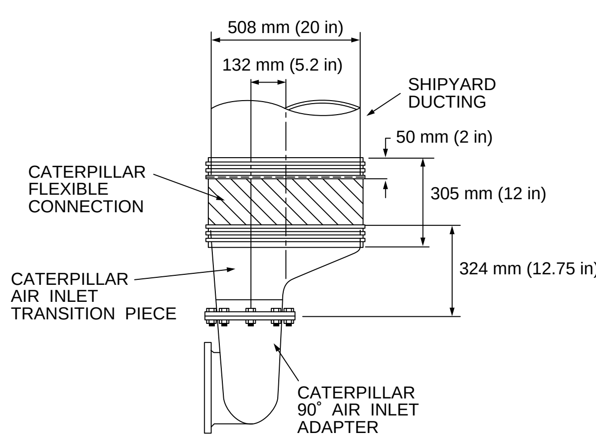


Figure 13

The inlet elbow shown in Figure 13 can be rotated in 30° increments.

Flexible Connections

Flexible connections are required to isolate engine vibration and noise from the ducting system. The flex should be as close to the engine as practical. The flex engagement with the air intake duct should be a minimum of 50 mm (2 in.) and a maximum of 200 mm (8 in) (see Figures 12 and 14). Care must be used to prevent exhaust piping heat from deteriorating rubber flex connections.

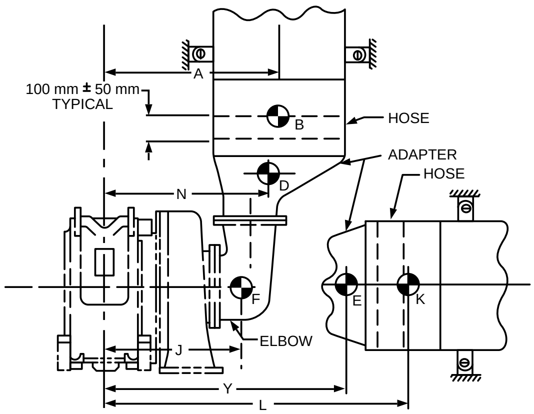


Typical Air Inlet Transition Piece Adapter (Rectangular To Round)

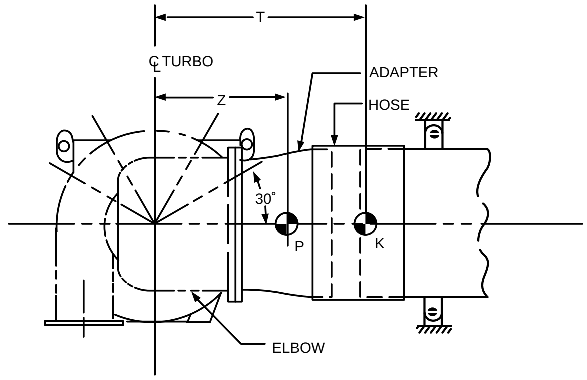
Figure 14

Maximum Loads For Turbocharger Intake

Vertical Or Axial Air Inlet



Horizontal Side Air Inlet



D, F & E = Adapter Weight
B & K = 1/2 Hose Weight
Moment (Vertical Inlet):
M_V = JF + ND + AB
Moment (Axial Inlet):
M_A = YE + LK

Allowable Max Moment = 30 kg-m

With Caterpillar Supplied Hardware

J = 548 mm N = 625 mm A = 700 mm
Y = 705 mm L = 945 mm
D = 13 kg E = 14 kg F = 16 kg
B = $\frac{3 \text{ kg}}{2}$ K = $\frac{3 \text{ kg}}{2}$
M_V = .548 (16) + .625 (13) + .700 (1.5)
M_V = 18 kg-m which is less than 30 kg-m/OK
M_A = .705 (14) + .945 (1.5) = 11 kg-m which is less than 30 kg-m/OK

P = Adapter Weight
K = 1/2 Hose Weight
M_S= ZP + TK ≤ 7 kg-m

With Caterpillar Hardware
P = 13 kg K = $\frac{3 \text{ kg}}{2}$
Z = 420 mm T = 500 mm
M_S = .420 (13) + .500 (3/2) = 6.21 < 7/OK

Figure 15

Air Inlet Shutoff

An inlet air shutoff *must* be mounted directly in the air stream between the turbocharger compressor outlet and the aftercooler housing. The shutoff is actuated either manually or electronically. It is for emergency use only, not for normal engine shutdowns.

Turbocharger Speed Sensor

If a turbocharger speed sensor is required, the magnetic speed pickup is mounted in the 90° inlet compressor inlet elbow (see Figure 13). A special compressor nose cone and signal conditioner is required with the straight inlet adapter shown in Figure 12.

Turbocharger Loading

Figure 15 shows the maximum turbocharger loads and how to calculate the turbocharger load.

Turbocharger Air Inlet Design

For an axial air inlet, the Caterpillar air inlet adapter shown in Figure 12 should be used. This ensures smooth flow conditions at the turbocharger inlet. If a bend is used to connect to the Caterpillar straight inlet adapter, make the bend radius as large as possible. As a minimum the bend radius should be equal to the pipe diameter, 508 mm [20 in.], or preferably one and a half times the pipe diameter. If an air inlet elbow is required, use the Caterpillar supplied adapter shown in Figure 14. These two adapters are designed in conjunction with the turbocharger to provide favorable air flow at the compressor inlet.

Ventilating Air Calculation Guide

Definition of Engine Room

The space containing propulsion machinery, auxiliary diesel engines, boilers, generators and other major electrical machinery, etc.

Design Conditions

The outside ambient air temperature is assumed to be 35°C (95°F).

Engine room air flow calculations

The total air flow is the sum of the combustion air flow for engines and boilers added to the ventilation air flow for removal of radiated engine room heat.

The total air flow should always be greater than 150% of the combustion air flow.

Machinery areas separated from the engine room, such as auxiliary machinery and boiler rooms, should be calculated separately.

Combustion Air Flow Requirements

Air flows at various engine ratings are in the Engine Data section of this guide. Consult TMI for the latest data.

For repowers where a non-3600 ship service generator engine may remain in place, the combustion air flow for the generator can be estimated by:

$$q_{dg} = \frac{P_{dg} \times Q_d}{p}$$

Where:

q_{dg} = Combustion air flow for non-3600 engines, m³/sec

P_{dg} = Maximum brake shaft power, kW

Q_d = Specific combustion air requirement per manufacturer's data

Note: *Where values for Q_d are not available, the following may be used for calculations:*

Q_d = 0.0023 kg air/kW x sec

p = 1.15 kg/m^3 (density of air)

Combustion air flow for boilers can be calculated as follows:

$$q_b = \frac{Q_s \times Q_f \times Q_a}{p}$$

Where:

q_b = Combustion air flow for boilers, m^3/sec

Q_s = Total steam consumption at sea, kg/sec

Q_f = Fuel consumption in kg (fuel) per kg (steam).

Note: *If specific data is not available, Q_f = 0.079 kg/kg may be used for calculations.*

Q_a = Combustion air requirements in kg (air) per kg (fuel)

Note: *If specific data is not available, Q_a = 16.8 kg/kg may be used for calculations.*

p = 1.15 kg/m^3 (density of air)

The total combustion air flow can be calculated as follows:

$$q_c = q_{dp} + q_{dg} + q_b$$

Where:

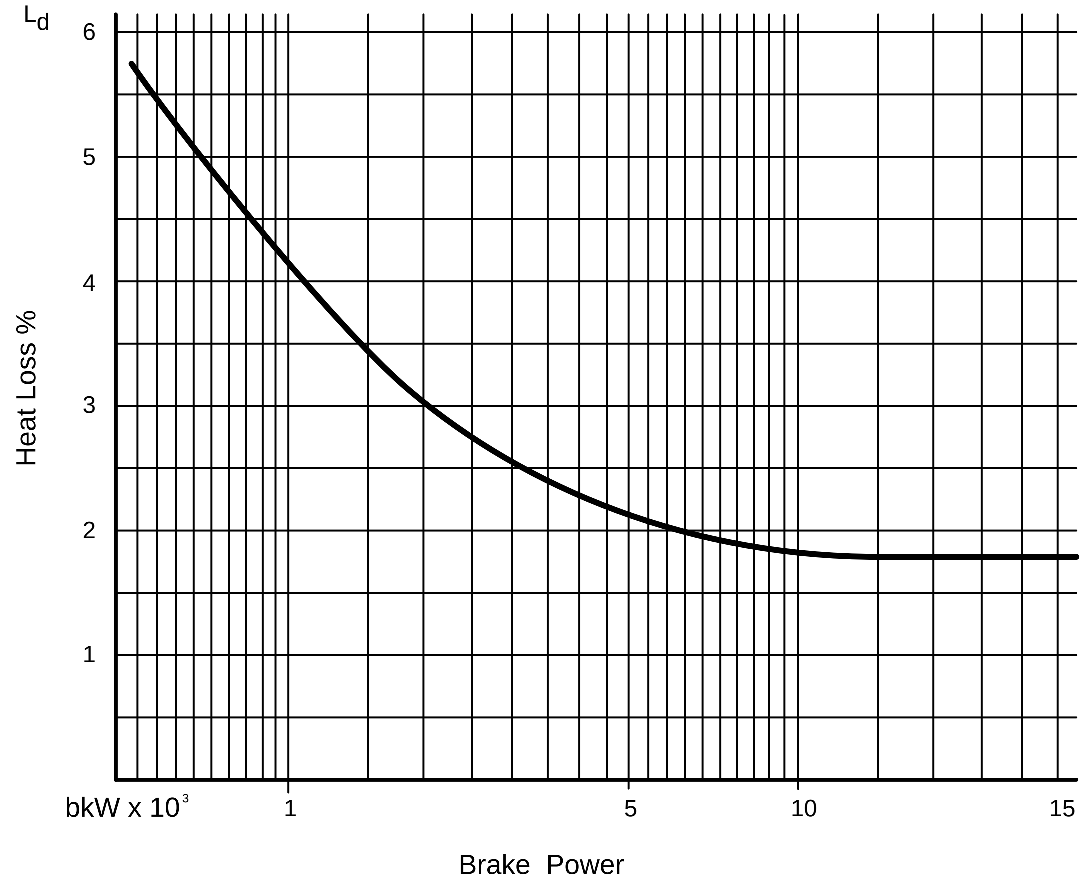
q_c = Sum of combustion air flow, m^3/sec

q_{dp} = Combustion air flow for propulsion engines, m^3/sec

Note: *If the main engines use combustion air directly from atmosphere, q_{dp} will be zero.*

q_{dg} = Combustion air flow for generator engines, m^3/sec

q_b = Combustion air flow for boilers, m^3/sec



Percent Of Heat Loss

Figure 16

Air flow requirements for removal of radiated heat

Heat radiated from propulsion engine

Heat radiated from the propulsion engines is found in the Engine Data section of this guide. Check the TMI system for the latest data.

Heat radiated from generator set engines

In repowers where a non-3600 generator set engine is already in place the radiated heat can be estimated by:

$$Ø_{dg} = P_{dg} \times \frac{L_d}{100}$$

Where:

$Ø_{dg}$ = Ship service generator engine radiated heat, kW

P_{dg} = Maximum brake shaft power, kW

L_d = Percent of heat loss as taken from Figure 16

Heat rejected from boilers

The heat radiated from boilers can be calculated as follows:

$$\O_b = Q_s \times Q_f \times h \times \frac{L_b}{100} \times B_{pl} \times B_e$$

Where:

$\O_b$ = Heat radiated from boilers, kW

Q_s = Total steam consumption at sea, kg/sec

Q_f = Fuel consumption in kg (fuel) per kg (steam)

Note: *If specific data is not available, Q_f = 0.079 kg/kg may be used for calculations.*

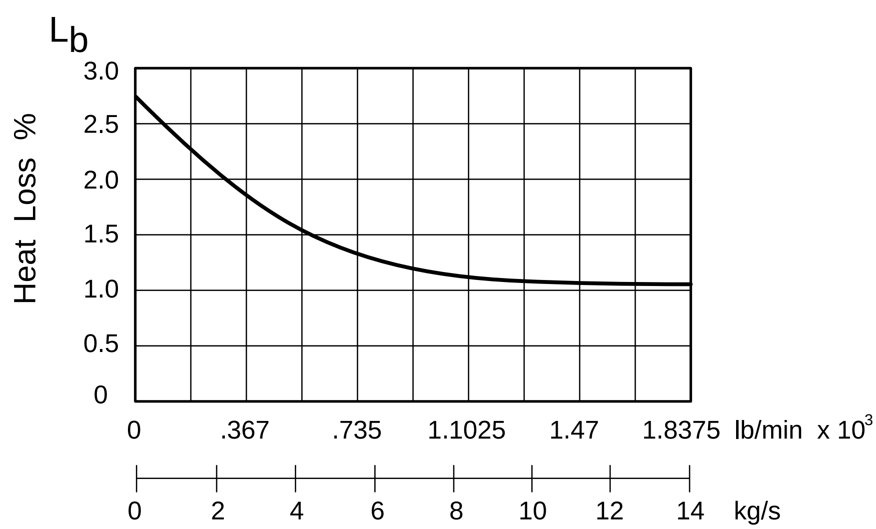
h = Lower heating value of fuel, kJ/kg

Note: *Where specific data is not available, h = 41800 kJ/kg may be used for calculations.*

L_b = Percent heat loss @ maximum steam consumption per Figure 17

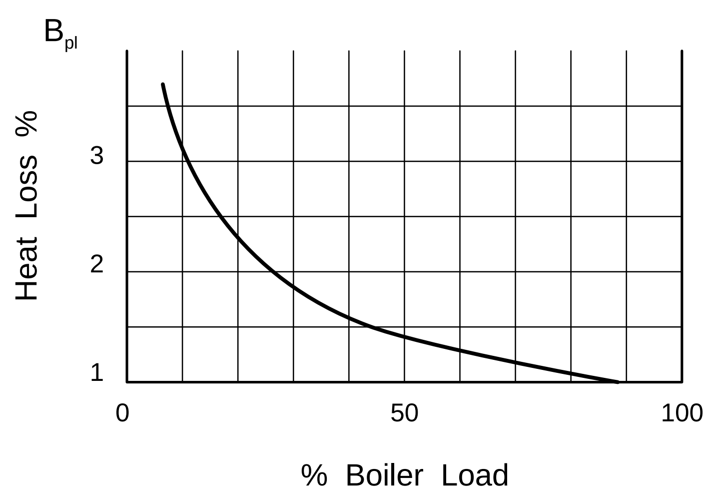
B_{pl} = Boiler partial load constant per Figure 18 below

B_e = 0.1 for boilers located directly below exposed casing



Heat Loss In Percent From A Boiler, At Maximum Steam Consumption At Sea

Figure 17



Boiler Constant At Partial Load In Percent

Figure 18

Heat rejected from steam and condensate pipes

The heat rejected from steam and condensate pipes can be calculated as follows:

$$Ø_p = Q_s \times Q_f \times h \times \frac{L_p}{100}$$

Where:

$Ø_p$ = Heat rejected from steam and condensate piping, kW

Q_s = Total steam consumption, kg/sec

Q_f = Fuel consumption in kg (fuel) per kg (steam)

Note: *If specific data is not available, Q_f = 0.079 kg/kg may be used for calculations.*

h = kJ/kg - Lower heating value of fuel

Note: *If specific data is not available, h = 41800 kJ/kg may be used for calculations.*

L_p = Heat loss from steam and condensate pipes as a percent of energy supplied to the boiler

Note: *If specific data is not available, 0.15 percent may be used for calculations.*

Heat rejected from generators

The heat rejected from generators can be calculated as follows:

$$Ø_g = P_g \times (1 - \frac{N}{100})$$

Where:

$Ø_g$ = Heat rejected by generator, kW

P_g = Output of generator, kW

N = Generator efficiency, percent

Note: *If specific data is not available, N = 96% may be used for calculations.*

Heat rejected from electrical equipment

For conventional ships where details of the electrical installation are not known the heat rejected is assumed to be 10% of the effective output of the generators and can be calculated as follows:

$$Ø_{el} = P_g \times \frac{10}{100}$$

Where:

$Ø_{el}$ = Heat rejected by electrical machinery, kW

P_g = Output of generator, kW

Heat rejected from exhaust pipes

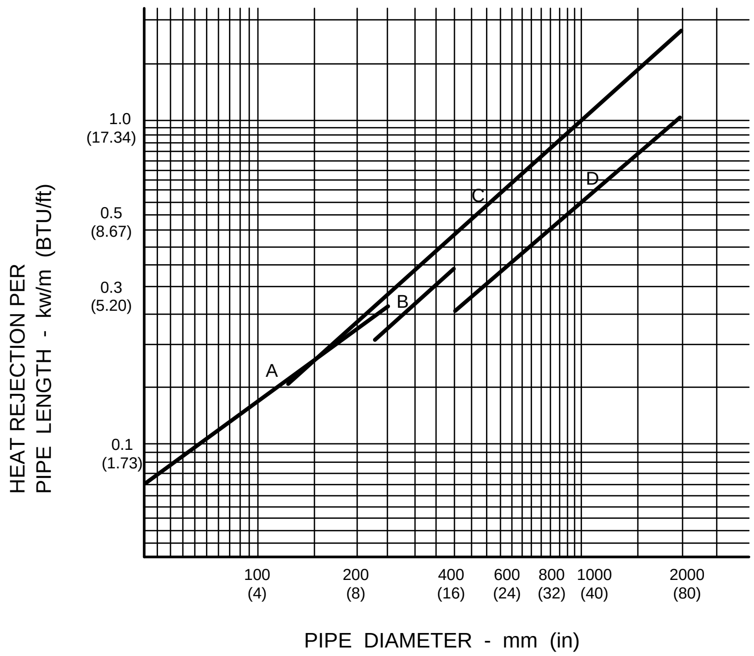
The heat rejected from exhaust piping, Q_{ep}, can be approximated from Figure 19. The heat rejection is given in kW/m of pipe versus diameter of pipe with four different types of insulation.

Heat rejected from hot tanks

The heat rejected by hot tanks, Q_t, is based on the sum of the hot tank surface area contiguous with the engine room. These values may be approximated from Figure 20.

Heat Rejection from Tanks		
	kW/m^2 ($Btu/min/ft^2$) @ 60° (140°F)	kW/m^2 ($Btu/min/ft^2$) @ 70° (158°F)
Uninsulated	0.060 (0.320)	0.105 (0.550)
Approx. 50 mm (2 in.) insulation	0.012 (0.063)	0.021 (0.111)

Figure 20



The graph is based on the temperature difference $\Delta t = 350^\circ C$
Curve **A** 40mm Mineral wool with $\lambda = 0.038$ W/m x C°
Curve **B** 50mm Mineral wool with $\lambda = 0.038$ W/m x C°
Curve **C** 70mm Asbestos free calcium silicate bowl with $\lambda = 0.070$ W/m x C°
Curve **D** 70mm Mineral wool with $\lambda = 0.037$ W/m x C°

Figure 19 **Heat Rejected From Exhaust Piping**

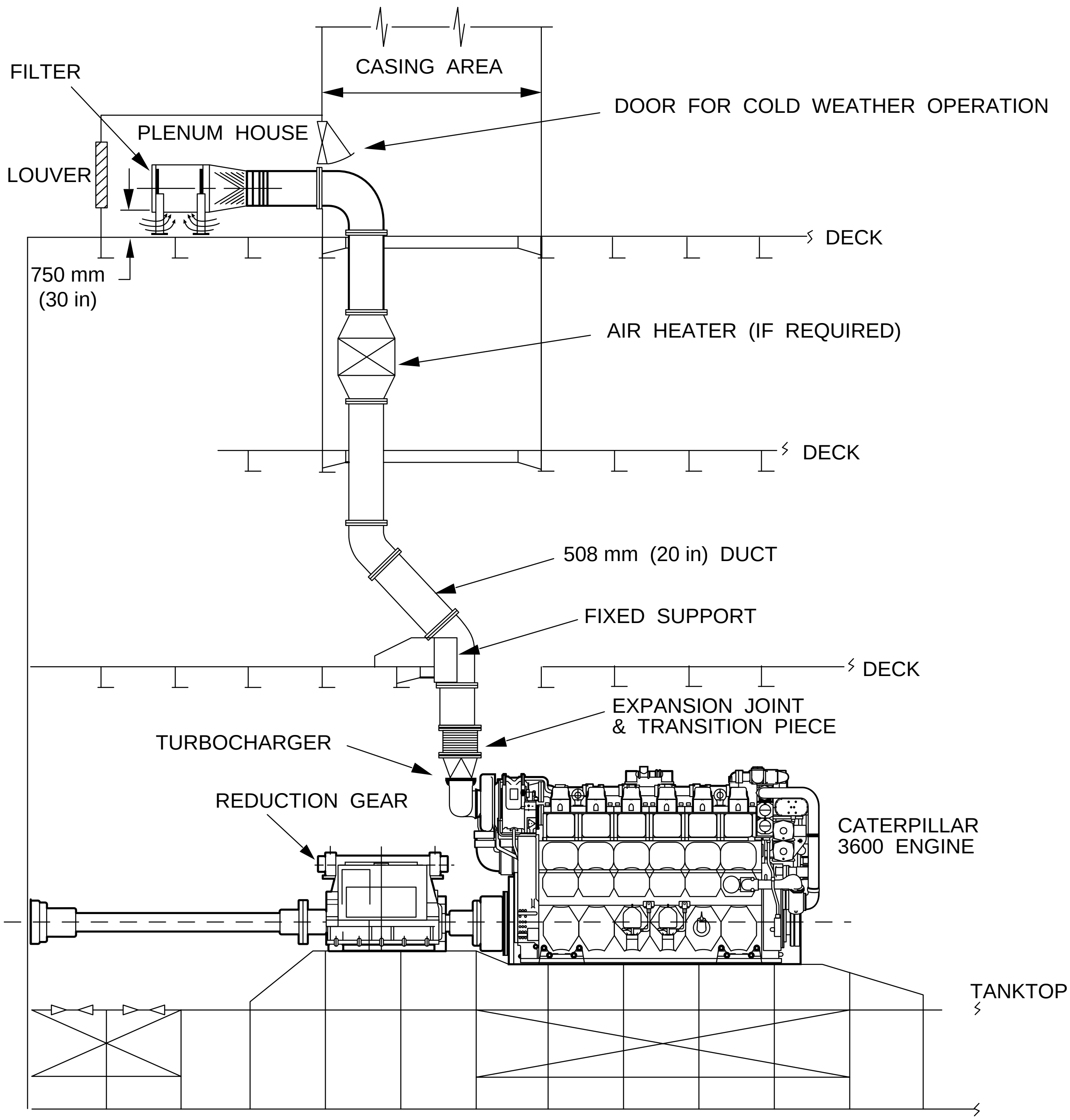
Heat rejected from other machinery
Evaluate the heat rejected from other machinery, Q_o. Include miscellaneous refrigeration compressors, steam turbines, incinerators, etc., which may be unique to the particular ship's engine room.

Total air flow for removal of machinery rejected heat
The sum of the air flow for removal of machinery radiated heat can be calculated as follows:

$$q_h = \frac{Ø_{dp} + Ø_{dg} + Ø_b + Ø_p + Ø_g + Ø_{el} + Ø_{ep} + Ø_t + Ø_o}{P \times c \times \Delta t}$$

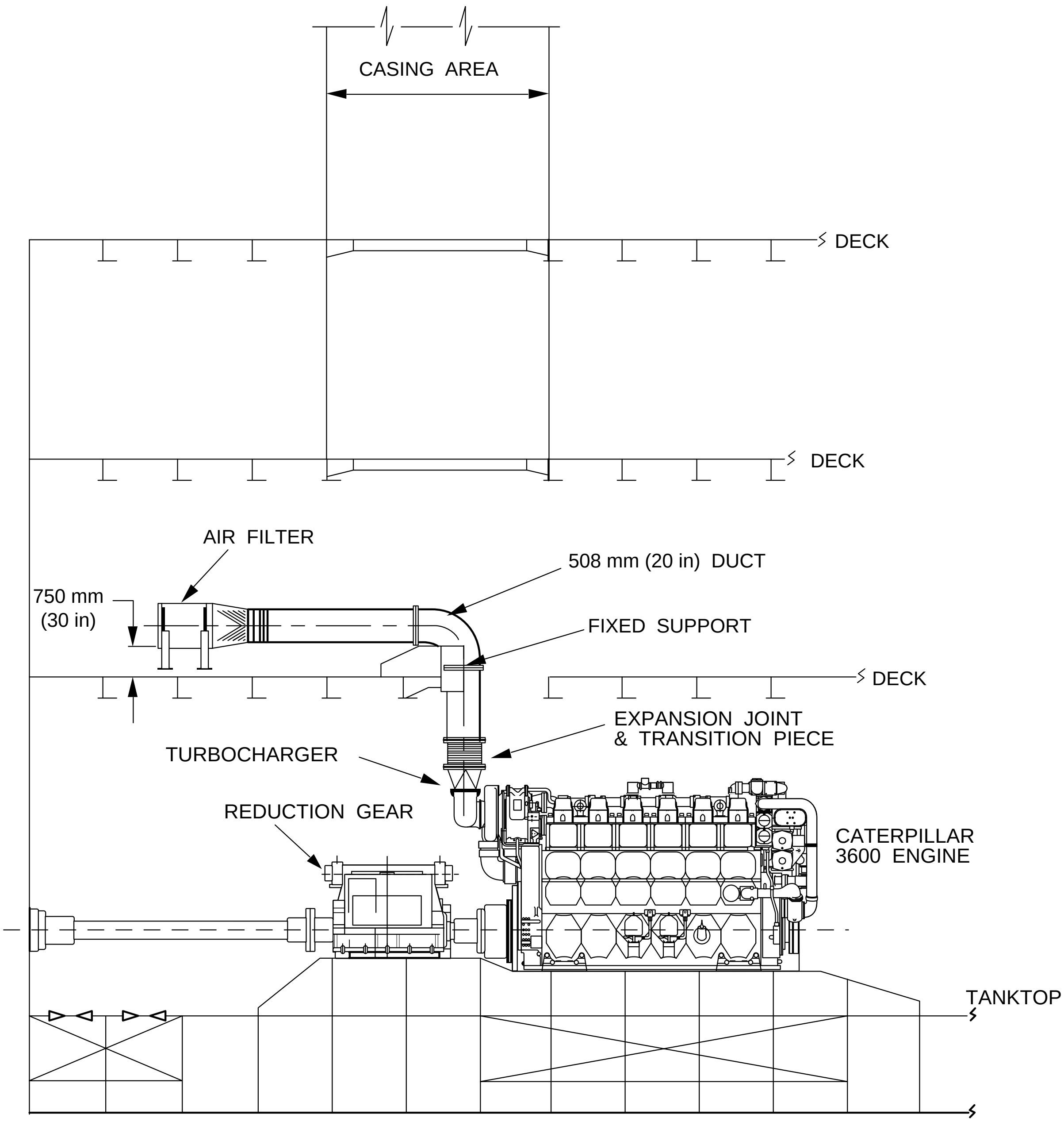
Where:

- q_h = sum of air flow for removal of rejected heat, m^3/sec
- $Ø_{dp}$ = heat rejected from propulsion engines, kW
- $Ø_{dg}$ = heat rejected from generator engines, kW
- $Ø_b$ = heat rejected from boilers, kW
- $Ø_p$ = heat rejected from steam and condensate pipes, kW
- $Ø_g$ = heat emitted from generators, kW
- $Ø_{el}$ = heat emitted from electrical installation, kW
- $Ø_{ep}$ = heat emitted from exhaust pipes, kW
- $Ø_t$ = heat emitted from hot tanks, kW
- $Ø_o$ = heat emitted from other components, kW
- P = 1.15 kg/m^3 (density of air)
- c = 1.01 kJ/kg °C (specific heat capacity of the air)
- Δt = 12.5°C (increase of mean temperature in the engine room)



Remote Mounted Air Cleaner Arrangement
Combustion Air From Outside Engine Room

Figure 3



Remote Mounted Air Cleaner Arrangement
Combustion Air From Inside Engine Room

Figure 4

CATERPILLAR®

Diesel Engine Systems - Exhaust

- Emissions
  - Nitrogen Oxide
  - Hydrocarbons
  - Particulates
  - Carbon Monoxide
  - Carbon Dioxide
  - Sulfur Dioxide
  - 3600 Emissions Data
  - Effect of Ambient Conditions
  - Control Methods
  - Measurement Units and Conversions

Manifolds

The General Information section of this guide gives a description of the engine exhaust manifold systems.

Manifold shielding is available to meet OSHA and various marine society temperature requirements. Shields also reduce heat rejection to the surroundings. Refer to the Caterpillar TMI System for manifold heat rejection to the atmosphere. The TMI data assumes shielded manifolds are used.

Exhaust Backpressure Limits

For distillate fuel operation, the total 3600 Engine exhaust backpressure limit is 2.5 kPa (10 in. H_2O). This level has been established to maintain low brake specific fuel consumption and exhaust temperatures, and it should be kept below this limit. However, some applications may have a higher backpressure level, particularly when repowering existing installations. An increase in fuel consumption of approximately 0.8% per 2.5 kPa (10 in. H_2O) of exhaust back pressure above 2.5 kPa (10 in. H_2O) will occur. Backpressures up to 6.7 kPa (27 in. H_2O) are allowed with factory approval.

The maximum exhaust backpressure limit for heavy fuel operation is 2.5 kPa (10 in. H_2O) due to the effect of higher backpressure on exhaust valve temperature. Consult the factory if higher backpressures are expected.

Vee engine exhaust piping should be designed with equal restrictions on each bank to prevent unequal bank-to-bank backpressures.

Measure system backpressure in a straight length of the exhaust pipe, preferably 3 to 5 pipe diameters away from the last size transition from the turbocharger outlet. See Figure 1 for a typical measurement location. In this example, the backpressure measurement would only include the components downstream of the measurement location. The actual backpressure includes the components upstream of the measurement location as well, and it can be calculated as shown in the following section.

Exhaust Backpressure Calculations

Use the following formula to keep exhaust backpressure below the limit. Calculate a pipe diameter according to the formula, then choose the next larger commercially available pipe size.

Pressure drop limits of the exhaust system include losses due to piping, fittings and the exhaust silencer.

Calculate backpressure by:

$$P\ (\text{kPa}) = \frac{L \times S \times Q^2 \times 3.6 \times 10^6}{D^5} +$$

(pressure drop of silencer and other components)

$$P\ (\text{in. } H_2O) = \frac{L \times S \times Q^2}{187 \times D^5} +$$

(pressure drop through silencer and other components)

P = Backpressure (kPa), (in. H_2O)
psi = 0.0361 x in. water column
kPa = 6.3246 x mm water column
L = Total Equivalent Length of pipe (m), (ft)
Q = Exhaust gas flow (m^3/min), (cfm)
D = Inside diameter of pipe (mm), (in.)
S = Density of gas (kg/m^3), (lb/ft^3)

$$S\ (kg/m^3) = \frac{352.5}{\text{Stack Gas Temperature} + 273°C}$$

$$S\ (lb/ft^3) = \frac{39.6}{\text{Stack Gas Temperature} + 460°F}$$

To obtain equivalent length of straight pipe for various elbows:

$$L = \frac{33\ D}{X}$$ Standard Elbow (Radius of elbow equals pipe diameter)

$$L = \frac{20\ D}{X}$$ Long Elbow (Radius > 1.5 diameter)

$$L = \frac{15\ D}{X}$$ 45° Elbow

$$L = \frac{66\ D}{X}$$ Square Elbow

where X = 1000 mm or 12 in.

As shown above, if 90° bends are required a radius of at least one and a half times the pipe diameter lowers the resistance.

The following table lists exhaust restriction for various Caterpillar supplied exhaust components (based on MCR ratings).

Rectangular to Round Adapter
(Turbo Outlet). . .0.5 kPa (2.0 in. H_2O)
Expander 356 mm x 457 mm diameter
(14 in. x 18 in.) (Round to Round
Expander). . . . . 0.25 kPa (1.0 in. H_2O)
356 mm (14 in.) Diameter
Bellows. . . . . .0.1 kPa (0.4 in. H_2O)
457 mm (18 in.) Diameter
Bellows. . . . . . .0.025 kPa (0.1 in. H_2O)

As a guide, the total flow loss of the standard Caterpillar exhaust adapters is 1 kPa (4 in. H_2O). This leaves an additional 1.5 kPa (6 in. H_2O) of flow losses for the exhaust piping and silencer.

Example:

Figure 1 shows a typical exhaust system for a 3600 Engine from the turbocharger to the stack outlet. The components included in this example are as follows:

Rectangular to 14 in. Round Adapter
14 in. Bellows
14 in. to 18 in. Round Adapter
Two Standard Radius 18 in. Elbows
Various Lengths of Straight Pipe
18 in. Bellows
Exhaust Silencer
Exhaust Opening to Atmosphere

To calculate the total backpressure for these components, use the preceding formulas to determine the equivalent length of piping and elbows, and add in the backpressure values for the other components. Assume the engine is a 3606 engine with an MCR rating of 2030 bkW at 1000 rpm (exhaust gas flow of 437 cmm at 412°C from the *Engine Data* section).

Equivalent length for 18 in. (457 mm) Standard Elbow:

$$L = \frac{33\ D}{X} = \frac{33\ (457)}{1000} = 15.1\ m$$

Total length of piping and equivalent length of two elbows:

$$L = 0.5\ m + 15.1\ m + 2\ m + 0.5\ m + 15.1\ m + 2\ m + 4\ m = 39.2\ m$$

Backpressure in piping and elbows:

$$S = \frac{352.5}{412+273} = 0.515\ kg/m^3$$

$$P = \frac{(39.2)(0.515)\left(437^2\right)(3.6)\left(10^6\right)}{457^5} = 0.7\ kPa$$

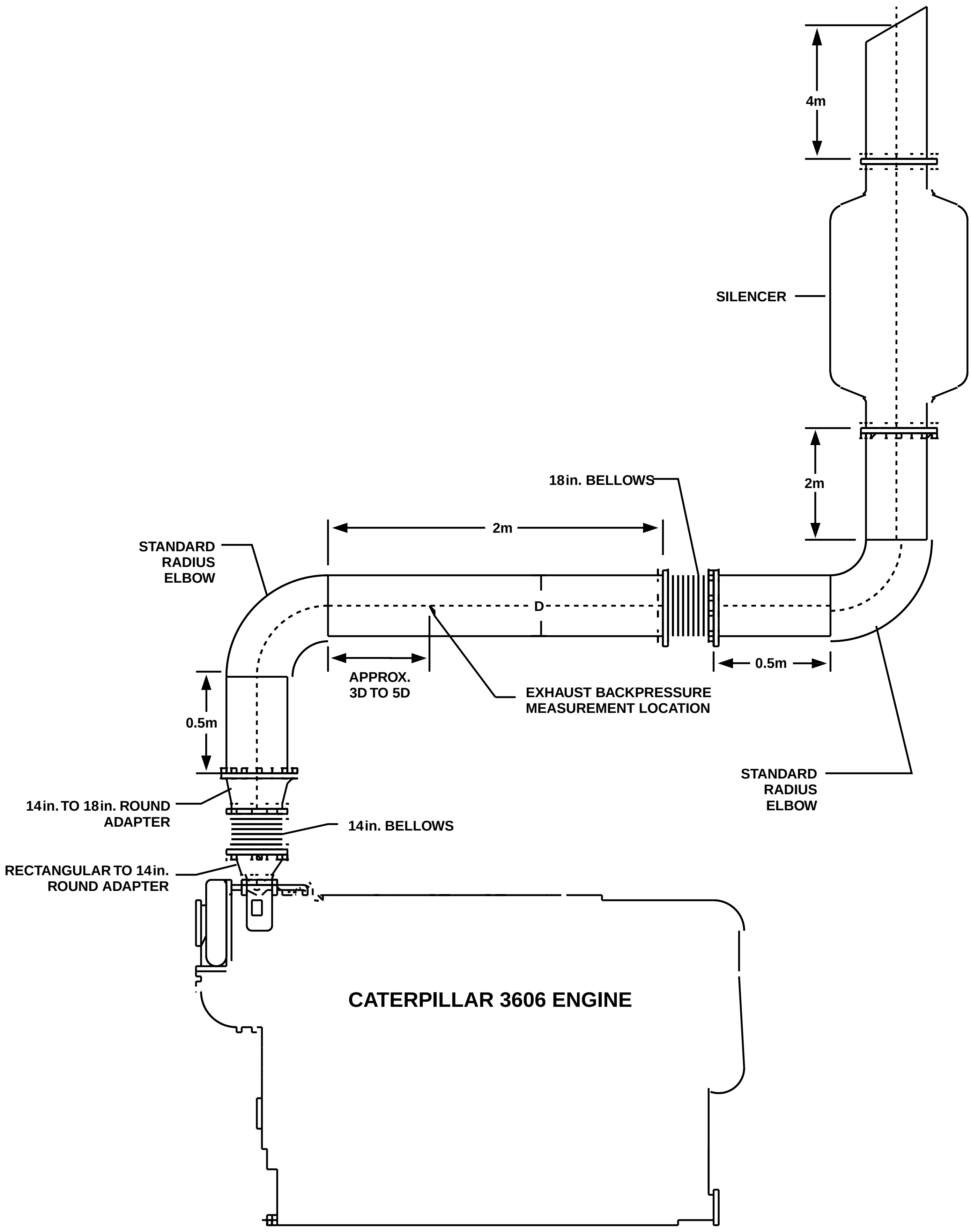

4m
SILENCER
2m
18in. BELLOWS
2m
STANDARD
RADIUS
ELBOW
D
0.5m
APPROX.
3D TO 5D
EXHAUST BACKPRESSURE
MEASUREMENT LOCATION
0.5m
STANDARD
RADIUS
ELBOW
14in. TO 18in. ROUND
ADAPTER
14in. BELLOWS
RECTANGULAR TO 14in.
ROUND ADAPTER
CATERPILLAR 3606 ENGINE

Figure 1

Backpressure in other components:

Rectangular to 14 in. Round Adapter	0.5 kPa
14 in. Bellows	0.1 kPa
14 in. to 18 in. Round Adapter	0.25 kPa
18 in. Bellows	0.025 kPa
Exhaust Silencer	0.375 kPa (estimated)
Exhaust Opening to Atmosphere	0.55 kPa (estimated)
	1.8 kPa

Total system backpressure:

P = 0.7 + 1.8 = 2.5 kPa

This meets the 2.5 kPa backpressure limit established for 3600 engines, so this application would be acceptable.

Exhaust Flow

Mass/Volume Conversions

Air flow and temperature data for propulsion engines can be found in TMI and the Engine Data and Engine Performance sections of this guide. The flows available in TMI and Engine Data and Engine Performance sections of this guide are volume flows. Mass flow conversions are:

$$\text{Exhaust flow in kg/hr} = \frac{(\text{exhaust flow in m}^3\text{/min})\ (21150)}{(\text{exhaust gas temp in °C}) + 273}$$

$$\text{Exhaust flow in lb/hr} = \frac{(\text{exhaust flow in ft}^3\text{/min})\ (2333)}{(\text{exhaust gas temp in °F}) + 460}$$

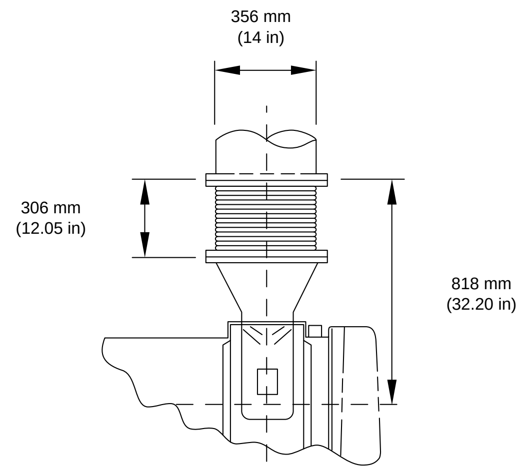


Figure 2

Exhaust Connections

Turbocharger

Turbochargers are located at the flywheel end of the engines. The turbocharger exhaust outlet is rectangular with an area equivalent to 311 mm (12 in.) diameter. An optional cast adapter provides a circular connection point (see Figure 2). Also available are a 355 mm (14 in.) flexible bellows (for misalignment and thermal growth), an expansion transition from 355 mm (14 in.) to 457 mm (18 in.), a 457 mm (18 in.) bellows and an exhaust flange with bolting and mounting hardware. See Figures 2 and 3.

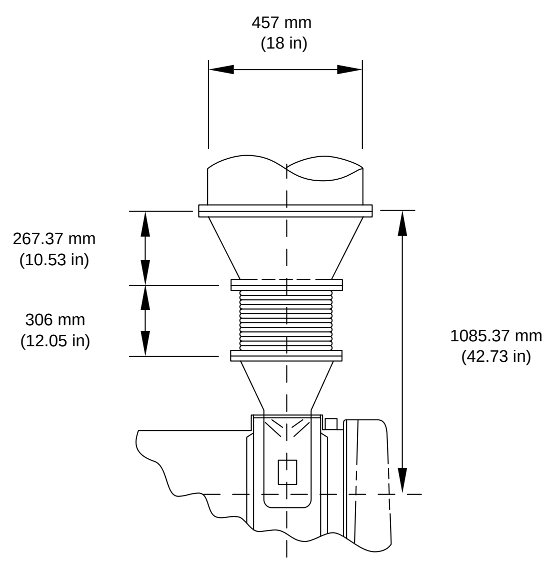


Figure 3

A 90° exhaust outlet adapter is also available. Its outlet can be oriented in 15° increments around a vertical plane (see Figure 8).

The exhaust outlet from the turbocharger can be rotated in 30° increments (see Figure 4). Turbocharger water lines are available for alternate turbocharger exhaust orientations.

Exhaust Stack Positions Possible On The Turbocharger

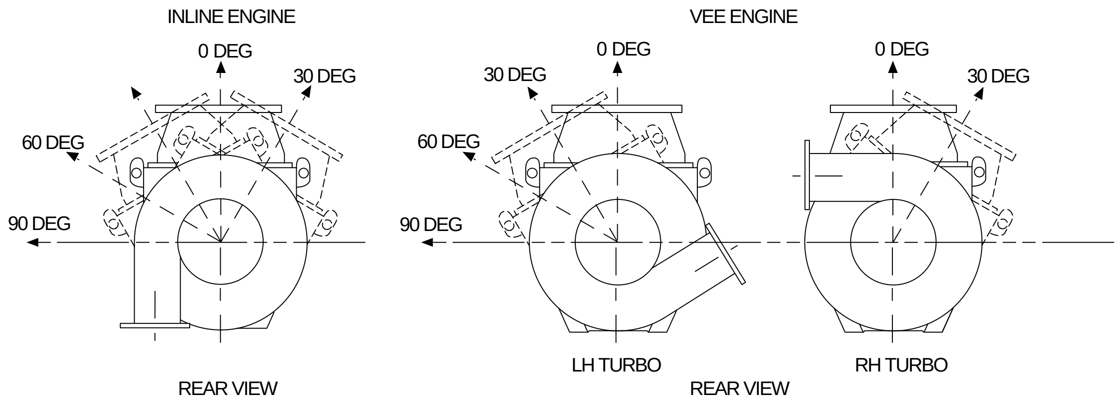


Figure 4

Flexible Connections

Exhaust piping must be isolated from the engine with flexible connections installed close to the engine exhaust outlet. It has three primary functions:

- Isolates the weight of the exhaust piping from the engine.
- Reduces vibrational fatigue stresses.
- Allows relative shifting of exhaust components. Shifting may result from expansion and contraction due to temperature changes and torque reactions when the engine or ship set generators are resiliently mounted.

Prestretch the bellows during installation to allow for thermal growth expected. *Approximately 20 mm (.8 in.) of vertical growth will occur at the exhaust bellows.* Four small straps can be tack welded between the two end flanges to prevent the bellows from being installed in a flexed condition. Attach a warning tag to note the weld straps; the tag *must* be removed before starting the engine.

The installation limitations of Caterpillar supplied flexible exhaust bellows are shown in Figure 5.

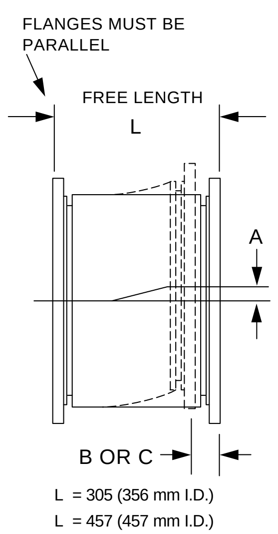


Figure 5

Installation Limitations Of Bellows - Type Flexible Exhaust Fittings

A Max. Offset Between Flanges		B Max. Compression From Free Length		C Max. Extension From Free Length	
355 mm (14 in.) I.D.					
mm	in.	mm	in.	mm	in.
0	0	99.06	3.90	52.32	2.06
22.20	.87	0	0	0	0
Spring rate of bellows = 55.8 kN / m (318.7 lb/in.) : Axial; 163.9 kN / m (936.0 lb/in.) : Lateral					
457 mm (18 in.) I.D.					
mm	in.	mm	in.	mm	in.
0	0	100.00	3.94	50.00	1.97
30.00	1.18	0	0	0	0
Spring rate of bellows = 13.37 kN / m (76.4 lb/in.) : Axial; 25.7 kN / m (146.8 lb/in.) : Lateral					
Lagging or insulation must not restrain flexibility of bellows.					

Exhaust Piping

A common exhaust system for multiple installations is not acceptable. Combined exhaust systems with boilers or other engines allow operating engines to force exhaust gases into engines not operating. Every gallon of fuel burned provides about one gallon of water in the exhaust. The water vapor condenses in cold engines and causes engine damage. Soot clogs turbochargers, aftercoolers, and air cleaner elements. Duct valves separating engine exhausts is discouraged. High temperatures warp valve seats and soot deposits cause leakage.

Each engine should have an exhaust pipe led to atmosphere at the top of the stack as shown in Figure 6. A flexible exhaust fitting must be mounted directly on the transition piece at the turbocharger outlet.

The maximum gas velocity should not exceed 50 m/sec (164 ft/sec) at full load. Avoid sharp bends, but where bends are necessary have the largest possible radius. The minimum radius should be two pipe diameters. The piping should be as short as possible and insulated. Protect the insulation by mechanical lagging to keep it intact. Insulate all flexible exhaust fittings with removable quilted blankets.

Exhaust piping must be able to expand and contract. Install flexible exhaust fittings between fixed points in the system. It is recommended that one fixed point be installed at the turbocharger outlet directly after the flexible exhaust fitting. This will prevent the transmission of forces resulting from weight, thermal expansion, or lateral displacement of the exhaust piping acting on the turbocharger.

Typical Exhaust Pipe System

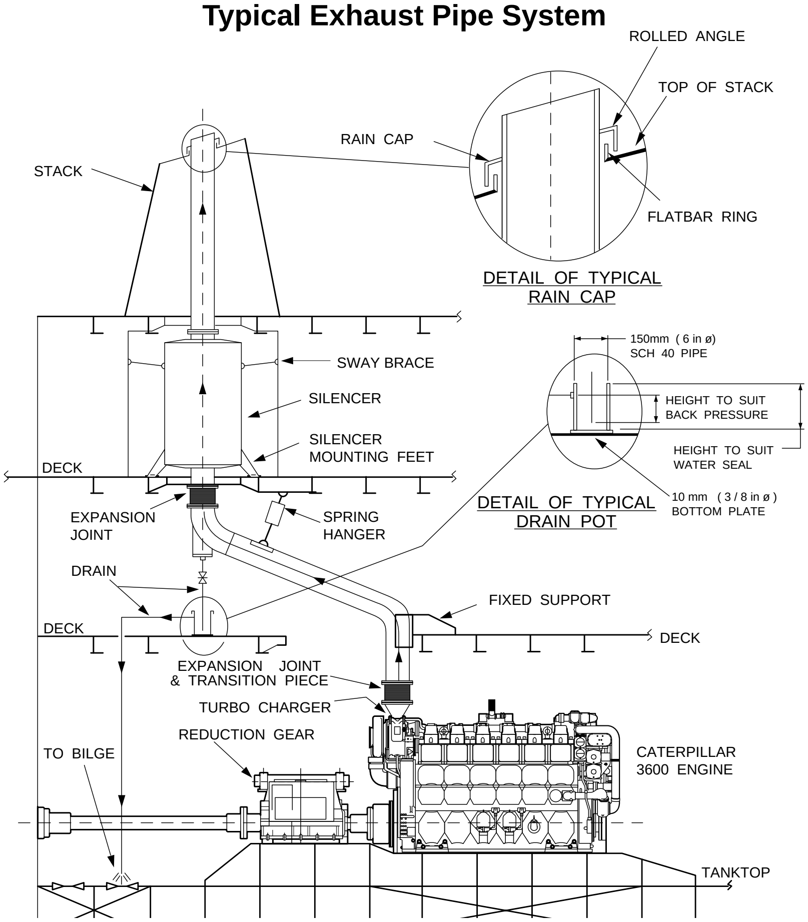
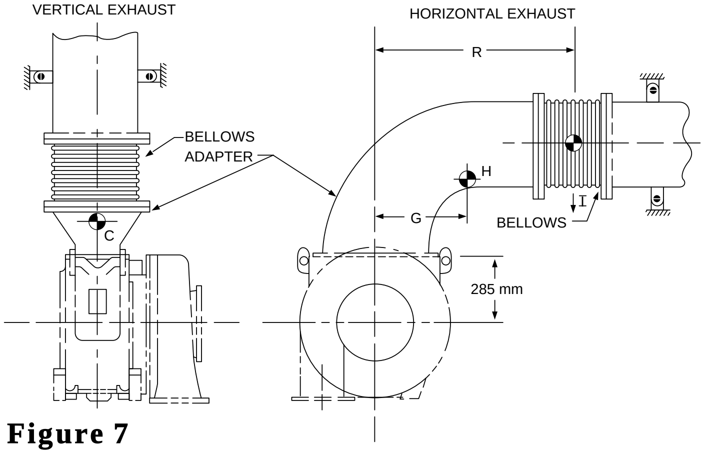


Figure 6

Maximum Loads For Turbocharger Exhaust



C, H & S = Adapter Weight
I = 1/2 Bellows Weight

Vertical Exhaust

C + I = 180 kg Maximum
(includes all forces acting on turbo)

Horizontal Exhaust

$$\left.\begin{array}{l} Mh_1 = MS + QI \\ Mh_2 = GH + RI \end{array}\right\} \begin{array}{l}\text{Allowable Maximum} \\ \text{Moment = 120 mkg}\end{array}$$

With Caterpillar Hardware

Q = 516 mm	R = 580 mm
M = 104 mm	G = 100 mm
H = 47 kg	S = 47 kg
$I = \frac{12 \text{ kg}}{2} = 6$ kg	C = 28 kg

Mh_1 = .104 (47) + .516 (6) = 8 mkg<120∴OK
Mh_1 = .100 (47) + .580 (6) = 8.2 mkg<120∴OK

Vertical Load

28 + 6 = 34 kg<180∴OK

Figure 7

Horizontal Exhaust

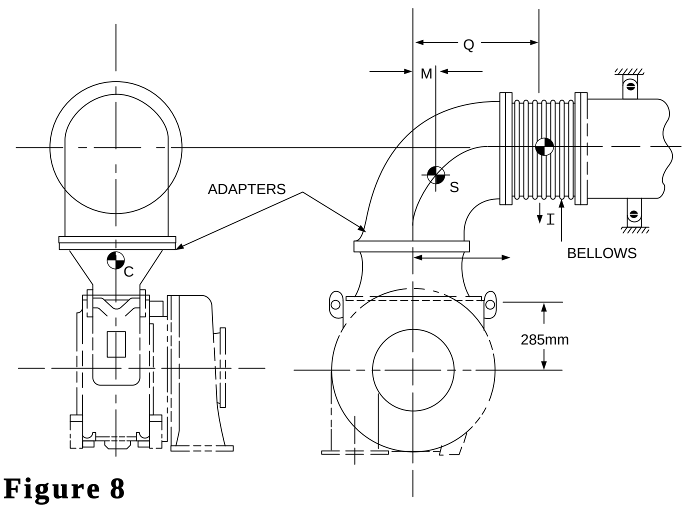


Figure 8

Careful consideration must be given to turbocharger loading. Figures 7 and 8 show the maximum allowable loads. Thermal growth of the exhaust piping must be anticipated to avoid excessive load on supporting structures. Steel exhaust pipe expands 1.13 mm/m for each 100°C (0.0076 in./ft for each 100°F) rise of exhaust temperature. This amounts to 16.5 mm (0.65 in.) expansion for each 3.05 m (10 ft) of pipe from 35° to 510°C (100° to 950°F).

Support piping using spring or roller type hangers to allow for pipe movement, and to minimize the transmission of sound to other parts of the ship.

Fit exhaust piping with continuously open water drains (see Figure 6).

Combining of the individual engine exhaust outlets on 3612 and 3616 vee engines can create problems. The combining fabrication may result in unequal thermal growth and backpressure from one bank to the other. The unequal growth can put unwanted loading into the turbocharger mounting or the flex bellows. Unequal backpressure can adversely affect the operation and performance of the engine. See Figure 9 for a suggested piping arrangement.

Piping must be designed with engine service in mind. In many cases an overhead crane is needed to service the heavier engine components.

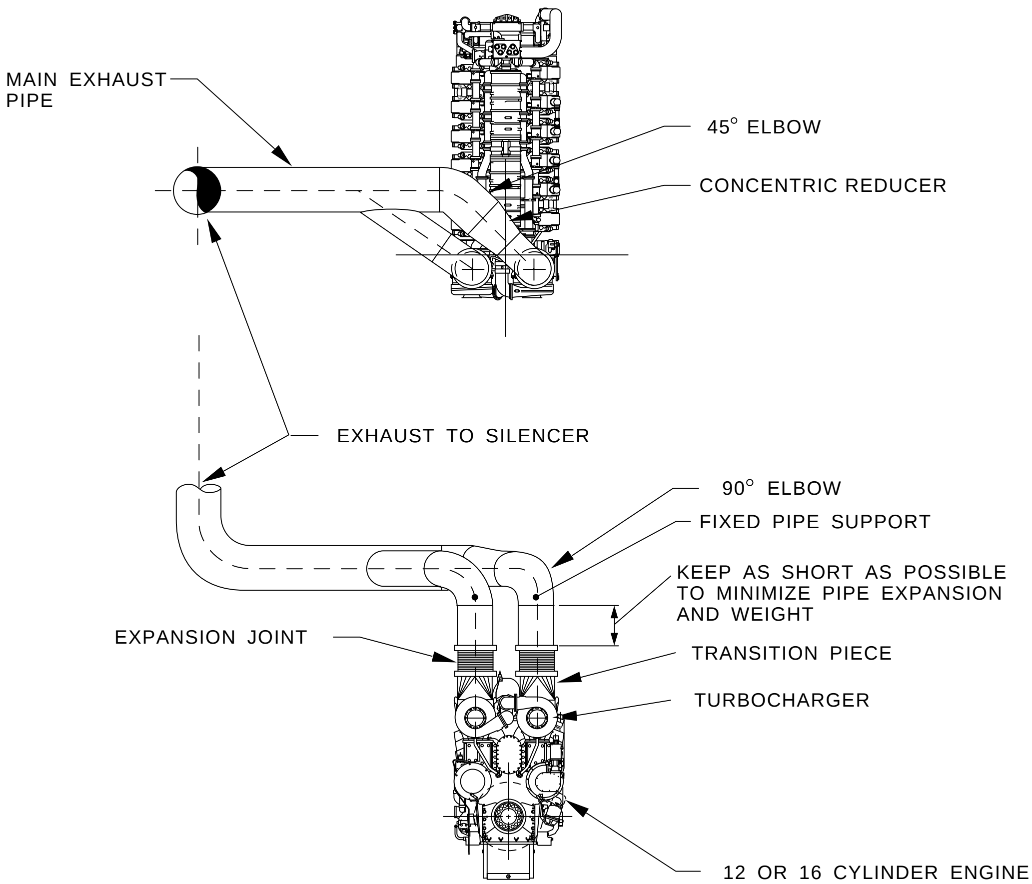


Figure 9

Cleanliness

Install an identifiable blanking plate to prevent debris from falling into the turbocharger during installation. The Caterpillar shipping cover can be used. Install it directly on the turbine housing and attach a warning tag indicating the plate must be removed before starting the engine.

Silencer

Vertical or horizontal silencers can be used. When practical orient the silencer vertically and use side inlets to eliminate extra inlet and discharge elbows. Locate them as close as possible to the end of the exhaust pipe. The exact location can be selected based on the available space within the engine room or casing areas. Silencers fitted with a spark box must have accessible cleaning ports. Use resilient mounts to limit noise and vibration transfer to the surrounding structures.

Single silencers on vee engines should have dual inlets rather than a “Y”, “T”, or 180 degree abrupt enlargement.

Provide a minimum of 5 diameters of straight piping upstream of the silencer inlet and 2.5 diameters downstream from the outlet to minimize turbulence.

Insulate the silencer to avoid temperatures below the dew point of sulfuric acid and to protect personnel from injury. A silencer with higher heat resistant material is required when insulating lagging is used.

Silencer Data

The following technical information has been obtained from Beaird Industries Inc. and is presented to provide a guide for silencer selection information. Other manufacturers can be used with 3600 Engines.

Exhaust Noise

See the *Noise* section of this guide for 3600 noise data. The procedure given in this section estimates the silenced A-weighted sound level of exhaust noise 3m (10 ft) from the exhaust pipe of an engine using a Maxim™ MSA1 or MSA2™ silencer. It may be used when unsilenced engine noise data is unavailable or when a first approximation of silenced sound levels is desired. The reduction in sound level achieved with a silencer is dependent on the frequency distribution of the noise source.

Information Required

- Engine horsepower
- Silencer model

Procedure:

$SL' = SL_o - NR$ dB(A) at 3m (10 ft)

SL_o = Unsilenced engine sound level at 3m (10 ft) determined from Figure 10 as a function of horsepower (dB(A))

NR = Silencer noise reduction factor obtained from Figure 11 as a function of silencer model (dB)

Example:

- Horsepower - 1000 hp
- Silencer Model - MSA1

SL_o = 114 dB (A) (from Figure 10)
NR = 20 dB (from Figure 11)
$SL' = SL_o - NR$
$= (114) - (20)$
SL' = 94 dB (A) at 3 m (10 ft)

Sizing Maxim™ Silencer Models MSA1 - MSA2

Information Required:

Q_o = Volume Flow Rate (ft^3/min)
T_o = Exhaust Gas Temperature (^oF)
ΔP = Allowable Silencer Pressure Drop (in. H_2O)

Procedure:

Determine standard velocity (V_s) from Figure 12, which corresponds to the allowable silencer pressure drop.

Determine velocity correction factor (C_r) from Figure 13, which corresponds to the Exhaust Gas Temperature.

Calculate minimum silencer area. A_{min} = Q divided by C_rV_s .
From Figure 11 select a silencer size with an area, m^2 (ft^2), equal to or greater than A_{min}

Example 1 (Determine silencer size):

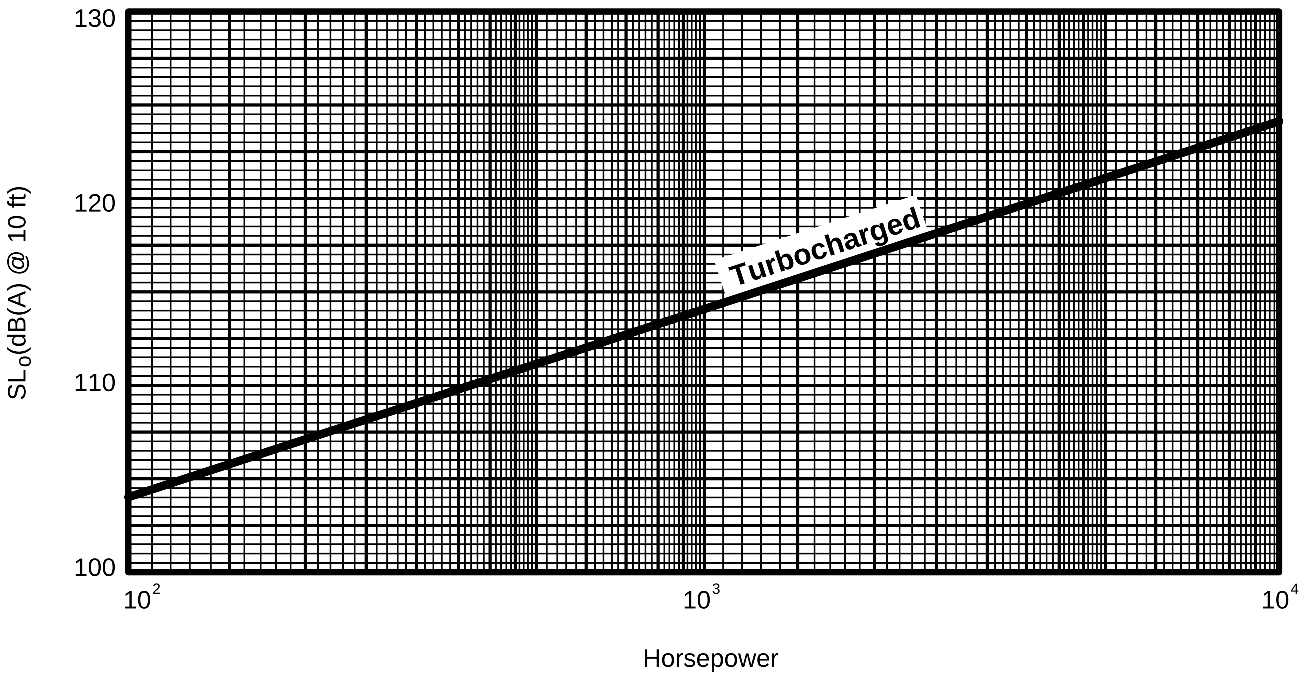
Q_o = 10,000 ft^3/min
T_o = 850°F
ΔP = 4 in. H_2O maximum

a. V_s = 4,000 ft/min (Figure 12)
b. C_r = 1.57 (Figure 13)
c. $A_{min.}$ = Q_o divided by C_rV_s = 10,000 divided by (1.57)(4,000) =1.59 ft^2
d. Silencer Size = 18 in. (A=1.77 ft^2) (Figure 11)

Example 2 (Determine actual pressure drop for the silencer sized in Example 1):

V_s = Q_o divided by C_rA = 10,000 divided by (1.57)(1.77) = 3599 ft/min
ΔP = 3.25 in. H_2O (Figure 12)

Note: *Heavy fuel engines require a higher air flow. This must be taken into account when sizing the silencer.*

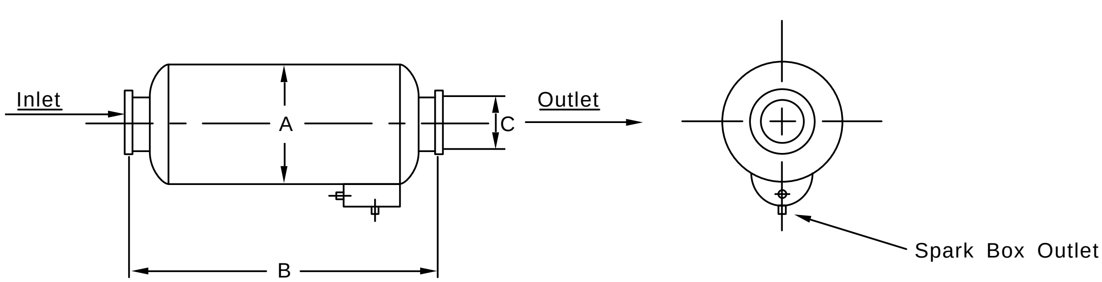


Unsilenced A-Weighted Sound Level Versus Engine Output

Figure 10

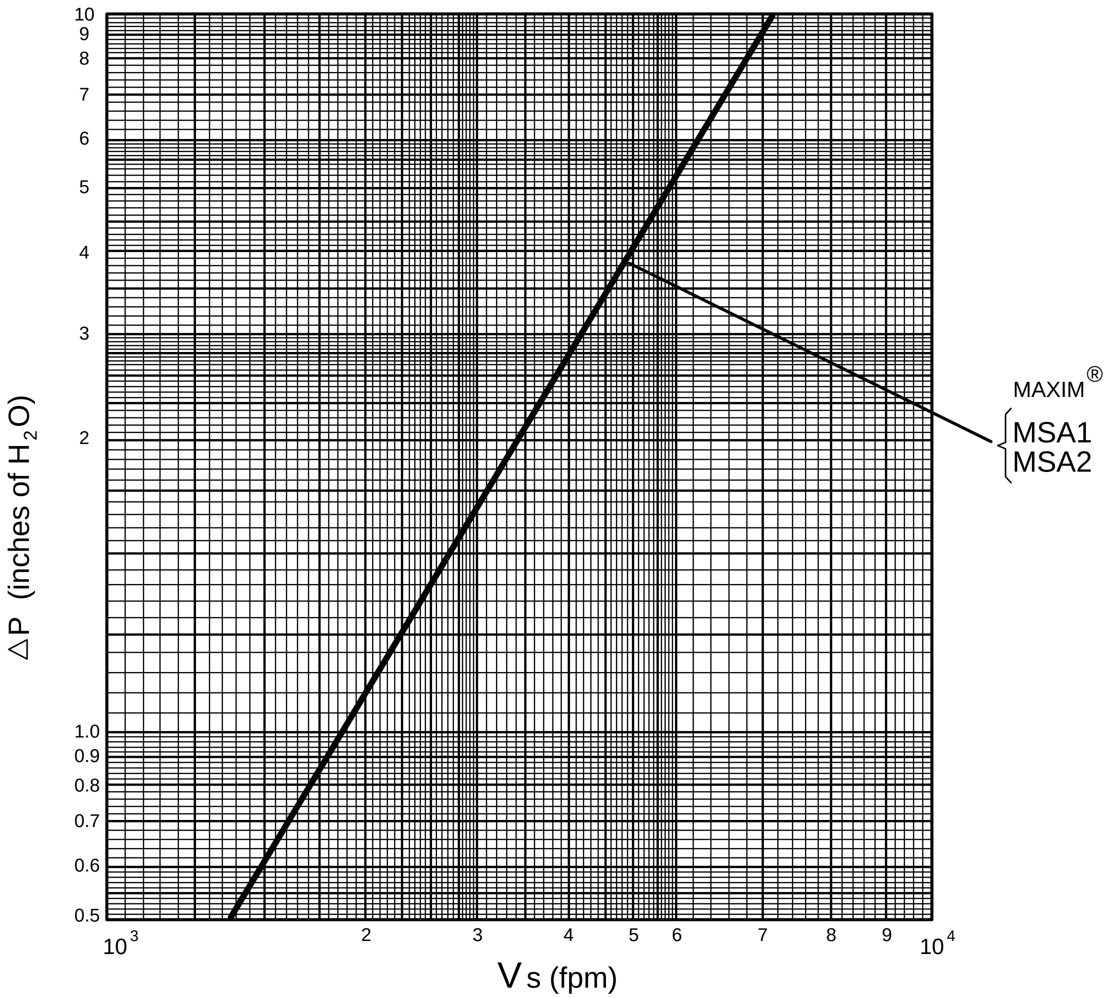
Exhaust Silencer Specifications												
	MSA1						MSA2					
Size mm (in)	Dimensions A	B	C	Weight kg (lb)	Area m² (ft²)	NR db	Dimensions A	B	C	Weight kg (lb)	Area m² (ft²)	NR db
305 (12)	76 (30)	175 (69)	305 (12)	259 (570)	.08 (.785)	**20**	76 (30)	277 (109)	305 (12)	338 (745)	.08 (.785)	**24**
356 (14)	91 (36)	196 (77)	356 (14)	338 (745)	.10 (1.07)	**20**	91 (36)	259 (102)	356 (14)	438 (965)	.10 (1.07)	**24**
406 (16)	102 (40)	221 (87)	406 (16)	494 (1090)	.13 (1.39)	**20**	102 (40)	302 (119)	406 (16)	608 (1340)	.13 (1.39)	**24**
457 (18)	114 (45)	254 (100)	457 (18)	649 (1430)	.16 (1.77)	**20**	114 (45)	323 (127)	457 (18)	839 (1850)	.16 (1.77)	**24**
508 (20)	127 (50)	274 (108)	508 (20)	812 (1790)	.20 (2.18)	**20**	127 (50)	366 (144)	508 (20)	987 (2175)	.20 (2.18)	**24**
559 (22)	137 (54)	295 (116)	559 (22)	1002 (2210)	.25 (2.64)	**20**	137 (54)	409 (161)	559 (22)	1202 (2650)	.25 (2.64)	**24**
610 (24)	152 (60)	325 (128)	610 (24)	1200 (2645)	.29 (3.14)	**20**	152 (60)	419 (165)	610 (24)	1542 (3400)	.29 (3.14)	**24**
660 (26)	163 (64)	345 (136)	660 (26)	1338 (2950)	.34 (3.68)	**20**	163 (64)	465 (183)	660 (26)	1746 (3850)	.34 (3.68)	**24**
711 (28)	173 (68)	384 (151)	711 (28)	1742 (3840)	.40 (4.28)	**20**	173 (68)	508 (200)	711 (28)	2195 (4840)	.40 (4.28)	**24**
762 (30)	183 (72)	411 (162)	762 (30)	2028 (4470)	.46 (4.91)	**20**	183 (72)	549 (216)	762 (30)	2336 (5150)	.46 (4.91)	**24**

Note: Dimensions are approximate, and listed in cm(in).



Typical MAXIM® Silencer

Figure 11



Maxim® Silencer Pressure Drop Versus Exhaust Gas Velocity (V_S)

Figure 12

Exhaust Gas Economizer

Separate exhaust gas economizers should be used for each engine. However, if each engine has separate gas sections and it is acceptable to the owner and regulatory agency, a common economizer can be used. Exhaust gas flow and temperature at various propulsion engine loads is found in the *Engine Data* section.

Exhaust Slobber (extended periods of insufficient load)

Extended engine operation at no load or lightly loaded conditions (less than 15% load) may result in exhaust manifold slobber, which is a black oily mixture of fuel and/or oil and soot. The presence of exhaust manifold slobber does not necessarily indicate an engine problem, and is not usually harmful to the engine. The results can be unsightly and objectionable.

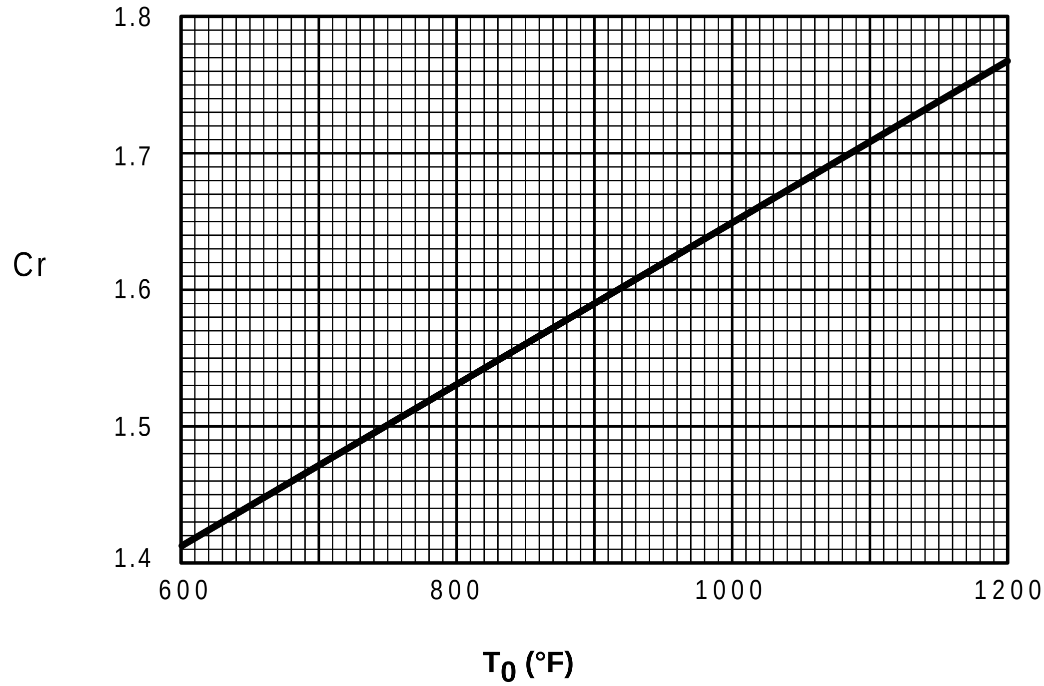


Figure 13 **Velocity Correction Factor (Cr) Versus Exhaust Gas Temperature**

A normally operating engine should be expected to run for at least one hour at light loads without significant slobber. Some engines may run for as long as four or more hours before slobbering. However, all diesel engines will eventually slobber if run at light loads.

If extended idle or lightly loaded periods of engine operation are mandatory, the effects of the engine slobber can be avoided by loading the engine to at least 30% load for approximately ten minutes every four hours. This removes fluids accumulated in the manifold. Correctly sized engines for each application minimizes exhaust manifold slobber.

Emissions

Diesel engines emit substances that are regulated in many areas. They include nitrogen oxides (NO_x), particulates, hydrocarbons, sulfur oxides, carbon monoxide, and carbon dioxide. Check local regulations to determine limitations and special permits which might apply.

Types of Emissions

Nitrogen Oxides

Nitrogen oxides are formed by decomposition of the molecular oxygen and nitrogen present in the combustion air and recombination as nitrogen oxides. This occurs during high temperature combustion. Nitrogen oxides consist primarily of nitric oxide (NO) and nitrogen dioxide (NO_2). The designation NO_x indicates 1 or 2 oxygen atoms can be present in the molecule. Generally, over 90% of the NO_x in diesel exhaust is in the form of NO. The NO gradually oxidizes to the more harmful NO_2 specie in the atmosphere. By convention, the NO_x mass emissions (such as g/hr) are usually given as an equivalent mass of NO_2.

NO_x emissions in parts per million by volume can be calculated approximately from the mass emission rate (if available) and the exhaust flow:

$$NO_x \text{ concentration} = 629 \times \frac{(NO_x \text{ mass emissions})}{(\text{Exhaust mass flow})}$$

Where:
NO_x concentration is in parts per million (ppm)
NOx mass emissions are in g/hr of equivalent NO_2
Exhaust mass flow is in kg/hr

Hydrocarbons

Hydrocarbons are unburned or partially burned fuel and lubricating oil. Hydrocarbon emissions in parts per million can be calculated approximately from the mass emission rate and the exhaust flow:

$$\text{HC concentration} = 2067 \times \frac{(\text{HC Mass Emissions})}{(\text{Exhaust Mass Flow})}$$

Where:
HC concentration is in parts per million (ppm)
HC mass emissions are in g/hr
Exhaust mass flow is in kg/hr

Particulates

Particulate emissions include unburned carbon (soot), ash, high molecular weight hydrocarbons, and sulfates. The level of particulate emissions depends on the type of measuring system used. There is no universally accepted method for measuring marine diesel emissions. Particulates can be measured by passing a known portion of the exhaust through a filter which is weighed before and after the sampling. The amount of particulate collected on the filter depends on the temperature of the filter, and on whether the sample is diluted with clean air. The dilution ratio is accounted for in calculating the emissions.
Caterpillar has developed a correlation between smoke and particulate concentration which can be used to approximate particulate emissions.

Carbon Monoxide

Carbon monoxide (CO) results from incomplete combustion of the fuel. CO emissions in parts per million (by volume) can be calculated from the mass emission rate (if available) and the exhaust flow:

$$\text{CO concentration} = \frac{1034 \ (\text{CO mass emissions})}{(\text{Exhaust mass flow})}$$

Where:
CO concentration is in parts per million (ppm)
CO mass emissions are in g/hr
Exhaust mass flow is in kg/hr

Carbon Dioxide

Carbon dioxide (CO_2) is one of the primary natural byproducts of combustion (water is the other primary byproduct). Since CO_2 emissions are being monitored increasingly worldwide, it is important to be able to determine the amount of CO_2 in the exhaust. Several factors affect CO_2 emissions including the engine output (amount of fuel burned), the carbon/hydrogen ratio of the fuel, and the heating value of the fuel. Consult a Caterpillar representative for CO_2 emissions data for a particular application.

Sulfur Dioxide

The sulfur present in the fuel oxidizes primarily to sulfur dioxide (SO_2). A small amount, generally 2% or less, ends up as sulfate. The emissions of sulfur dioxide depend only on the sulfur level of the fuel and the fuel consumption rate of the engine. Sulfur dioxide emissions can be calculated by the formula:

Specific SO_2 emissions =
(0.01998) (bsfc) (Fuel sulfur in percent)

Where:
Specific SO_2 emissions are in g/kW-hr
Fuel sulfur is in percent by weight
bsfc is in g/kW-hr

Example:
Fuel sulfur..0.25%
Fuel consumption.......................................195 g/kW-hr

Specific SO_2 = (0.01998) (195) (0.25)
Emissions = 0.974 g/kW-hr

SO_2 emissions in parts per million (by volume) can be calculated from the mass emission rate and the exhaust flow:

$$SO_2 \text{ concentration} = \frac{452 \ (SO_2 \text{ mass emissions})}{(\text{exhaust mass flow})}$$

Where:
SO_2 concentration is in parts per million (ppm)
SO_2 mass emissions are in g/hr
Exhaust mass flow is in kg/hr

3600 Emissions Data

Factors affecting emissions include engine rating, rated speed, turbocharger, timing, ambient conditions, and fuel. Emissions levels for some ratings are available in the TMI. Consult the factory for emission estimates for ratings not in the TMI. Information that must be provided with an emissions request includes:

- Rated speed and power
- Type of rating (e.g., MCR, Ship set auxiliary)
- Duty cycle description
- Ambient conditions
- Fuel type
- Speed and load point for requested emissions.

Effect of Ambient Conditions

Ambient conditions affect emissions. Hotter inlet air and higher altitudes will increase NO_x and particulate emissions.

Control Methods

Caterpillar Engines are developed to minimize exhaust emissions. Features of 3600 Engines including high pressure unit injectors and low temperature aftercooling reduce exhaust emissions.

On some ratings NO_x emissions can be reduced by retarding injection timing. NO_x emissions can be reduced by approximately 20%. Particulates, visible smoke, fuel consumption, exhaust temperature, exhaust flow, and turbocharger speed are all increased by retarding timing for NO_x control. Altitude capability is reduced with retarded timing. Consult the factory for availability of reduced NO_x emission engines.

Exhaust after treatment of various types has been tested on diesel engines. NO_x can be reduced by selective catalytic reduction by ammonia in which ammonia is added to the exhaust gas and reacted with the NO_x as a catalyst. Particulates can be removed by ceramic filters. These systems are considered experimental.

Measurement Units and Conversions

Emission rate can be calculated from brake specific emissions:

Emission rate (g/hr) =
(brake specific emissions in g/hp-hr) x (power in hp)

Emission regulations are often in terms of parts per million (ppm) or grams per standard cubic meter at a reference exhaust oxygen concentration to take dilution into account. The following formula can be used to convert pollutant concentration actually present to the reference oxygen concentration:

$$X\ \text{ref} = X\ \text{actual}\ \frac{20.9 - 0\ \text{ref}}{20.9 - 0\ \text{actual}}$$

Where:

X actual = Pollutant concentration in ppm at actual exhaust oxygen concentration.

X ref = Pollutant concentration in ppm at reference exhaust oxygen concentration.

0 actual = Oxygen concentration in actual exhaust in percent

0 ref = Reference exhaust concentration in percent

Example:
Measured 1000 ppm NO_x at 8% oxygen.
Equivalent at 5% oxygen

$$X\ \text{ref} = 1000\ \text{ppm}\ \frac{20.9 - 5}{20.9 - 8}$$

$$= 1233\ \text{ppm}$$

Diesel Engine Systems - Starting Air

- Starting Systems
  - Ambient Capability
  - Prelubrication
  - Air Starters
  - Air Tank Sizing
  - Air Tank Requirements
  - Customer Connections
  - Cleanliness
  - Testing

Starting Systems

Air starting motors are used on virtually all 3600 Engines. Figure 1, on page 45, is a typical overall schematic of a marine engine air starting system.

Ambient Capability

The 3600 Engine can be started without combustion aids down to 0°C (32°F). Do not load the engine until it has reached proper operating temperatures.

Note: *Do not inject ether into the air intake system*. If ambients below 0°C (32°F) are to be encountered, use jacket water and/or oil preheaters. See the *Cooling* and *Lubricating Oil* sections of this guide.

Most 3600 Engines are started with jacket water and oil temperatures near a 25°C (77°F) ambient. Jacket water and/or oil preheating may be required in some applications. Additional air tank volume may be required with lower ambient temperatures.

The approximate effect of low temperatures on engine cranking is shown in Figure 2.

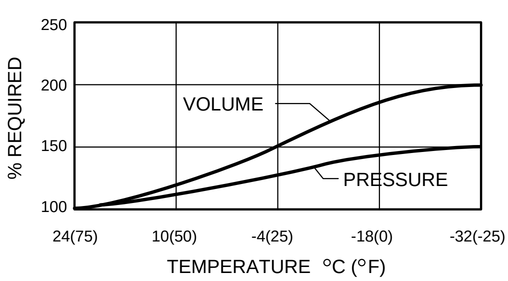


Figure 2

The curves show approximately:

- The amount of pressure increase at the starter air inlet to achieve the equivalent of 24°C (75°F) cranking rpm.
- The amount of air tank capacity increase to achieve the equivalent of 24°C (75°F) cranking time.

Example:

- If a 1000 L (265 gal) air tank at 828 kPa (120 psi) cranks an engine for 6 seconds at 24°C (75°F), approximately 50% more, or 1500 L (397 gal), is needed to crank for 6 seconds at -4°C (25°F).
- If 1034 kPa (150 psi) air at 24°C (75°F) cranks an engine to 180 rpm, approximately 25% more, or 1293 kPa (188 psi), is needed to crank to 180 rpm at -4°C (25°F).

Prelubrication

The engine must be prelubed prior to each start. The continuous prelube pump is electrically driven. If an intermittent air driven prelube pump is used, increase the air tank volume accordingly. *The Caterpillar intermittent air prelube pump consumption rate is 28.2 L/sec (60 cfm) based on free air at 15.6°C @ 99 kPa (60°F @ 14.4 psia). See the "Lubricating Oil" section of this guide for prelube time requirements.*

Air Starters

The Caterpillar supplied air starting system includes vane type air starting motors, a lubricator, an air relay valve, a strainer, a shutoff valve, and a pressure regulator if required by the air supply system.

Figure 3, page 46, shows an air starting system with electric prelube and Figure 4, page 47, shows an air starting system with air prelube.

Typically the in-line engines use one vane type starting air motor and the vee engines use two.

Turbine starters are also available by special order for installations requiring low pressure air starting. They operate on air pressures from 621 kPag (90 psig) to 829 kPag (120 psig).

Pressure Requirements
Vane type starters operate on gauge air pressures from 621 kPag (90 psig) to 1550 kPag (225 psig) *at the starter inlet ports. Air pressure at the starter must not exceed 1550 kPag (225 psig).* An air pressure drop is associated with each air supply component (such as the lubricator, strainer, relay valves, etc.) during starting. The dynamic losses range from 207 to 414 kPa (30 to 60 psi) depending on engine model and supply line pressure. *Thus, 621 kPag (90 psig) air tank pressure will not start the engine.* A minimum supply line pressure of 862 kPag (125 psig) is recommended for proper starting, regardless of starter type.

Every installation will have a different pressure drop in the supply line, depending on the length of supply line, piping size, and the number of valves, elbows, etc. For an initial system evaluation, a 207 kPa (30 psi) supply line pressure drop may be assumed.

Note: *The air pressure in the air receiver will decrease when the starter operates if the system pressure is the same as the pressure delivered to the starting air motors. In this case, the air starting pressure must be higher at the beginning of the starting sequence. If system pressure is much greater than that required by the air motor(s) and a regulating valve is used, then air pressure in the air receivers will not decrease upon initial cranking.*

A pressure regulator must be used to reduce the air pressure when the supply pressure exceeds 1550 kPag (225 psig). Depending on starter type, the pressure regulator should be set to operate between 860 to 1550 kPag (125 to 225 psig). This will ensure 621 kPag (90 psig) or greater pressure to the starter inlet port during cranking. The regulator must be sized to handle the following air flows at the stated regulator outlet pressure settings:

Static Regulator Outlet Pressure kPag (psig)	Estimated Dynamic Pressure At The Starter kPag (psig)	Air Flow Capacity Per Starter L/sec (SCFM)
862 (125)	620-655 (90-95)	400 (720)
1550 (225)	1172 (170)	615 (1300)

The higher 1550 kPag (225 psig) setting will improve starting under adverse starting conditions such as low ambient temperature. Two Caterpillar supplied pressure regulators are available. They are rated for tank pressures of up to 4140 kPag (600 psi).

Air Tank Sizing
At least two electric motor driven air compressors are normally used to fill the ship's starting air tanks from atmospheric pressure to maximum pressure in the time required by regulatory agencies. About 60 minutes should be allowed if the ship is not classed. The compressors should be arranged for automatic start/stop operation and fitted with an unloading device.

Due to the many variables encountered in the engine starting process, the exact amount of starting air required for all engine installations cannot be predicted. The 3600 Air Start Tank Sizing Curve, Figure 5, shows the required tank volume for in-line or vee engines versus the desired number of starts for different initial tank pressures. Most marine societies require a minimum of 6 consecutive starts for propulsion engine applications. Refer to the applicable marine society rules for other applications. The curves for 1600 kPa (230 psi) and less allow for 6% pressure drop between the tank and the starter. For pressures greater than 1600 kPa (230 psi), the curves assume regulation to 860 kPa (125 psi) at the starter. See the table above for regulator air flow capacities.

3600 Air Start Tank Sizing

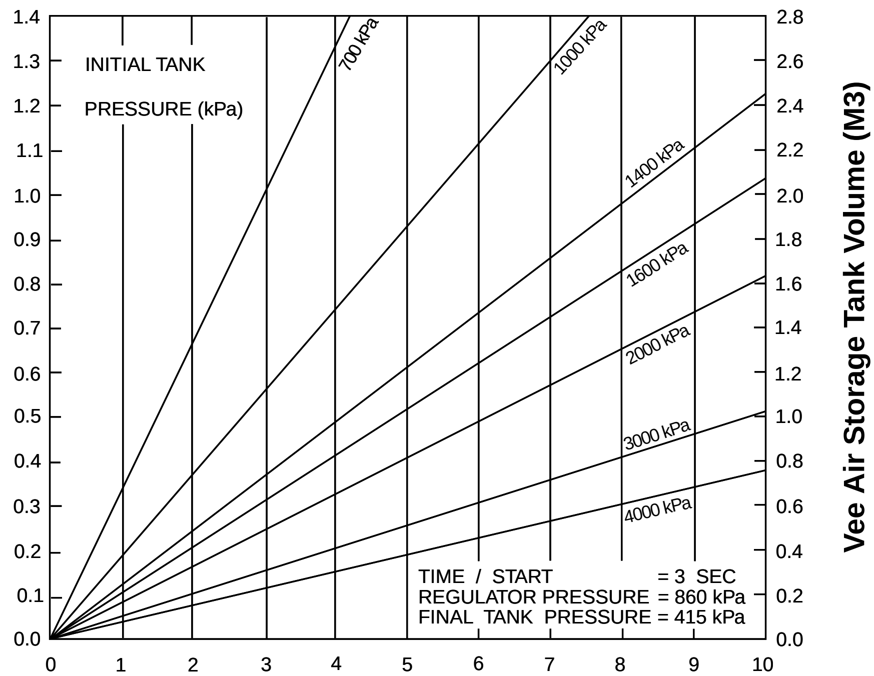


Figure 5

If the engine will be started at ambient temperatures lower than 25°C (77°F), additional storage tank volume may be required. Additional volume may also be required if the air is used for other purposes besides starting air, such as air prelube and pneumatic controls. The Caterpillar intermittent air prelube pump consumption rate is 28.2 L/sec (60 cfm). The pump motor operating air pressure is 689 kPa (100 psi), and it is supplied with its own air pressure regulator. The intermittent prelube pump will normally operate between one and five minutes before the engine is started, but should not be run for longer than ten minutes.

Air Tank Requirements

Air tanks must meet all applicable specifications [e.g., American Bureau of Shipping, Lloyds Register, The American Society of Mechanical Engineers (ASME)] and be complete with the following:

- Safety Valve
- Gauge
- Inlets
- Drains
- Inspection Openings
- Outlets

Check the safety valves periodically for sticking. Fit the receiver drains with automatic drain traps to keep water and compressor oil from accumulating.

Customer Connections

Vane type starters must be supplied with clean air. Deposits of oil-water mixture must be removed by traps installed at intervals in the lines. Lines should slope toward the traps and away from the engine.

Air supply pipes should be short and at least equal in size to the motor intake. Black seamless steel ASTM-A106 grade 'B' pipe is preferable with wall thickness dependent on the line air pressure and the type of connections (socket weld, threaded, etc.) used in the system.

A flexible connection is required close to the engine and positioned to make maximum use of its flexibility. Caterpillar supplied starting systems include a flexible hose 610 mm (2 ft) long.

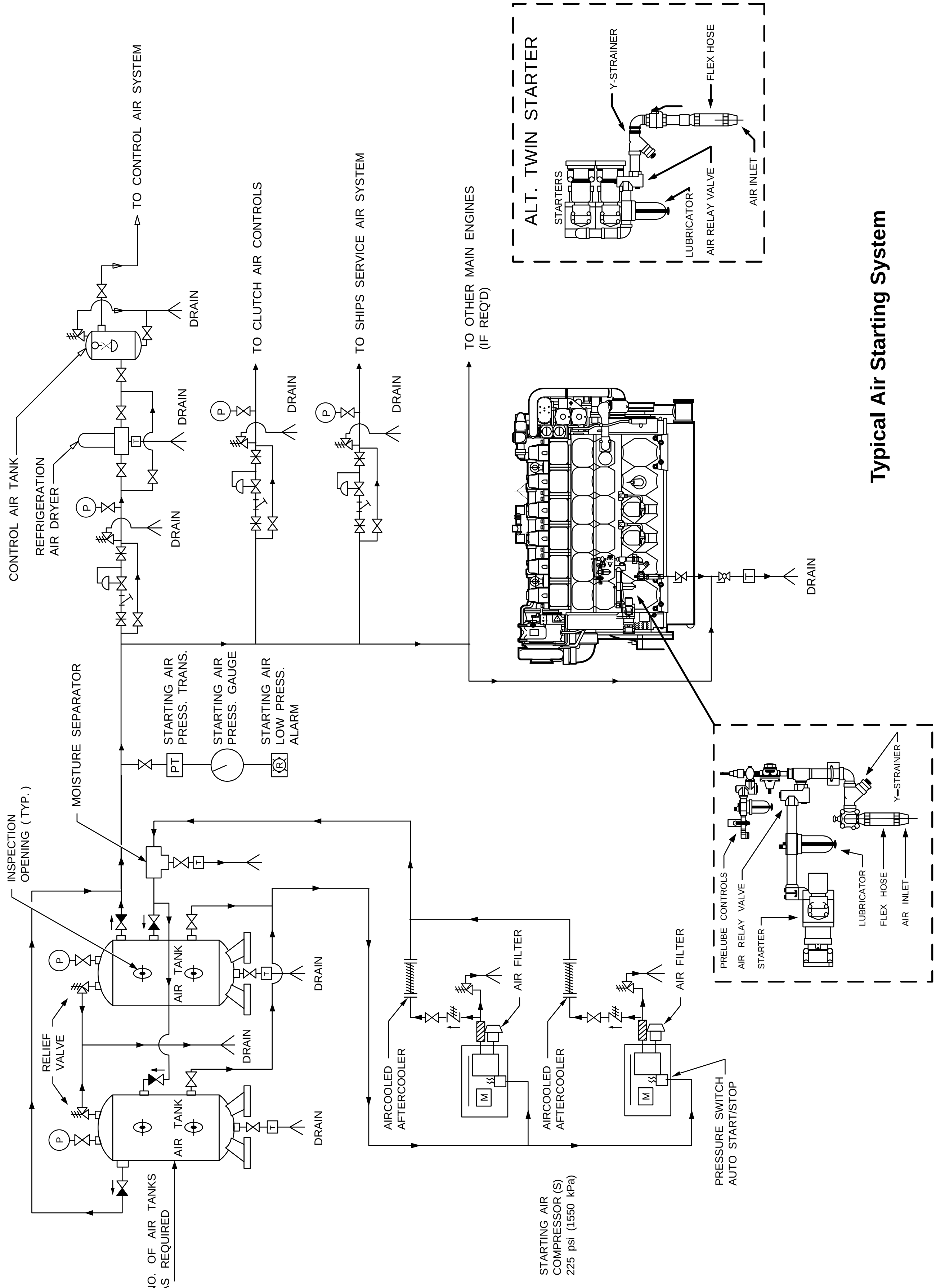
If the engine operates at ambients below 0°C (32°F), and operates in a high humidity environment, an air dryer is needed to prevent condensed water from freezing in piping. *When the same air is used for other purposes, e.g., engine controls, the air dryer is essential.*

Cleanliness

Purge the compressed air lines of debris and loose weld material prior to initial startup. Dirty supply lines can damage starters and cause malfunctions of the relay valve. A damaged valve can open or keep open the main air supply lines and cause pinion and flywheel ring gear teeth damage (pinion spinning while engaging).

Testing

Hydrostatically test the compressed air lines to at least 1.5 times the system working pressure, or to the requirements of the applicable regulatory agency.



Typical Air Starting System

Figure 1

Air Starting Motor - Electric Prelube Pump with Electric Controls

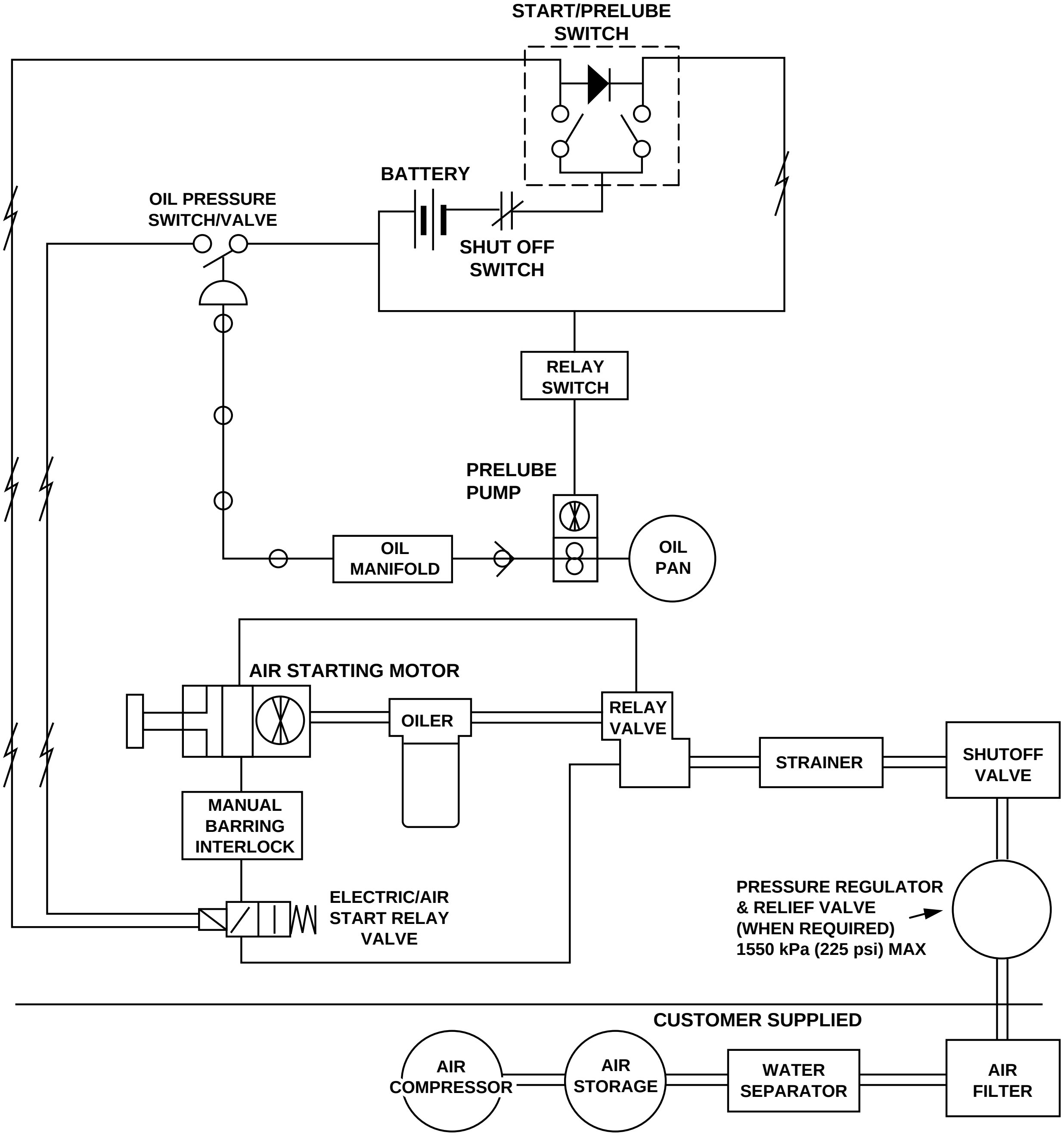


Figure 3

Air Starting Motor - Air Driven Prelube Pump with Electric Controls

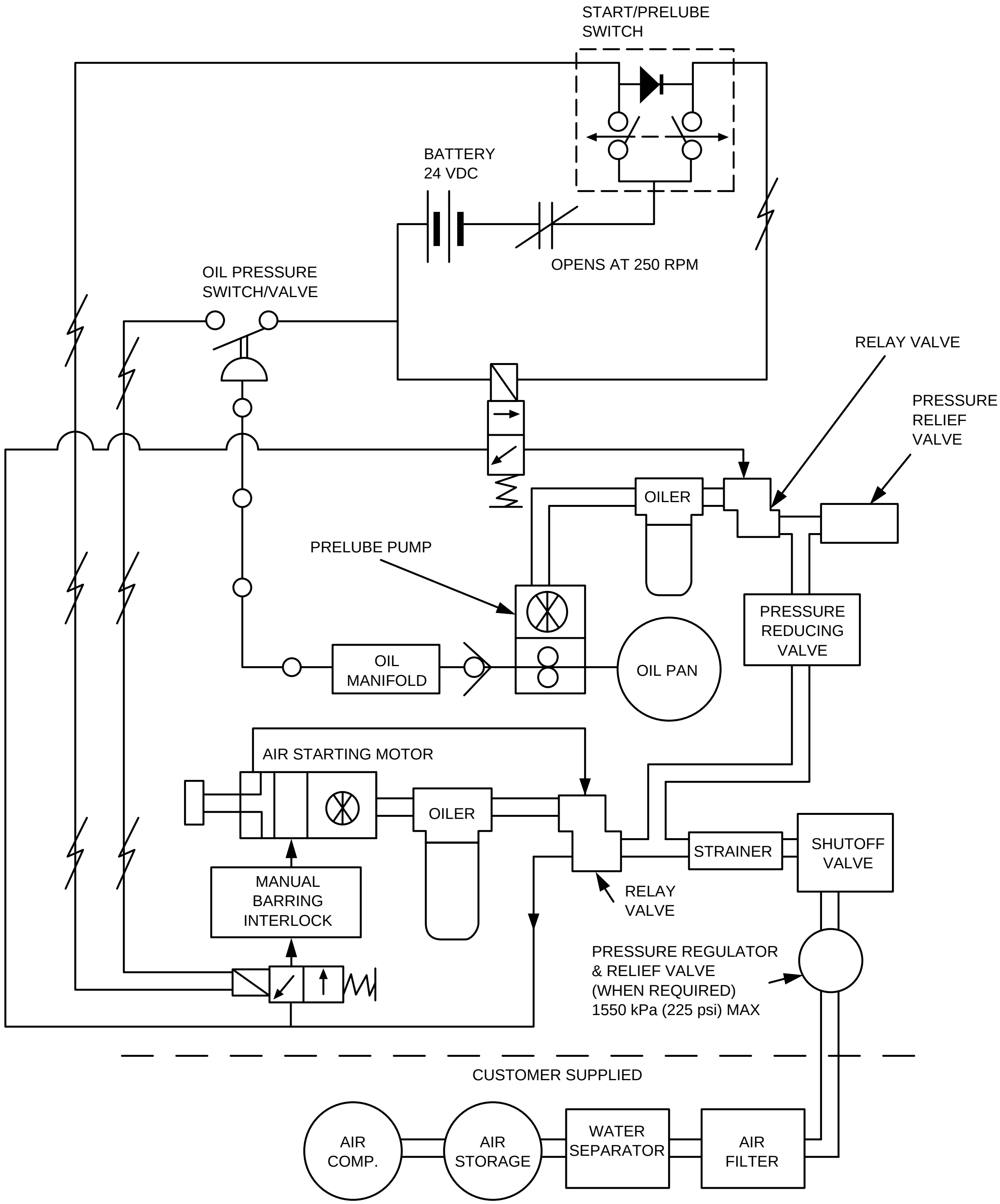


Figure 4

Engine Systems - Crankcase Ventilation

Crankcase Ventilation

Normal combustion pressures in an internal combustion engine cause some blowby past piston rings into the crankcase. To prevent pressure buildup within the crankcase, vent tubes and crankcase breathers are provided.

Do not vent crankcase fumes into the engine room. Fumes clog air filters and increase air inlet temperature causing engine damage. They can also cause problems in the electrical equipment.

Crankcase fumes should be discharged to the atmosphere through a venting system as shown in Figure 1. A separate vent line for each engine is required. The vee engines have breathers located on the service side of the engine. Crankcase vent pipes must be large enough to minimize backpressure. Blowby on a new engine will be approximately .02 m^3/hr/bkW (.5 ft^3/hr/bhp). The pipes should also be adequately sized to accommodate a worn engine. Size vent piping for .04 m^3/hr/bkW (1 ft^3/hr/bhp) with a maximum of 13 mm H_2O (0.5 in. H_2O) pressure drop in the piping.

Loops or low spots in a crankcase vent pipe must be avoided to prevent condensation from collecting in the pipe and restricting normal fume discharge. Where horizontal runs are required, install the pipe with a gradual 41.7 mm/m (.5 in./ft) slope from the engine. In typical marine installations, the weight of the vent pipes will require separate off-engine supports as part of the installation design (see Figure 1).

Vent the pipe directly to atmosphere at the top of the stack and fit with a gooseneck (with flame screen) to keep rain or spray from entering the engine. Give consideration to other equipment located near the discharge area. The small amount of oil carryover can accumulate over time and become unsightly.

An oil vent/condensate trap installed in the piping will minimize the amount of oil discharge through the vent pipe (see Figure 1).

In cold climate conditions the oil vent/condensate trap should be installed closer to the engine breather connection to prevent condensation from freezing in the trap.

Under no circumstances should crankcase pressure vary more than 25.4 mm H_2O (1.0 in. H_2O) from ambient barometric pressure. Make measurement at the engine dipstick location with the engine at operating temperature and speed, and at 50%-75% rated load.

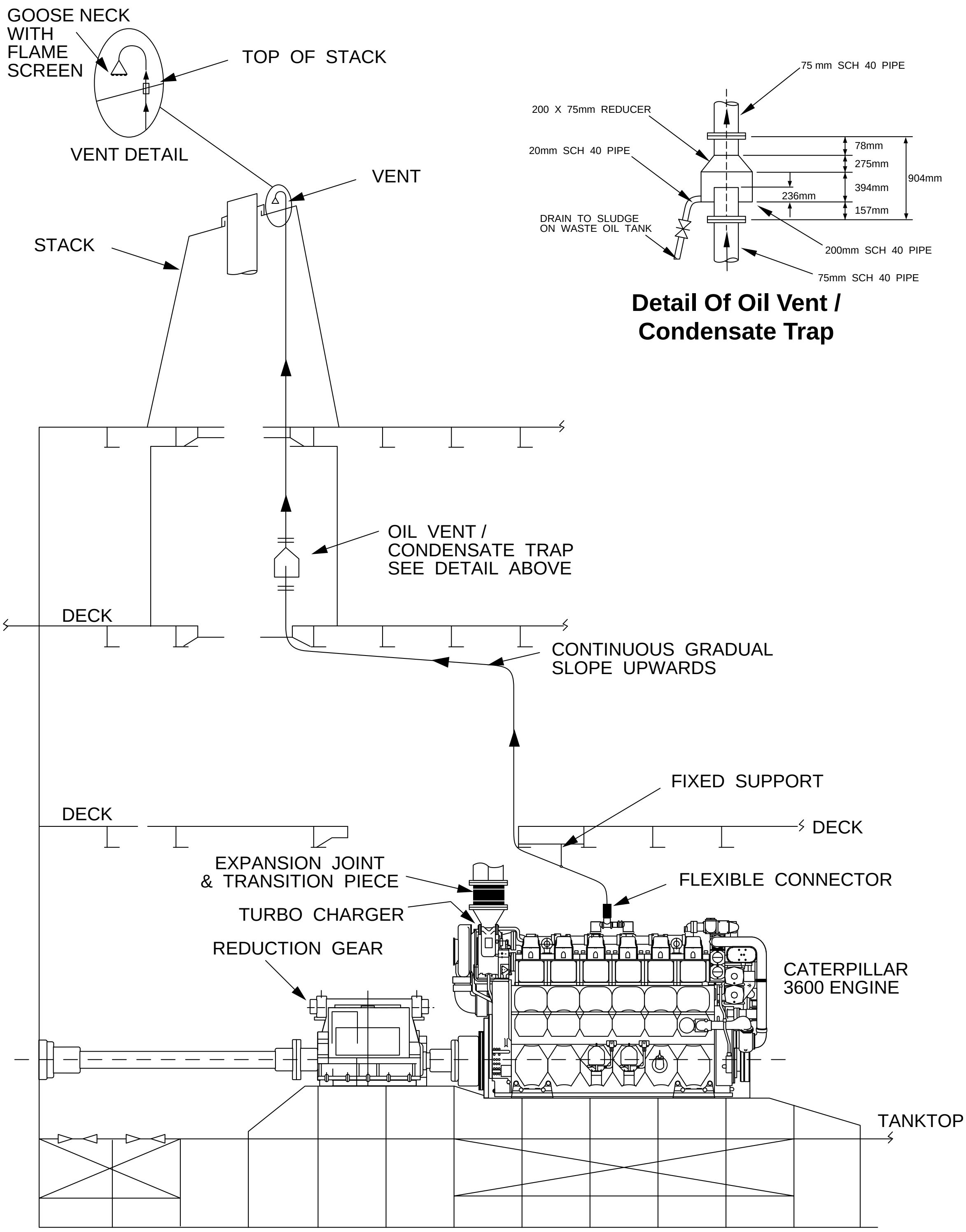

GOOSE NECK
WITH
FLAME
SCREEN
TOP OF STACK
VENT DETAIL
VENT
STACK
75 mm SCH 40 PIPE
200 X 75mm REDUCER
20mm SCH 40 PIPE
DRAIN TO SLUDGE
ON WASTE OIL TANK
78mm
275mm
394mm
157mm
236mm
904mm
200mm SCH 40 PIPE
75mm SCH 40 PIPE
Detail Of Oil Vent /
Condensate Trap
OIL VENT /
CONDENSATE TRAP
SEE DETAIL ABOVE
DECK
CONTINUOUS GRADUAL
SLOPE UPWARDS
FIXED SUPPORT
DECK
DECK
EXPANSION JOINT
& TRANSITION PIECE
FLEXIBLE CONNECTOR
TURBO CHARGER
REDUCTION GEAR
CATERPILLAR
3600 ENGINE
TANKTOP

Figure 1

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

● Mounting and Alignment

LEKM8467 8-98

Mounting and Alignment

Foundation Design

Engines

This section deals with propulsion engine and marine gear foundations and their relationship to ship framing. Refer to *Mounting* and *Alignment* of this section for information on bolting, chocking, and alignment.

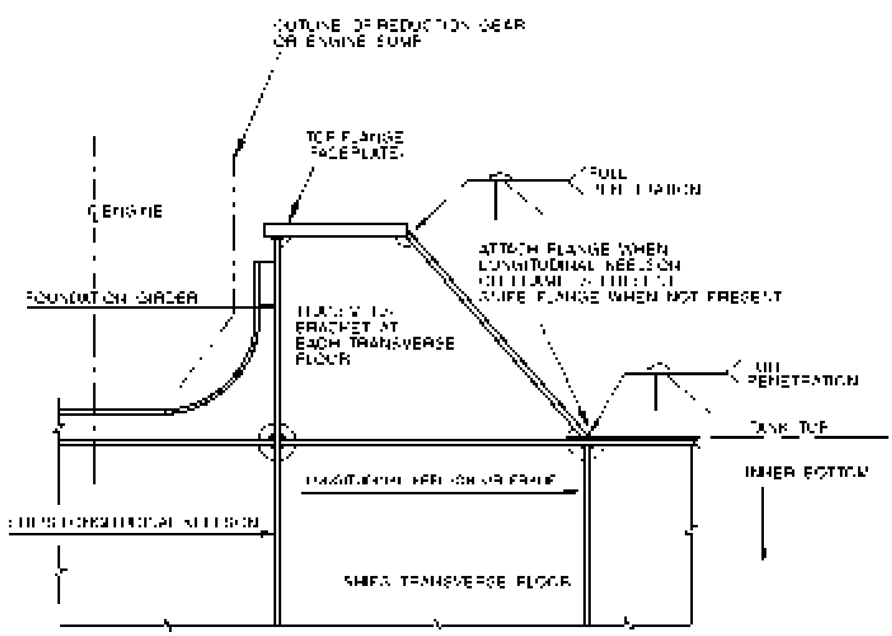
The majority of 3600 Marine applications will be classed by a Marine Classification Society. The contractor or engineering firm must submit structural drawings and/or modifications to the society for approval. Also, submit the drawings to Caterpillar for review. If required, engine foundation steel should be certified and approved by the classification society.

Frame line and floor spacing will depend on the ship type, classification society requirements, shipyard procedures, production and fabrication techniques, etc. From a machinery standpoint, it is desirable for floors and brackets to be aligned vertically with the engine crankshaft bearings and cylinder block bulkheads. This provides rigidity for the engine and reduction gear units.

Main bearing spacings on the Caterpillar 3600 Family of Engines are 410 mm (16.1 in.) and 460 mm, (18.1 in.) for the in-line and vee engines respectively. At this distance the frame and/or floor spacing may be too close for inspection and maintenance of the inner bottom structure. When this occurs the spacing requirement may increase to a maximum of 610 mm (24 in.).

Exact analytical methods cannot always be used to design engine foundations. The design is also influenced by several factors, including previous successful installations, the designer's experience, and the basic dimensions of the specific engine being installed. See the *Engine Data* section of this guide for specific information on 3600 Engine weights and dimensions.

The engine foundation must resist vertical, horizontal, and fore-and-aft deflection. Integrate the foundation into the reduction gear foundation to connect the overall structure to the ship's inner bottom structure as shown in Figure 1. The thrust from the propeller and the dynamic forces from the main engine and reduction gear are evenly distributed over a large area of the inner bottom structure.



Sectional View At A Ship's Transverse Frame

Figure 1

As shown in Figure 2 on page 28, the foundation's longitudinal foundation girders located on each side of the engine or gear box continue below the tank top as keelsons in the inner bottom structure. When it is not possible to use one piece girders and keelsons, they should at least be in alignment above and below the tank top.

The main engine foundation must have sufficient rigidity to transmit static and dynamic forces from the main engine into the foundation. The girder and face plate must:

- Increase bending inertia of the structure
- Facilitate chock installation
- Permit installation of side blocks and collision chocks
- Provide a *work shelf* for servicing the side of the engine

The main engine and reduction gear foundation must also be designed to absorb the loads from:

- Ship's vibration
- Propeller thrust
- Thrust and torque of the engine
- Ship's motion at sea
- Thermal, static and dynamic effects
- Crash reversals

Because the loads originate from sources other than the engine, the foundation sections should be uninterrupted and have adequate section strength.

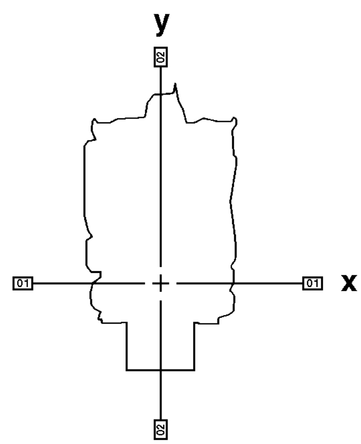
To avoid natural frequency resonance between engine and hull, the ship builder must ensure resonance between torque excitation and the natural transverse hull frequencies does not occur.

Foundation Deformations

The designer must assess the rigidity of the foundation versus the engine and gear deformation. The following engine bending inertias may be used to evaluate the foundation system:

Table of Bending Inertias

Engine Model	Bending Inertia (I_x)
3606	3.8 E11 mm^4
3608	3.8 E11 mm^4
3612	6.0 E11 mm^4
3616	6.0 E11 mm^4



I_X = Inertia About x Axis

Figure 3

Double continuous fillet welding must be used for the entire engine foundation and inner bottom structure in the proximity of the engine and gear box. Full penetration welds are recommended when heavy scantlings are required, such as longitudinal girders and engine foundation top flange. Submit details of the main engine scantlings and welding to the appropriate classification society.

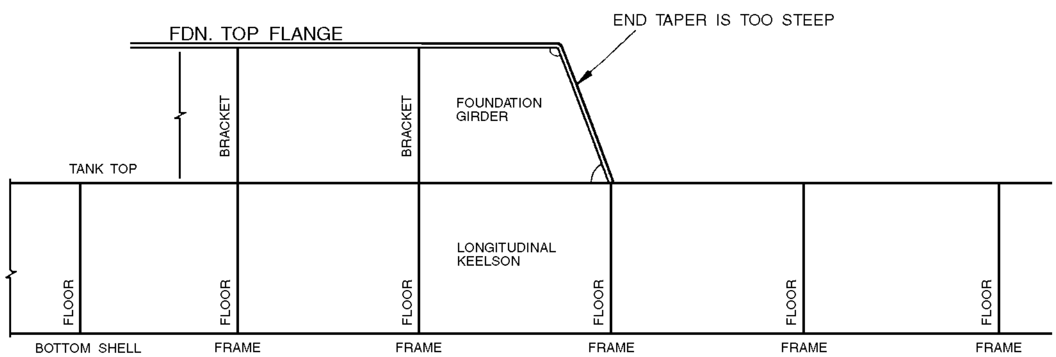
Engine foundation design involves:

- Engine position relative to the structure, either as new construction or repower. This may be the most important consideration.
- Bulkhead and deck locations.
- Depth of double bottom.
- Spacing and location of the transverse floor and longitudinal girders.
- Other engine room machinery.

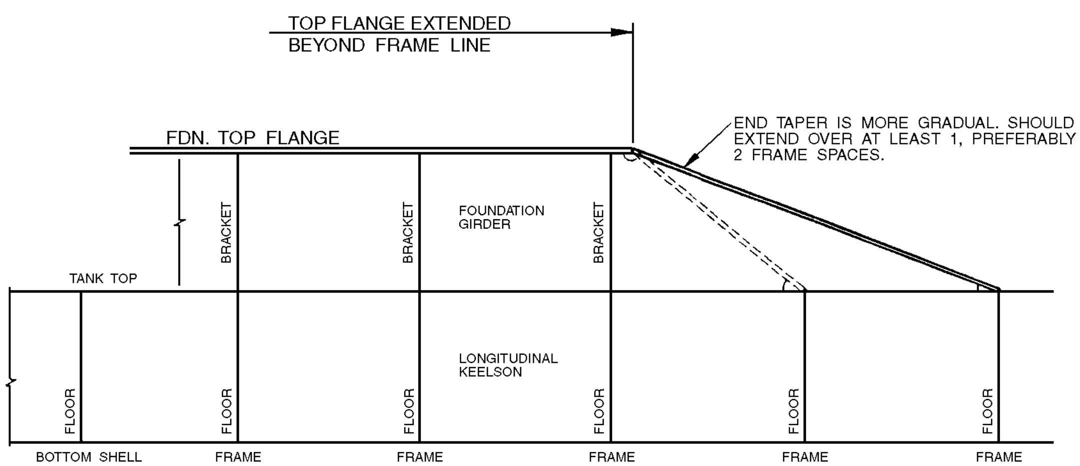
More engine location possibilities will be available in new ship construction. The main engine's location may be moved somewhat to facilitate optimum shafting positioning. Specific repowering is discussed in more detail in the *Repowering Applications* section of this guide. The foundation girders must be integral with the longitudinal keelsons within new engine room construction. The distance of the foundation girders from the engine centerline is determined by the engine mounting feet location shown in Figures 4 through 8 on pages 29 through 33 in the *Mounting* section. After allowing chocking clearance, the height of the mounting feet below the horizontal centerline of the engine determines the foundation height. See the *Mounting* section for chocking discussion.

Extend the engine foundation top flange beyond the forward engine mounting foot to allow room for collision blocks. At this point, taper the flange downward to meet the tank top at a floor. Review the top flange length and its location relative to the ship's framing. It must extend beyond a frame to accommodate one pair of brackets at the forward end before it tapers gradually downward to the tank top.

The forward taper is generally determined by the ship's transverse frame spacing. In closely spaced framing, the end taper should extend over two frame spaces while in ships with larger frame spaces, the forward taper would generally extend over one frame space, Figure 9. The taper should be gradual, but will depend on the floor spacing; approximately 30°- 45° above the horizontal.



Improper Tapering Off - Engine Foundation

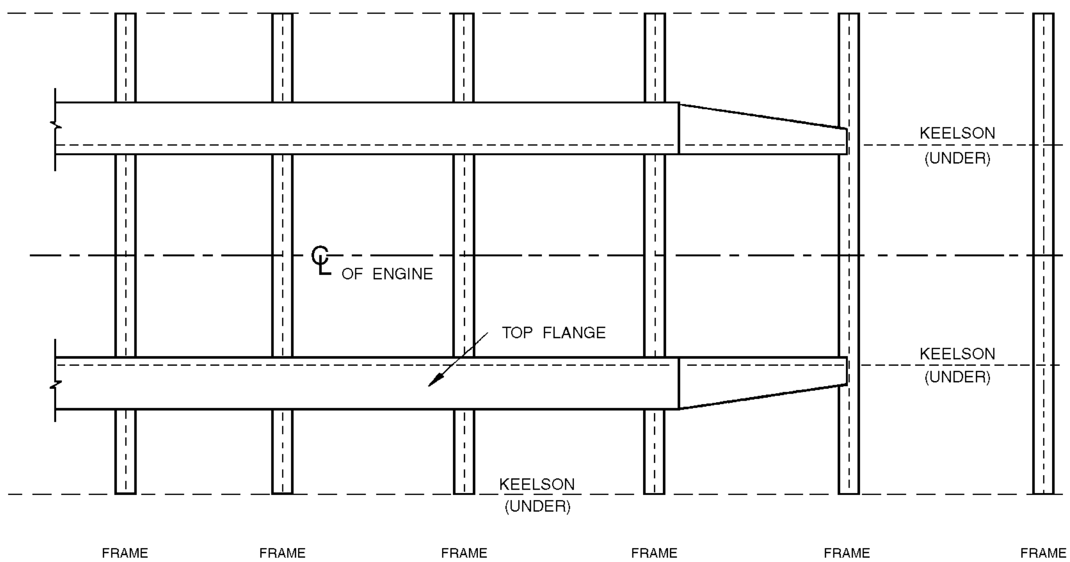


Proper Tapering Off - Engine Foundation **Figure 9**

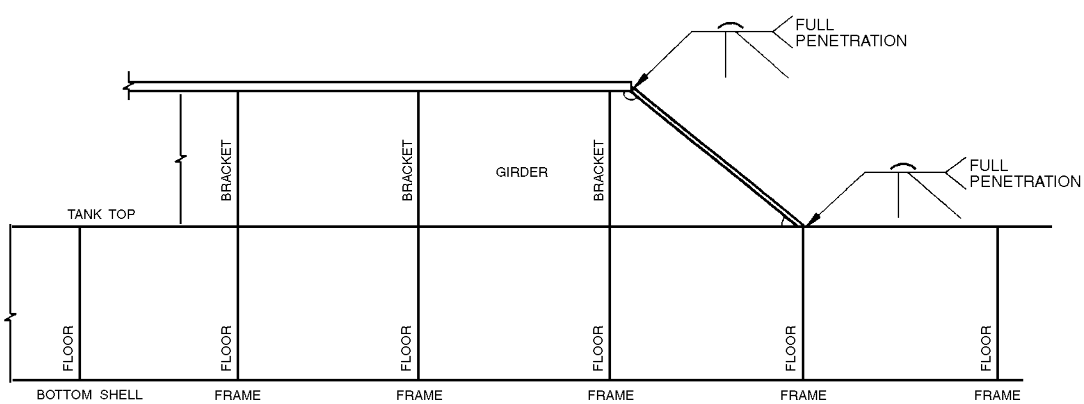
Also taper the foundation girder top flange down to the tank top. The sloping flange can be thinner than the foundation top flange, about 60 to 75% of the top flange thickness. Make the sloping flange from straight flat bar or flat bar tapered to a lesser width at the tank top end, Figure 10. The flange must have a full penetration weld at the tank top. Double continuous welds are generally used in the foundation and full penetration welds are used where thick plates (≥1/2 in.) join each other.

The foundation top flange must be wider than required for engine mounting feet. Include requirements for side guide blocks and damming when using poured chocking.

The aft end foundation location is determined in a similar manner to the forward using the last set of mounting foot bolts and the need for rear collision blocks. The engine top flange should have a transition into the reduction gear foundation.



Plan View Of Main Engine Girders



Foundation Girders-Tapered Brackets

Figure 10

Transverse brackets must be provided at each frame. In general, the brackets are welded at the top to the top flange, and at the bottom to the tank top unless there is no longitudinal structure under the tank top. Where no longitudinal keelson or frame is present, the bracket flange must be cut to clear the tank top. See Figure 11. Brackets and bracket flanges must never be placed on unsupported *soft* plating. The transverse width of each bracket is generally determined by the space between the longitudinal keelson at the foundation girder and the next outboard longitudinal keelson or frame. The bracket shape is in general terms about 45°, but is determined by the geometry of the structure. Where widely spaced transverse floors are present on the ship, intermediate brackets with intermediate frames under the tank top must be installed. See Figure 12.

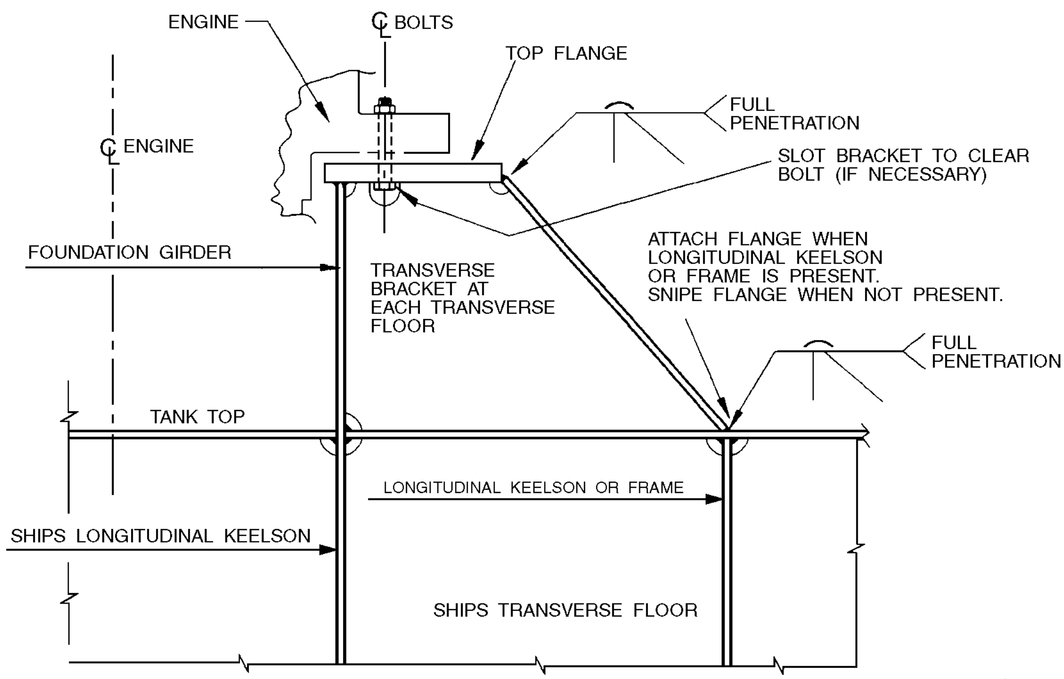


Figure 11

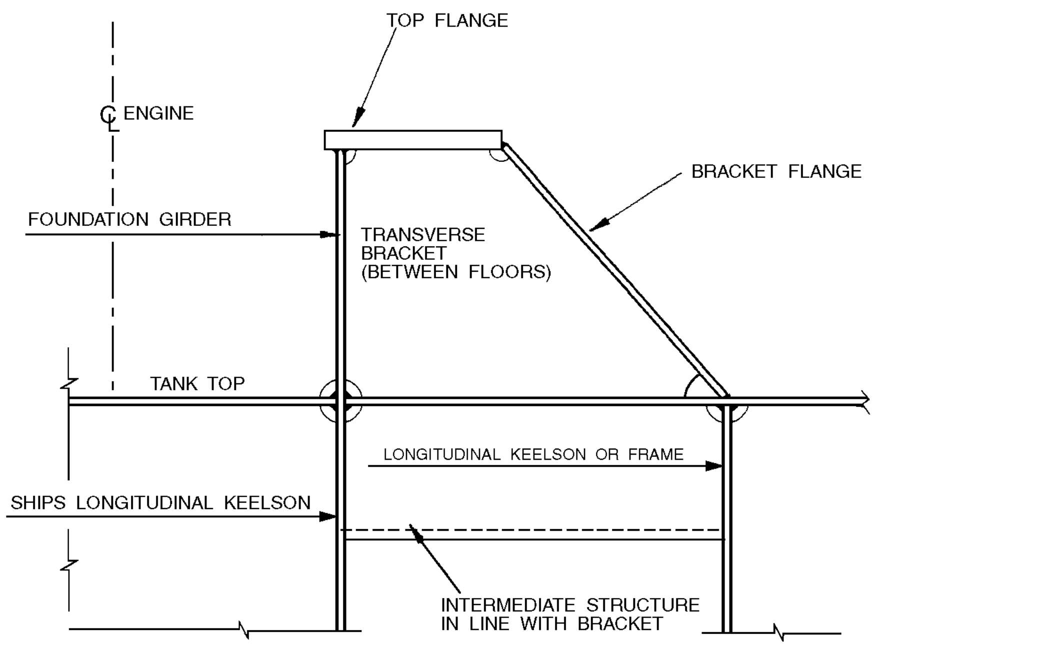


Figure 12

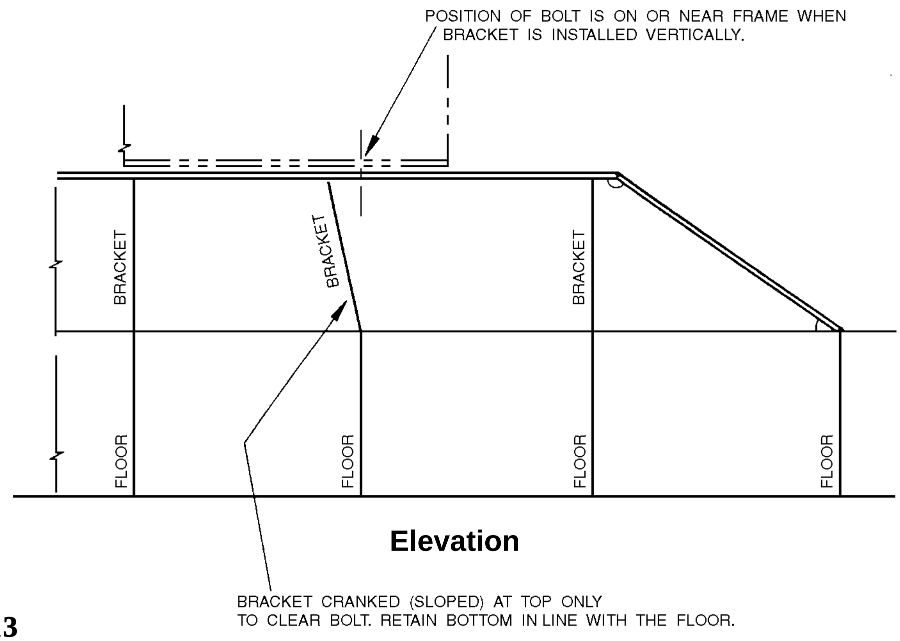


Figure 13

Brackets, whether at frames or at intermediate frames, will occasionally interfere with engine hold down bolts. When this occurs two options are:

- Slot the transverse bracket to permit inserting the bolt. See Figure 11
- *Crank* (slope) the bracket to clear the bolt. See Figure 13.

Marine Gear Foundation Design

The marine gear fore and aft position is determined by the propeller shaft coupling flange location. The height above baseline is established by the propeller shaft elevation. Elevation and geometry above baseline of the reduction gear input shaft establishes the engine crankshaft centerline.

The reduction gear mounting flange is generally much wider than the mounting flange under the main engine. In many installations they are located at differing distances from the engine centerline. Consequently, the reduction gear foundation has a different configuration than the engine foundation. As mentioned previously, the engine and gear box foundations must be integrated into one unit. This allows the combined foundation to be connected to the ship's inner bottom structure for engine and gear support.

With the reduction gear positioned, the forward and aft ends of the gear foundation top flange can be determined.

The elevation of the top flange above baseline can also be established by allowing 25 to 40 mm (1 to 1 1/2 in.) for chocking below the reduction gear mounting flange. Join the two foundations to form one unit integral with the ship's structure. In new ship construction, the longitudinal girders in the engine room are usually positioned to accommodate the main engine foundation requirements, Figure 14. In new ship construction, the girders would be *cranked* (sloped) to match the position needed for the engine and gear box foundation. This may not be true on repowers, as the girders were positioned to suit the original engine. See the section on *Repowering Applications*.

Avoid cutouts through the foundation longitudinal girder where possible. Occasionally, an opening will be required in a foundation girder for access or for piping. When this occurs the opening should be circular in shape or have rounded corners to eliminate stress concentrations. Openings in foundation girders should be as small as practical and near the neutral axis of the girder.

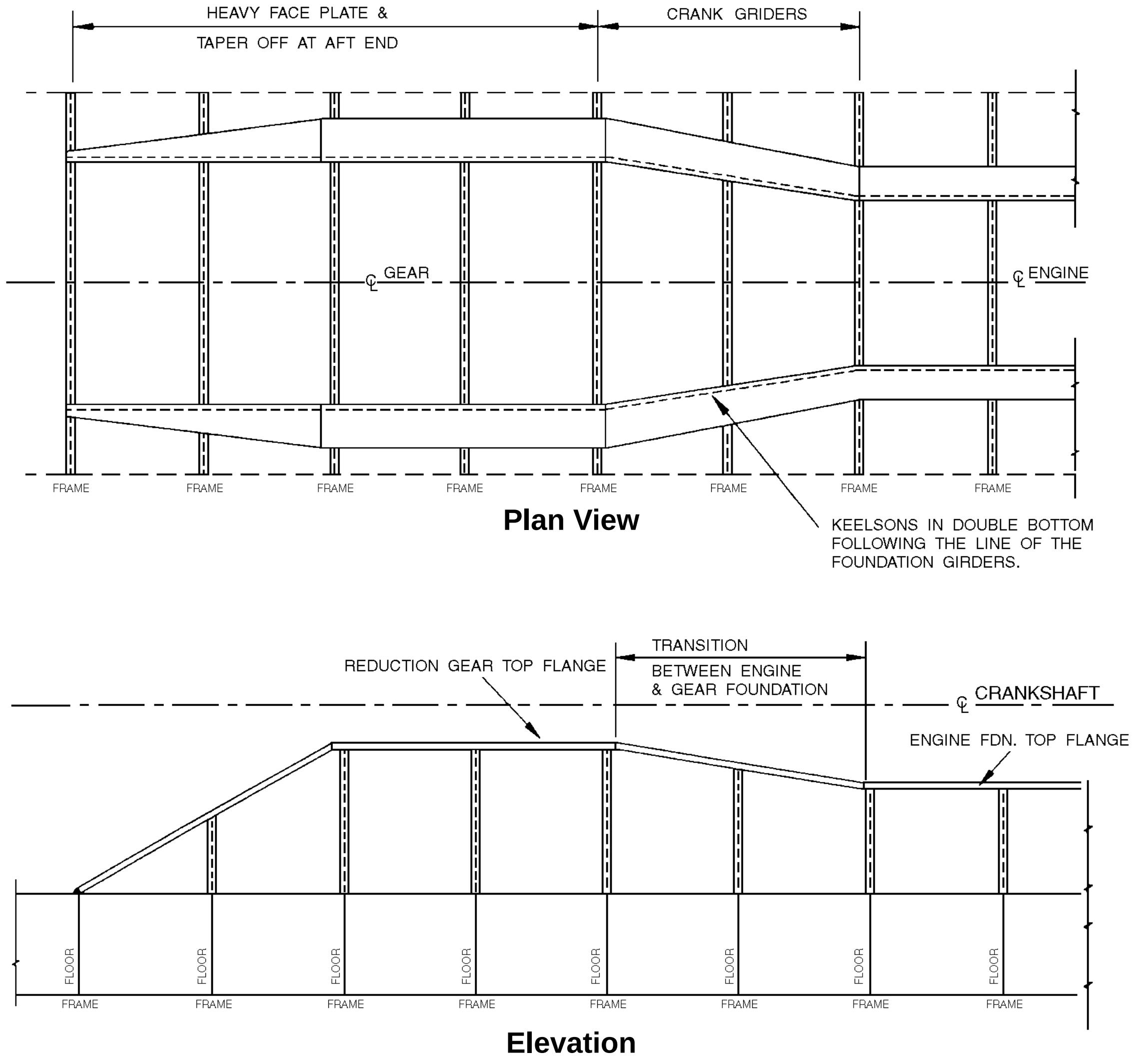


Figure 14

In cases where the cutout becomes too large (about 1/3 the depth of the girder) weld a reinforcing ring or doubler plate to the girder to compensate for the removed material.

Generator Set Foundations

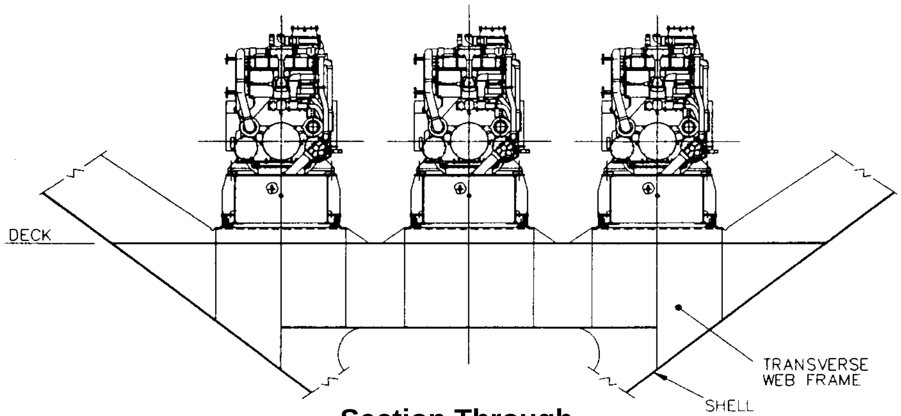
The principals of propulsion engine foundations at the tank top level apply to generator sets as well. Align the generator foundation with longitudinal girders. It must be supported by transverse brackets or chocks between the foundation flange and the tank top. Align the brackets with the floors or frames.

Generators mounted on Caterpillar's rigid base and sitting on spring isolators do not need the foundation depth required by propulsion engines. They are often constructed of two heavy angles tied together by several transverse angles.

Figure 15 illustrates generator sets located on intermediate deck levels above the tank top; the same foundation principals apply.

Deep transverse web frames tied into the hull or supported by columns are optimum for intermediate deck level mounting.

Use continuous welding at all foundation locations.



Section Through
Generator Set Foundation

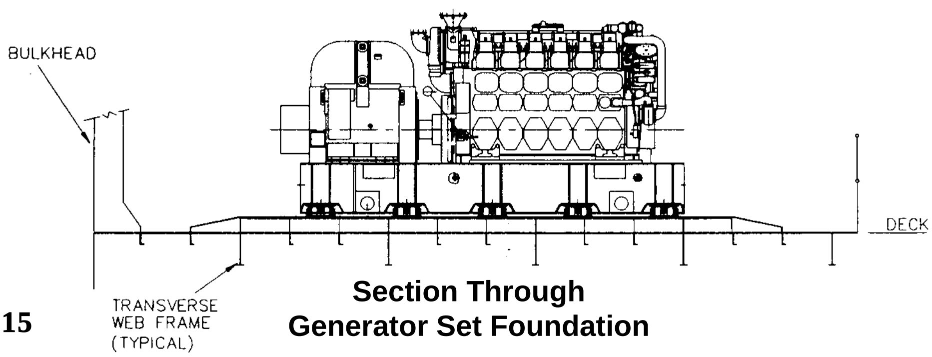


Figure 15 Section Through
Generator Set Foundation

Construction Materials

Fabricated foundation steel must meet classification society requirements. Society requirements are also a good guide for unclassed vessels. Higher strength steels are normally not used in engine and gear box foundations as thinner scantlings may lead to potential problems with foundation buckling.

Plate thicknesses of the various structural components may vary with the selection of the engine. In general, the following *minimum* plate thicknesses are provided for guidance.

- Engine foundation top flange - 38 mm (1 1/2 in.)
- Engine foundation girders - 19 mm (3/4 in.)
- Reduction gear top flange - 44 mm (1 3/4 in.)
- Reduction gear girder - 22 mm (7/8 in.)
- Transverse brackets - Same as girder thickness or at least equal to the thickness of the floors in the double bottom.
- Bracket flange - No less than 60% of the bracket thickness but at least 13 mm (1/2 in.). Brackets may be flanged or have a flat bar welded to the web of the bracket. In either instance, the free bar width should be a minimum of 152 mm (6 in.).

Dual Engine Installation

The principles outlined previously for single main engine installations are applicable for multiple main engines. One further recommendation is to join the main engine foundations together with a bracket extending between the two inboard foundation girders, Figure 16. The bracket depth is determined by the desired floor plate height. The thickness and scantlings are determined by the depth and span of the bracket between the two girders. Where deep brackets or long spans are present, stiffen the bracket between the two longitudinal girders by a standard size rolled beam or flat bar. The center brackets may have small lightening holes for piping, etc.

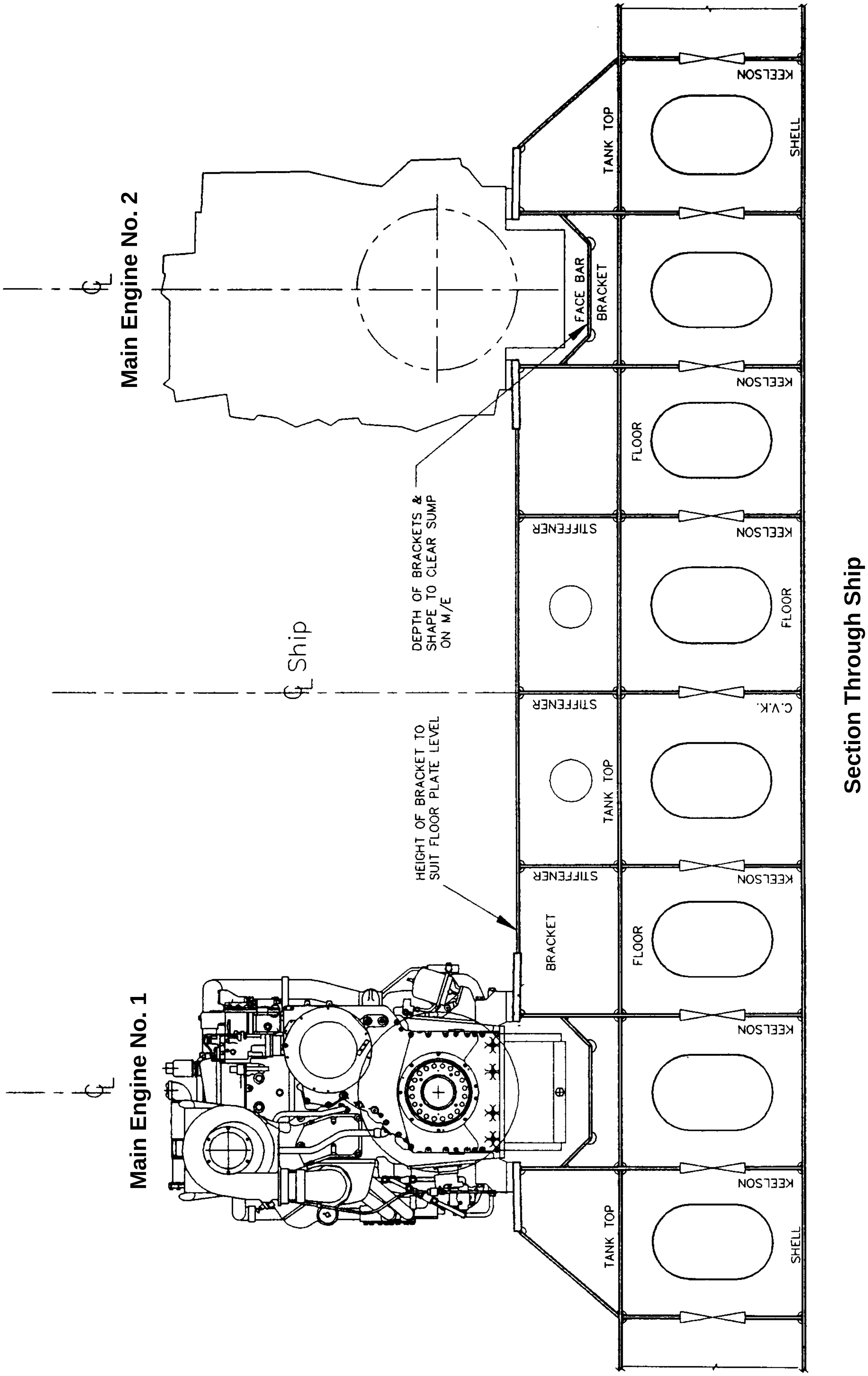

Main Engine No. 2
Main Engine No. 1
℄ Ship
DEPTH OF BRACKETS & SHAPE TO CLEAR SUMP ON M/E
HEIGHT OF BRACKET TO SUIT FLOOR PLATE LEVEL
FACE BAR
BRACKET
TANK TOP
KEELSON
SHELL
FLOOR
STIFFENER
C.V.K.
Section Through Ship

Figure 16

Installations Near the Ship's Side

In small ships or where twin screw/twin engines are used, the main engine girders may be close to the ship's side. When this occurs the outboard engine girder may be bracketed directly to the ship's web framing as shown in Figure 17.

The bracket web would usually be of a thickness equivalent to the web frame thickness. The face bar of the bracket may be sniped or welded directly to the web frame face plate. A welded connection is preferable. However, when welded directly a flat bar chock must be provided on both sides of the web frame.

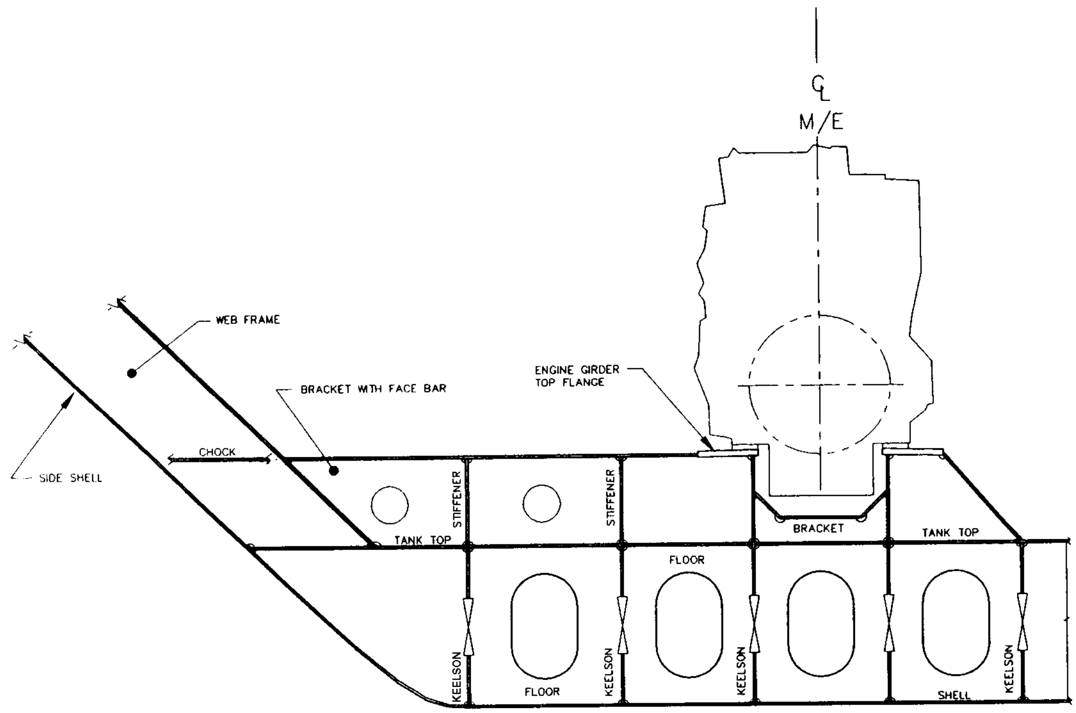


Figure 17 **Section Thru Ship**

Mounting

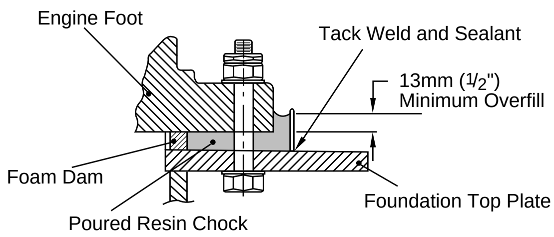
Main propulsion engines are normally bolted directly to the engine foundation using resin chocks. Steel shims can also be used. Isolation mounting is also available from Caterpillar. Engine mounting *"Footprints"* are shown in Figures 4 through 8, pages 29 through 33.

This section primarily deals with propulsion engine mounting systems. Mount marine auxiliary engines used for ship's service generator set applications on the factory supplied rigid base setting on factory supplied spring isolators. See the *3600 EPG Application and Installation Guide*, Form No. LEKX1002 for further details.

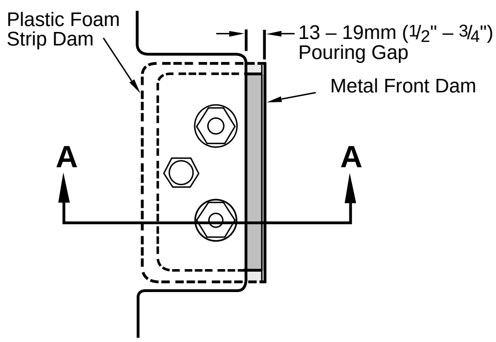
Hard Mounting

Resin Chocking

Marine Classification Society rules may apply on specific installations using poured resin chocks. *Do not use lead as a shim material. It is easily deformed and has poor support characteristics.* Figure 18 is an example of a poured resin chock.



Section A-A Elevation



Plan View

Figure 18

Use the following criteria:
- Normally six mounting feet (3 per engine side) are used for resin chocking. However, four mounting feet have sufficient area for resin chocks on the 3606 and the 3608 Engines. The 3612 and 3616 Engines require 6 feet.
- The chocking arrangement, planning and pouring should be reviewed by an approved resin manufacturer.
- The shipyard normally has final responsibility for chocking material installation.

Most classification societies permit the use of Chockfast Orange, manufactured by the Philadelphia Resins Corp., USA. The following guidelines apply:

- A maximum dead weight loading of 7 kg/cm^2 (100 psi).
- A maximum total loading, deadweight plus bolt tension, of 35 kg/cm^2 (500 psi).
- The combined bolt tension should exceed 2.5 times deadweight, but cannot exceed the requirement above.
- Permanently lock the hold-down bolts.
- The chock operating temperature must not exceed 80°C (176°F).
- The chock area should be greater than 130 cm^2 (20 in^2).
- Increase the amount of resin used by 10% to provide allowances for damming. The seating must have enough footprint to facilitate foam rubber damming strips.
- The resin thickness must be 12 mm to 45 mm (0.5 in. to 1.75 in.). *Also see section on Isolation Mounts.*
- Do not allow resin material to flow between the engine and the foundation mounting plate.

Mounting surfaces must be free of dirt, grease and rust. Spray adjoining surfaces and bolts with a release agent for future removal of machinery bolts, jacking screws, etc.. For detailed information contact the resin manufacturer.

Steel Chocking

Caterpillar does not offer steel mounting plates for marine propulsion engines. Plates available for generator set engines can be modified to fit. They are 50 mm (2 in.) thick. An example of typical plates is shown in Figure 19.

The following can be used for guidance:
- Chocks must be manufactured from steel plate or cast steel material. Use the same type of material for all chocking on an engine. They are also required at each mounting foot.
- The recommended finished machined chock thickness is 38 mm (1.5 in.). Minimum thickness is 25 mm (1 in.). *Using several loose metal shims is not recommended.*
- Dirt, grease, paint and rust must be removed from the mounting surfaces prior to installing the chocks.
- The chock and top plate surface smoothness should be at least 3.2 micrometer (125√) finish and have a minimum of 80% contact surface on each side of the chock.

- Do not weld chocks in place. They must be removable for inspection.
- The final location of hold down bolt holes is determined with the engine in place on the foundation. See guide section, *Hold Down Bolts*, on page 18.
- For easy positioning, the top flange of the engine foundation should allow for tapered chocks. Taper the chock approximately 1°, see Figure 20. An alternative is a parallel top flange and tapered steel pads welded to the engine top flange, Figure 20.

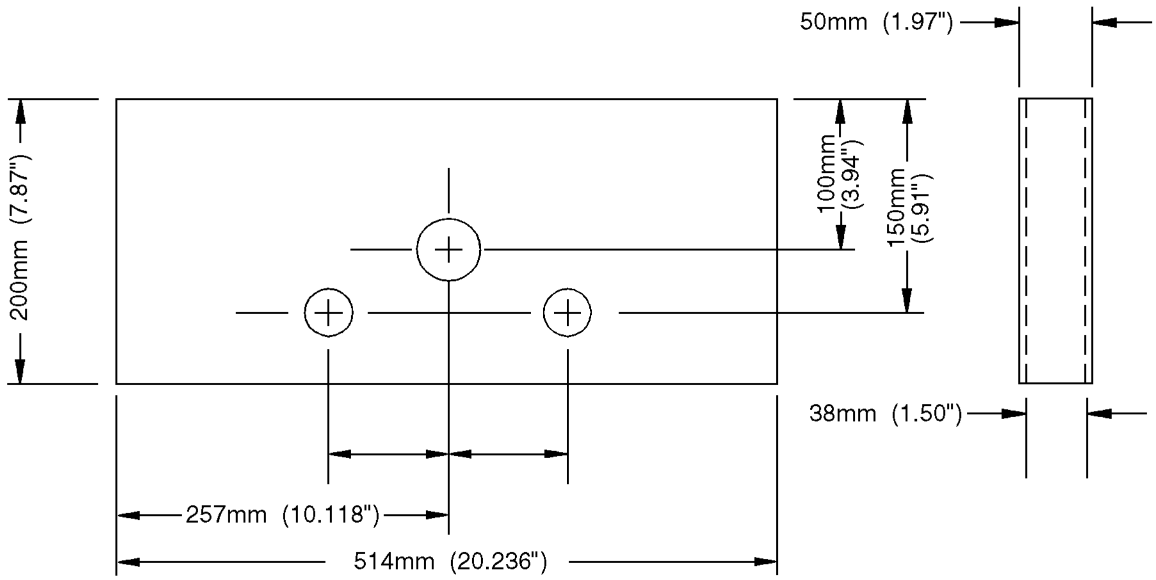


Figure 19

Typical Steel Chock

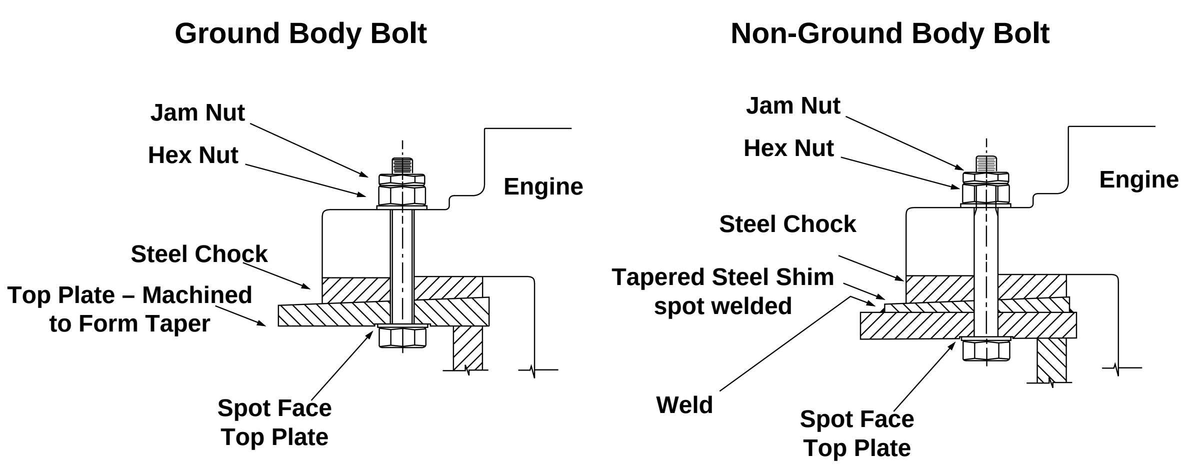


Figure 20

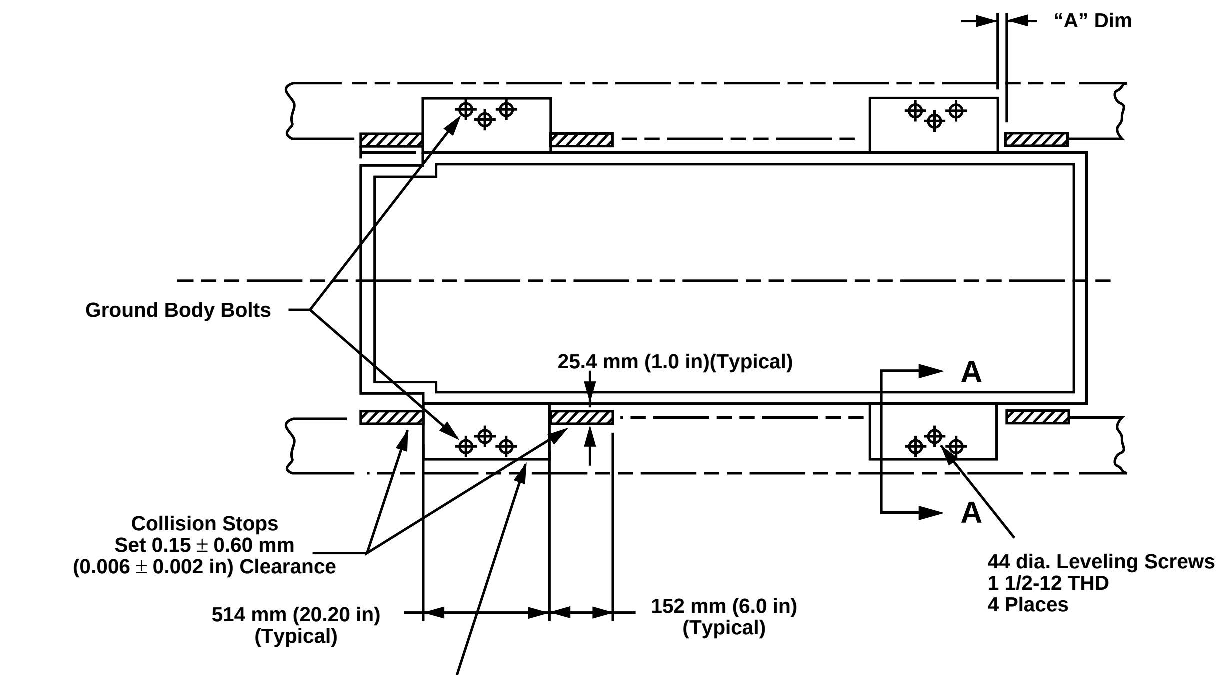
Collision Blocks

Collision blocks are normally required on marine installations. Guide blocks are optional when using the recommended bolting method described below. For location, see Figure 21. The figure also shows hole and bolt size detail of the normal hold down bolts as well as the ground body bolts used at the rear of the engine.

Collision blocks are normally manufactured by the engine installer. Use steel plates 25-38 mm (1 to 1.5 in.) thick. Extend the top of the plate to the top of the engine mounting foot. The base must be welded to the top plate of the engine foundation. Collision blocks must have clearance to allow for thermal growth of the engine. At engine operating temperature, the rear collision blocks should have a 0.15 mm (0.006 in.) gap between the feet and the blocks. See Figure 21. Use the following values for engine thermal expansion:

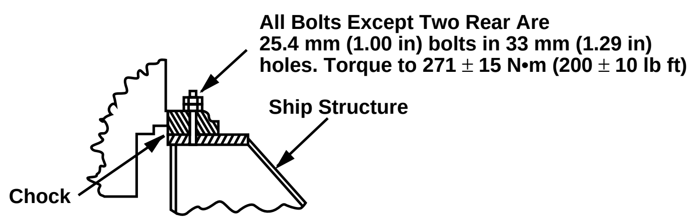
- The thermal expansion coefficient for the 3600 Engine block is equal to:
  10 E^{-6} mm/mm/°C
  (5.6 E^{-6} in./in./°F)

Optional collision blocks can also be located at the front of each of the front mounting feet. Allow enough clearance for thermal growth of the engine. Locate them close enough to be used as an alignment reference point. See Figure 21.



Plan View
(Viewed from top of engine)

Front Chock Spacing	
Engine Type	"A" dim
3606	2 mm (0.08 in.)
3608	2.5 mm (0.10 in.)
3612	2 mm (0.08 in.)
3616	3 mm (0.12 in.)



Section A-A

Figure 21

Guide Blocks
Front guide blocks are not required if ground body bolts are used in *both* rear mounting feet. See *Hold Down Bolts*. If guide blocks are used, permanently secure them at the sides of each front mounting foot with 0.50 ± 0.05 mm (0.02 ± 0.002 in.) clearance.

Hold Down Bolts
After final alignment of the marine gear and engine, secure both rear engine mounting feet to the ship structure with one ground body bolt per foot. Use the rear and outermost existing holes in the feet as a guide for drilling and reaming to a nominal size of 35 mm (1.38 in.) diameter. Maximum clearance between the ground body bolt and reamed hole is 0.020 mm (0.0008 in.). Torque the bolts to 338 ± 13 N•m (250 ± 10 lb-ft) (see Figure 20).

The ground body bolts should be torqued to 338 ± 13 N•m (250 ± 10 lb-ft) when the engine is mounted on resin chocking (see figure 18). The ground bolt torque should be increased to 900± 20 N•m (665± 15 lb-ft) when the engine is mounted on steel chocks (see figure 20).

The two front bolts in the outermost hole of each rear foot and the two bolts in the outermost holes of each of the remaining mounting feet are 25.4 mm (1.00 in.) bolts in a 33 mm (1.29 in.) clearance hole. The torque value for bolts which are installed in these locations is 271± 15 N•m (200± 10 lb-ft) when the engine is mounted on resin chocking and should be increased to 800± 20 N•m (590± 15 lb-ft) when the engine is mounted on steel chocks. The mounting feet holes can be used as a drill guide. The clearance allowed is sufficient to accommodate thermal growth of the engine.

Using ground body bolts in both rear feet does not pose thermal expansion problems across the engine width. An optional bolting method allows one ground body bolt to be used at the rear outermost hole of the right rear mounting foot. With this option, all the remaining hold down bolts would be treated the same as in the paragraph above. ***Note**: This method does require guide blocks at the front of the engine.*

If practical, insert the bolts with the bolt head down and the nuts on top. This permits periodic inspection of the bolted connection. After drilling the bolt holes in the foundation, spot face the lower contact face of the top flange normal to the bolt hole.

Eight or twelve hold down bolts will be required based on four or six mounting feet. *The bolt material should be SAE grade 8 steel or better.*

Isolation Mounts
Caterpillar's isolation mounting systems:
- Transfer steady state engine torque reaction to the ship structure.
- Allow alignment of the engine to the marine gear.
- Isolate the ship from engine vibration.
- Isolate the engine from ship vibration.

Caterpillar offers two types of isolation mounting systems:

Caterpillar silicone shear pads and the Christie and Grey system. For either, locate the six engine rigid body modes at the mounts within the following constraints:

- Keep the roll mode below 70% of the engine firing frequency at low idle. Isolate excitation pulses from torque reaction.
- One-half order resonances, particularly the side-side and roll modes, are excited at speeds close to low idle when the engine is operating under no load conditions. This must be considered.
- In general, keep modes away from typical one-half and first order resonances.

Contact Caterpillar for the suitability of a soft mount design for a particular installation.

Caterpillar Silicone Shear Pad

The silicone shear pads, Figures 22 and 23, provide isolation for higher frequency vibration, such as the vibration causing structureborne noise. At the same time they restrain overall engine motion. *Large engine displacements need not be accommodated at the torsional coupling and other engine/installation interfaces.*

***Note:** The Caterpillar shear pad mounting system is not recommended for 3606 engines rated or operated below 900 rpm for an extended period of time.*

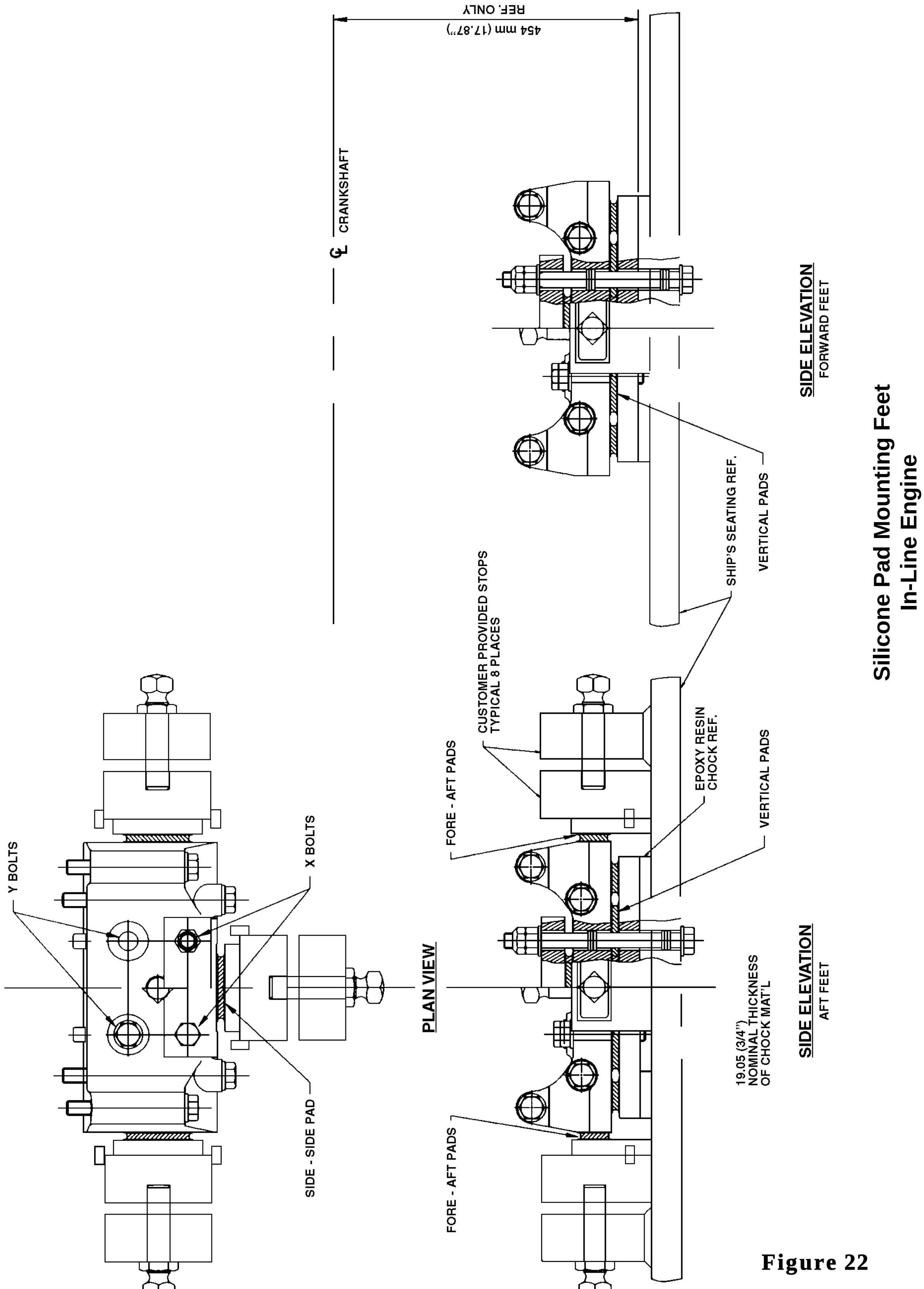
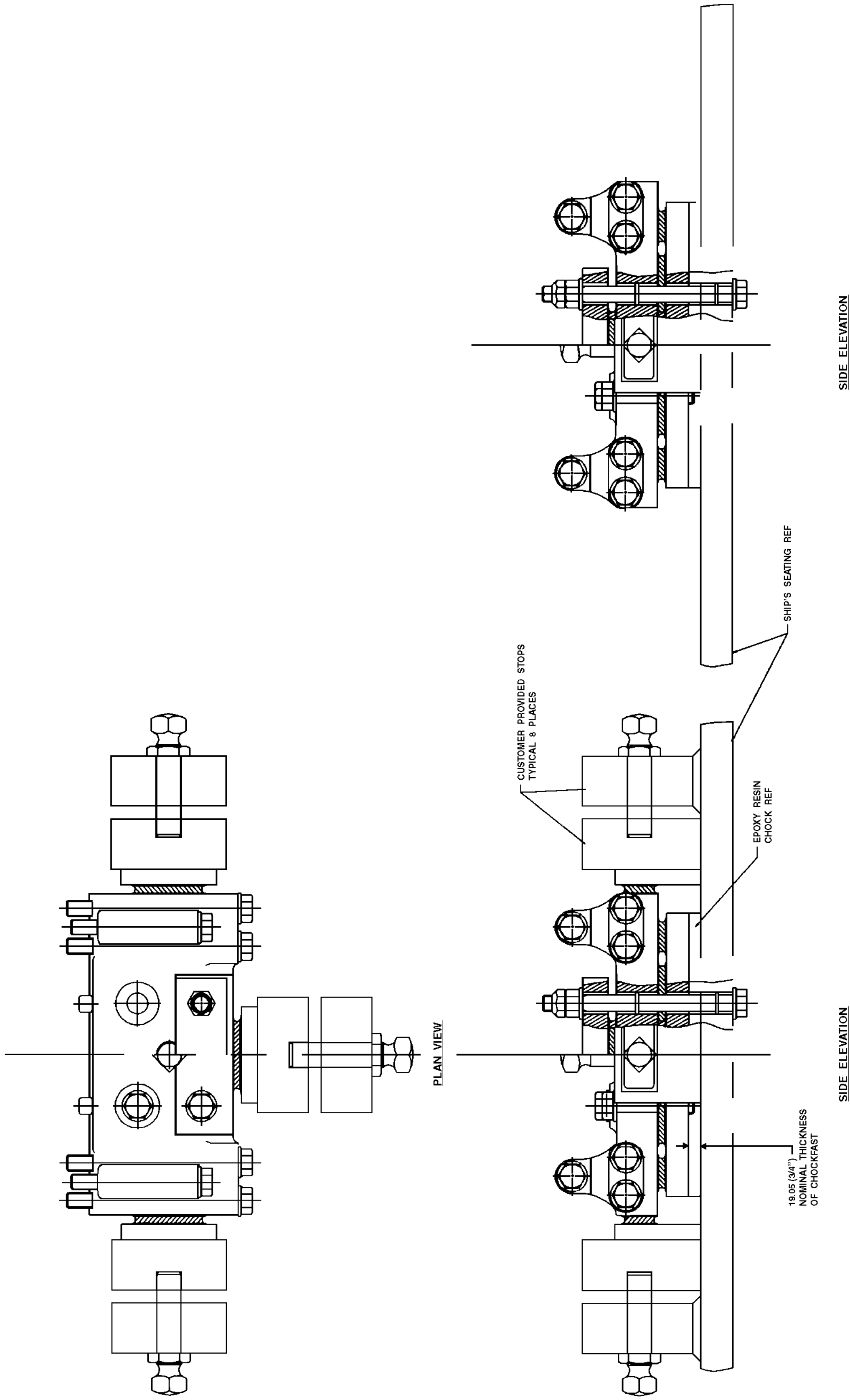


Figure 22



Typical Arrangement of Silicone Pad Mounting Feet Vee Engine

Figure 23

A thin layer of high silicone rubber is sandwiched between two metal plates, eliminating metal-to-metal contact between the engine and the ship structure. The pads are also used between the mounting feet and restraining stops on the engine foundation plates. This prevents excessive movement forward, aft, and side-to-side. Shear pads on top of the feet are used for vertical restraint. The following table lists the shear pad mounting configurations for all four 3600 engines:

3600 Shear Pad Mounting Configurations

Engine Total Number of Feet	Rear Foot Configuration	Middle Foot Configuration	Front Foot Configuration
3606 Four (4) Mounting Feet	5 pads vertically Fore-Aft collision pad Side-to-side pad Top pad	Not Required	5 pads vertically Top pad Side-to-side pad
3608 Six (6) Mounting Feet	5 pads vertically Fore-Aft collision pad Side-to-side pad Top pad	5 pads vertically Top pad (vertical restraint)	5 pads vertically Top pad Side-to-side pad
3612 Six (6) Mounting Feet	5 pads vertically Fore-Aft collision pad Side-to-side pad Top pad	5 pads vertically Top pad (vertical restraint)	5 pads vertically Top pad Side-to-side pad
3616 Eight (8) Mounting Feet	5 pads vertically Fore-Aft collision pad Side-to-side pad Top pad	5 pads vertically Top pad (vertical restraint)	5 pads vertically Top pad Side-to-side pad

Christie & Grey Mounts
This mounting system, Figure 24, uses six spring-rubber combination isolators to isolate vibration and noise. *During operation the engine is "free" to move. The torsional coupling, water, oil, fuel lines and exhaust connections must accommodate greater engine motion.* In addition, the engine coupling and/or output drive line must be flexible enough to maintain the engine bearing loads, as well as driven equipment bearing loads below appropriate limits.

Christie & Grey isolators are built with an internal buffer unit to eliminate the need for collision blocks on most applications.

Installation and Alignment

This section provides the basis of the alignment process and alignment variables. *Always use the appropriate Caterpillar Special Instruction, Service Literature and Instructions. Use the specifications from the coupling and driven equipment manufacturer to install and align the components.*

When the engine transitions from an at rest condition to normal operating temperatures, the thermal growth of the engine and the driven equipment must be compensated for during the alignment process. As an example, the total engine crankshaft centerline change due to thermal growth and oil film lift can be expected to be approximately 0.38 mm (0.015 in.)

Hard Mounting

These recommendations cover the installation and alignment of couplings to the 3600 Family of Engines engines driving free standing marine reduction gears. These recommendations apply specifically to hard mounted engines. The recommendations offered are a guideline only. Correct alignment of the equipment is the responsibility of the person performing the alignment.

***Caution**: The person performing the alignment procedure should be familiar with basic alignment terminology as well as the basic alignment tooling and its use. Improper alignment may result in loss of life, serious injury, and/or equipment damage. Alignment should be performed by trained and qualified personnel.*

Before the final alignment procedure can be started the following conditions must be met:

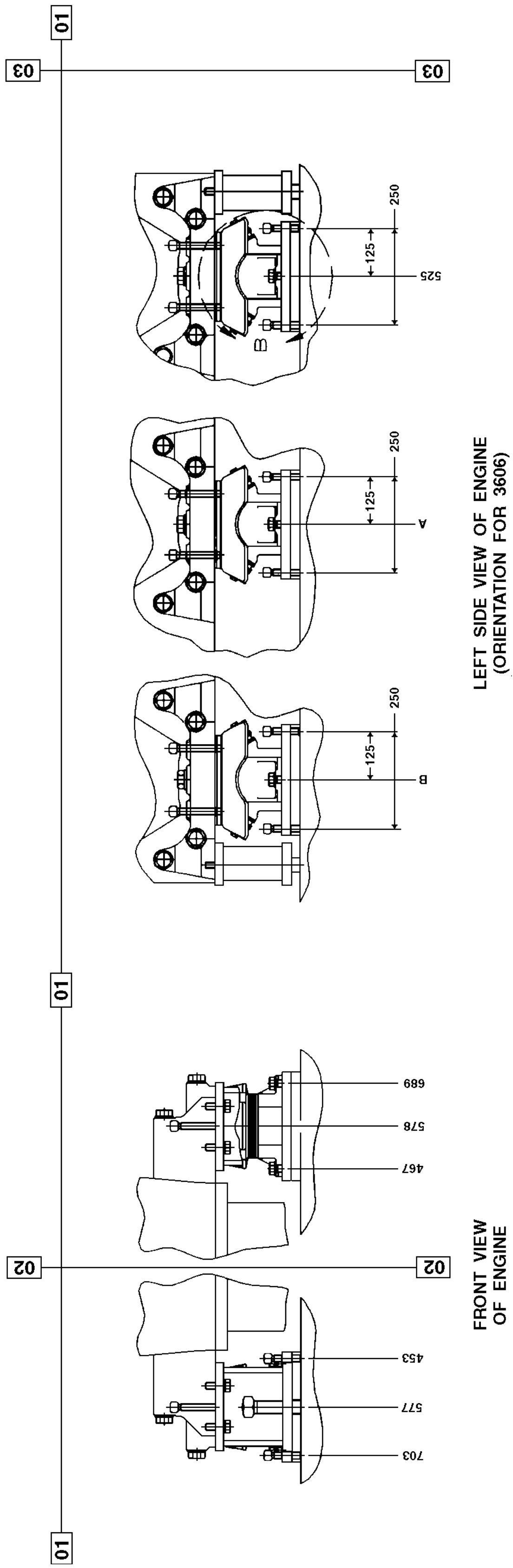
- Per manufacturer's installation instructions, install and align the propeller shaft and marine gear to each other.
- Permanently anchor the marine gear.
- The ship must be in the water with all permanent ballast in place.
- Fuel, water, and temporary ballast tanks must be filled to normal operating levels (generally 1/2 to 3/4 full).
- All major machinery weighing over 450 kg (1000 lb) must be installed or simulated by equivalent weights appropriately located.

Preparation and Cleaning
Remove all dirt, burrs, grease and paint from:

- Mating surfaces of the engine mounting feet and the mounting pads.
- Matching surfaces of the engine flywheel and coupling.
- Mating surfaces of the marine gear input shaft and the coupling.
- Mounting surfaces of the Caterpillar split spacer ring, if applicable.

Engine Installation

- Locate the approximate location of each engine mounting foot on the engine foundation rails. This can be done by referring to the ship installation drawings and using the centerline of the marine gear input shaft as a reference. Mark a rough outline of the mounting feet locations on the engine foundation rails.



Typical Christie and Grey Mounting Feet

Figure 24

- Inspect the engine foundation rails. The engine mounting feet areas must be rust free, smooth, and free from weld splatter, etc.
- Move the engine into place over the foundation.
  Caution: *Use lifting equipment with sufficient capacity to handle the weight of the engine.*
- Position the engine flywheel face relatively parallel to the marine gear's input flange. Exact parallelism is not necessary at this point.
- Lower engine onto the foundation with the mounting feet on the previously marked outlines.
- *Lightly* lubricate the engine foundation under the vertical alignment jacking bolts with oil or grease.
- Install horizontal jacking screws and brackets. Note the screws and brackets are not part of the normal engine supply. Typically the brackets are installed on the four corner feet and they must be positioned to allow sufficient travel of the jacking bolts for movement of the engine to its final aligned position.
- Prior to the coupling installation, check flywheel face and bore runout according to the procedures and specifications outlined in the engine service manual. See the guide section on *Service and Maintenance.*

Note: *Damage to the main and rod bearings may occur if they are not prelubed prior to rotating the engine.*

Marine Gear Input Shaft Runout (Face and Bore)

Follow the marine gear manufacturer's procedures for installation and alignment. Check the input shaft face and bore runout. Dimensions must meet the marine gear manufacturer's specifications.

Axial Alignment

The exact axial spacing between the face of the engine flywheel and the gear input flange must be checked and adjusted prior to final placement of the engine and coupling installation.

a. Measure Crankshaft End Play

Prior to performing the axial alignment the crankshaft end play must be measured.

- Remove one crankcase inspection cover.
- Use a 1524 mm (5 ft) pry bar between the crankshaft and the cylinder block. *Do not pry on the damper.* Move (thrust) the crankshaft all the way towards the front of the engine. A definite *klunk* can be heard when the crankshaft bottoms out against the thrust washer.
- Install a dial indicator with the tip on the flywheel face.
- Preload the dial indicator stem a minimum of one turn. Adjust the indicator bezel so the pointer is set on zero. Do not rotate the flywheel or runout error may be introduced resulting in incorrect readings.
- Move (thrust) the crankshaft all the way towards the rear of the engine and record the reading on the dial indicator. This measurement is known as crankshaft end play.
- Move (thrust) the crankshaft forward again. The dial indicator should return to zero.
- Repeat this procedure two or three times to verify results.
- Verify that the measured end play is within 0.4 ± 0.2 mm (0.016 ± 0.008 in.). See the service manual for the latest specifications.

Note: *Do not remove the dial indicator at this time. Periodically check to ensure the crankshaft does not move while positioning the engine to the appropriate axial spacing dimension.*

b. Measure the Marine Gear Input Shaft End Play

- Follow the marine gear manufacturer's procedure to accurately measure total input shaft end play.
- Record input shaft total end play.
- Verify that the end play measured meets the tolerances specified by the manufacturer.

c. Calculate the modified axial spacing dimension.

To accurately place the engine, the engine crankshaft and marine gear input shaft must remain fixed. Ideally the shafts would be placed in their normal axial operating positions while positioning the engine. This is not easily done, and once set they tend to move one way or the other. It is suggested that both shafts be thrusted completely forward or completely aft and axial spacing be modified accordingly.

For example:

Coupling overall length
(mating surface to mating surface) =
431.8 mm (17 in.)

Split spacer ring width =
63.5 mm (2.5 in.)

Total measured crankshaft end play =
0.36 mm (0.014 in.)

Total measured input shaft end play =
0.10 mm (0.004 in.)

Assume that both the crankshaft and the input shaft normally center themselves in the middle of their total end play when rotating (this must be verified with the marine gear supplier).

If both shafts are thrusted fully aft, 0.05 mm (0.002 in.) must be added to the axial spacing dimension. This compensates for the marine gear input shaft movement that will occur once the shaft is rotating. To compensate for the engine crankshaft movement that will occur, 0.18 mm (0.007 in.) must be subtracted from the axial spacing dimension.
Axial spacing dimension = coupling length + split spacer ring length.

Axial spacing dimension =
431.8 mm (17 in.) + 63.5 mm (2.5 in.) =
495.3 mm (19.5 in.).

Modified Axial Spacing Dimension =
495.3 mm (19.5 in.) + 0.05 mm (0.002 in.)
- 0.18 mm (0.007 in.) =
495.17 mm (19.495 in.).

Position the Engine

- Thrust the engine crankshaft and gear input shaft fully forward or aft.
- Mount a dial indicator with the tip on the marine gear input flange face.
- Preload the indicator a minimum of one revolution.
- Adjust the indicator dial to zero.
- Preload the dial indicator (previously installed on the engine flywheel) a minimum of one revolution and set the indicator to zero.
- Use an inside micrometer to measure the distance between the engin flywheel face and the pilot of the marine gear input flange. Measure along a line perpendicular to the marine gear input flange.
- Compare the figure to the modified axial dimension calculated previously. If this number is not within the tolerances specified by the coupling supplier, use the fore and aft jacking screws to position the engine accurately.
- After the engine is accurately placed, check the dial indicators on the flywheel and the marine gear input flange making sure the crankshaft or the marine gear input shaft has not moved. If the dial indicators are not on zero, the engine must be moved in the correct direction by the amount shown on the dial indicators.

Coupling Installation

Install and align the coupling according to instructions and specifications supplied by the coupling manufacturer. *The coupling must have enough axial tolerance to avoid restricting movement of the engine crankshaft and marine gear input shaft within their respective end play allowances.* The tolerances must be met in both cold and hot conditions. Allowance must be made for a change in crankshaft centerline from cold alignment conditions to hot running conditions. Vertical thermal growth changes the location of the crankshaft centerline as the engine's block temperature increases. Typically the growth of the engine will be greater than the driven equipment. Vertical growth of the engine and driven equipment must be evaluated to determine the cold alignment crank offsets.

The total engine crankshaft centerline change due to thermal growth and oil film lift can be expected to be approximately 0.38 mm (0.015 in.). Obtain the driven equipment growth from the manufacturer.

Note: *Damage to the main and rod bearings may occur if they are not prelubed prior to rotating the engine.*

Final Axial Alignment
Measure the axial space dimension and crankshaft end play. If these dimensions are not within appropriate tolerances, they must be corrected and the entire alignment procedure repeated.

Shimming, Bolting, Dowelling, Guide & Collision Stop Recommendations
After final cold alignment is completed and checked, the engine must be shimmed and dowelled in position. Collision stops may also be required. See guide section on *Mounting*.

Cold Crankshaft Deflection Check
The crankshaft deflection must be checked to verify stress has not been induced into the engine cylinder block as a result of engine mounting and alignment. Follow the engine service manual procedure to perform this check. Refer to the service manual to verify that crankshaft deflection is within specified limits.

Hot Alignment
Repeat the cold alignment procedure after the engine has been run and water and oil temperatures have reached normal operating points. Record the temperatures every 15 minutes as the alignment is being checked.

Record the dial indicator readings and verify they are within specified coupling limits in the hot condition.

Hot Crankshaft Deflection Check
Follow the engine service manual procedure to check crankshaft deflection after the engine has been run and the water and oil temperatures have reached their normal operating point.

Note: *Attention must be given to the warning statements in the service manual concerning the removal of crankcase access covers when the engine is hot. Explosions in the crankcase can occur, resulting in injury or damage if the covers are removed too soon after operating the engine.*

The combined overhung weight of the flywheel and coupling influences the static deflection of the crankshaft. Figure 25 shows the allowable cantilevered crankshaft loads.

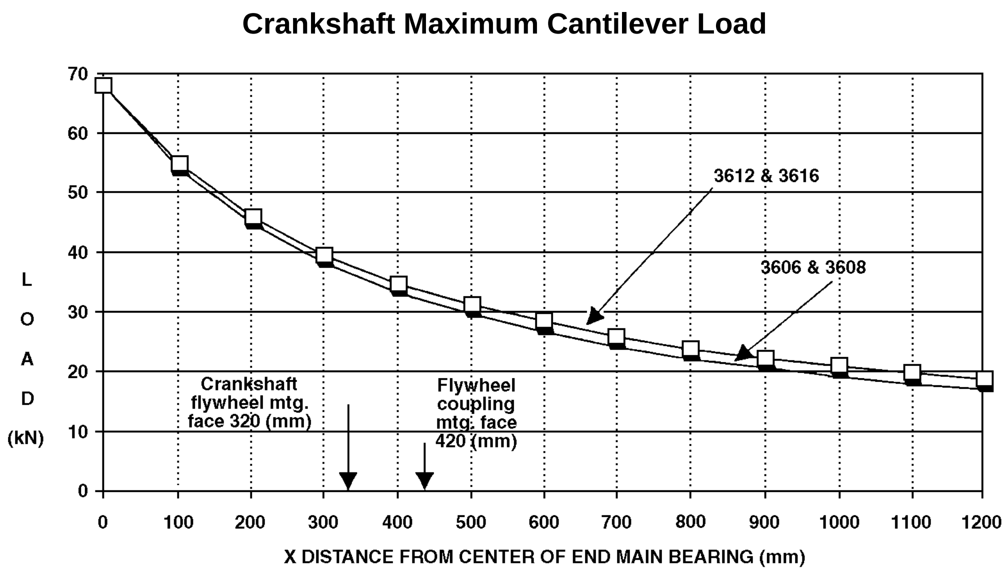


Figure 25 For a given X distance the cantilever load must not exceed the allowable load limit.

Isolation Mounting

Caterpillar Silicone Shear Pads

The procedure for this mounting system is very similar to the alignment used for the hard mounted system described above. Read that section before beginning the alignment of shear pad mounting system.

Note: *Before beginning the alignment procedure, read and understand the entire procedure. Improper alignment of this machinery may result in loss of life, serious injury, and/or equipment damage.*

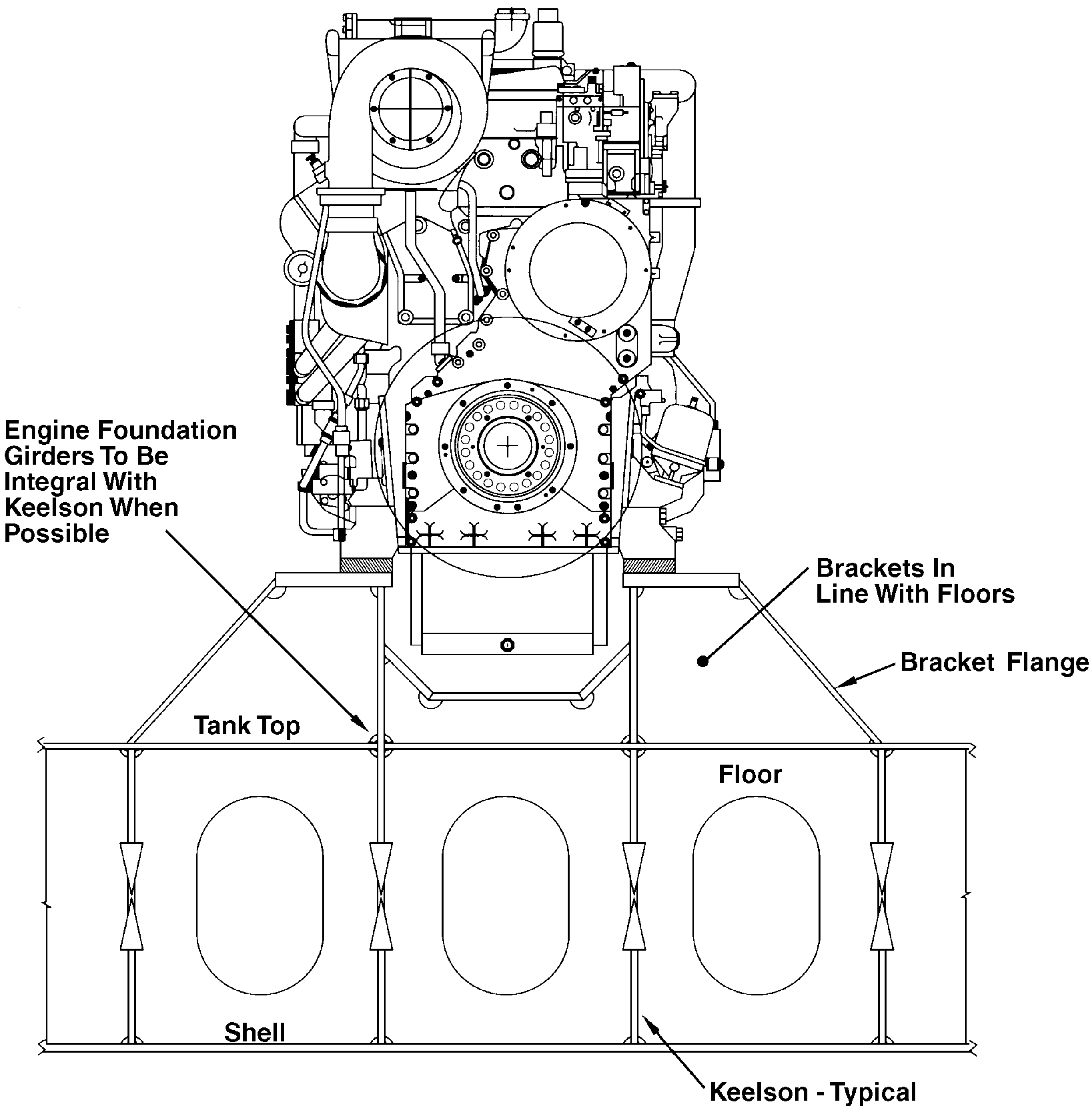
Contact a Caterpillar 3600 Marine Project Engineer at (765) 448-5000 to receive a copy of the installation procedures for the silicone shear pads.

Christie & Grey Alignment

With this mounting system, the engine is free to move during engine operation. It is necessary to select the torsional coupling, water, oil, fuel, and exhaust connections to accommodate increased engine motion. The engine coupling and/or output drive line must be flexible enough to maintain the engine bearing loads, as well as driven equipment bearing loads, below appropriate limits.

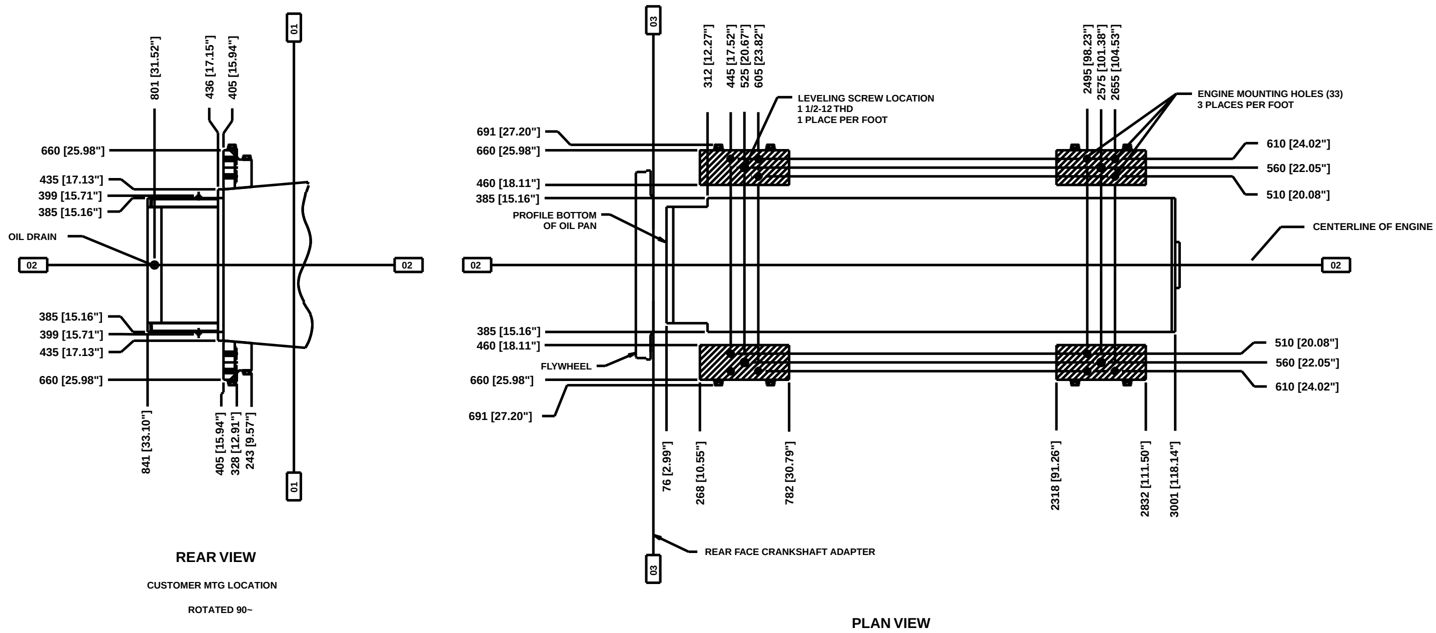
The engine torque reaction will cause the isolators to compress/decompress and the crankshaft centerline to change; this must be compensated for during engine alignment. This alignment value is established for each application. Engine power rating, the type of isolators, operating temperature, and the coupling used are major factors affecting engine alignment values.

Christie & Grey isolators are built with an internal buffer unit to eliminate the need for collision blocks on most applications.

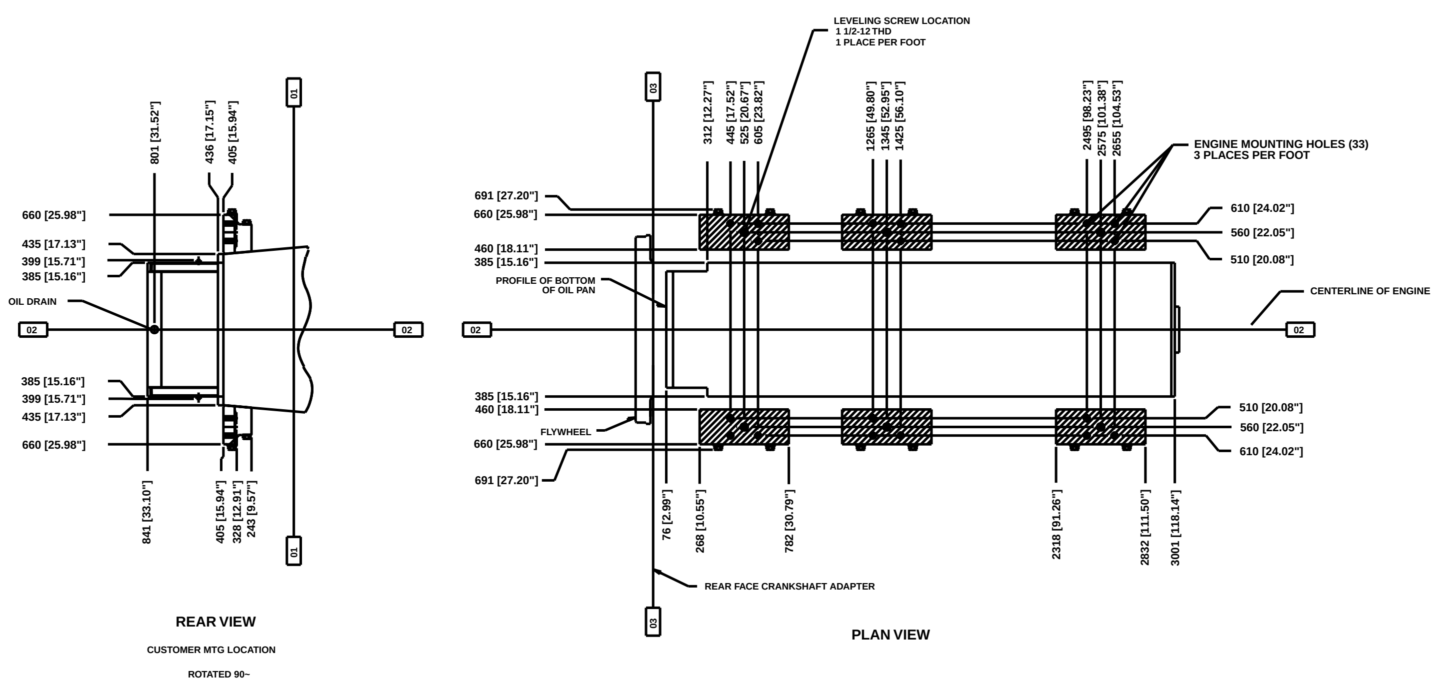


Typical Section Through Main Engine Foundation

Figure 2



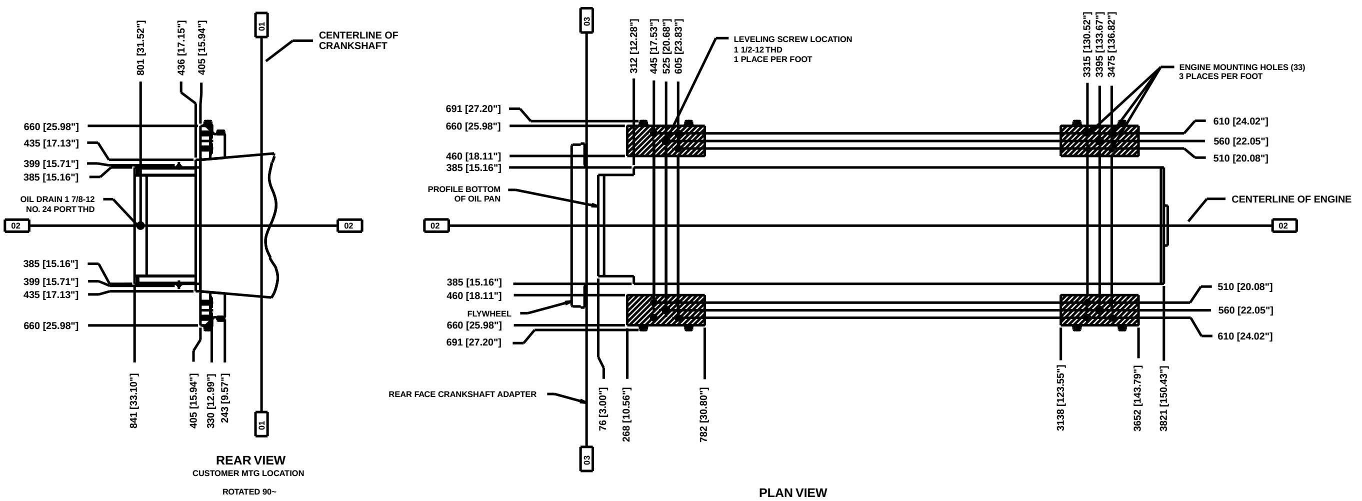
4 Pads-Plan View



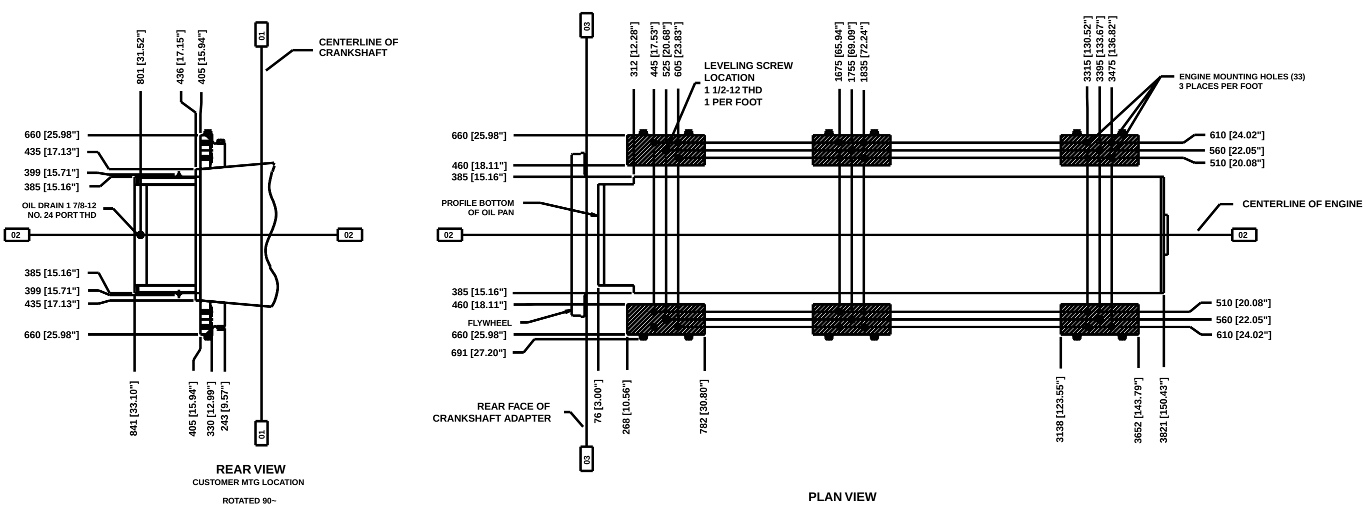
6 Pads-Plan View

Mounting Feet Arrangement
3606 Marine Engine

Figure 4



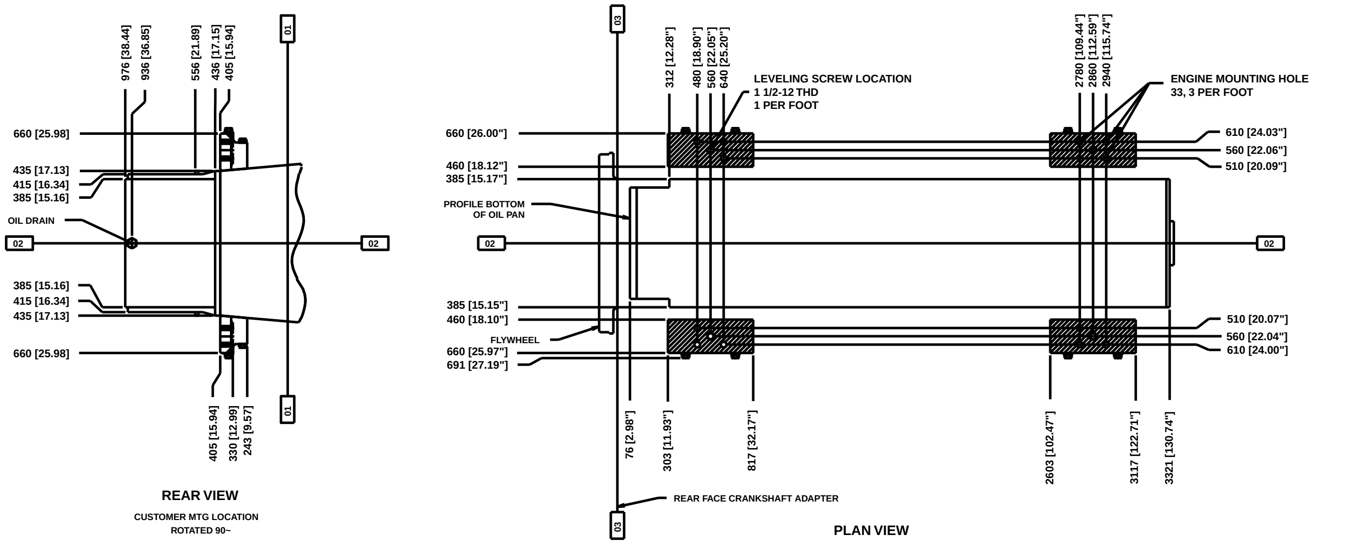
4 Pads-Plan View



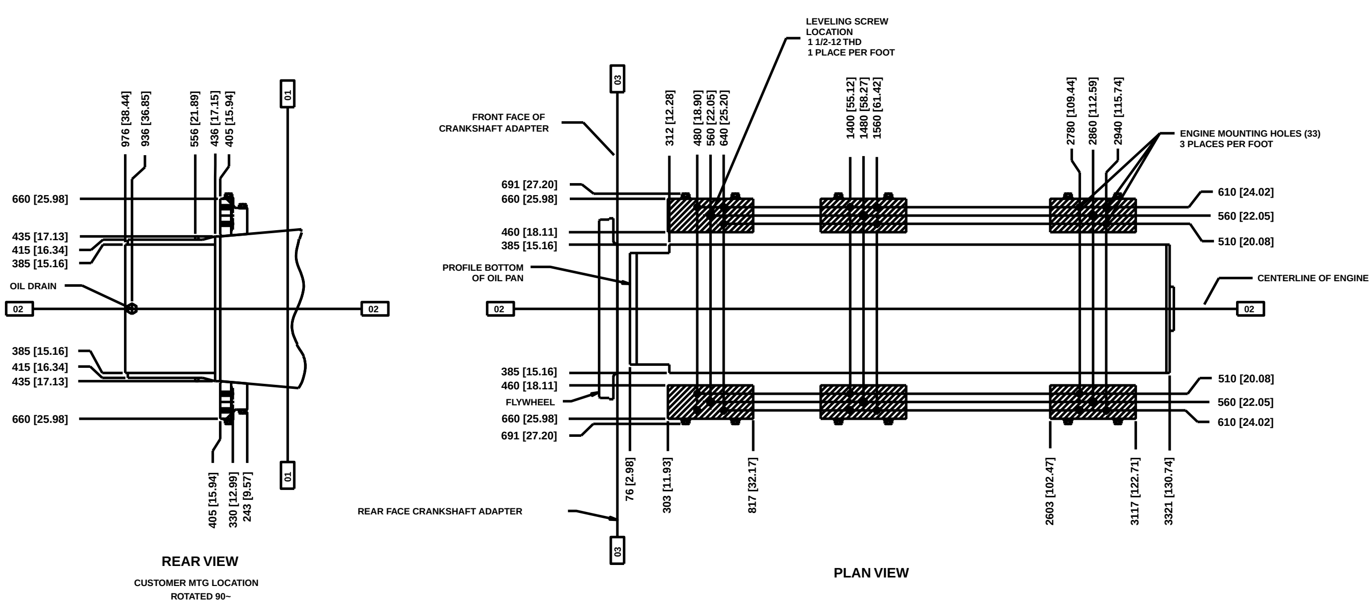
6 Pads-Plan View

Mounting Feet Arrangement
3608 Marine Engine

Figure 5



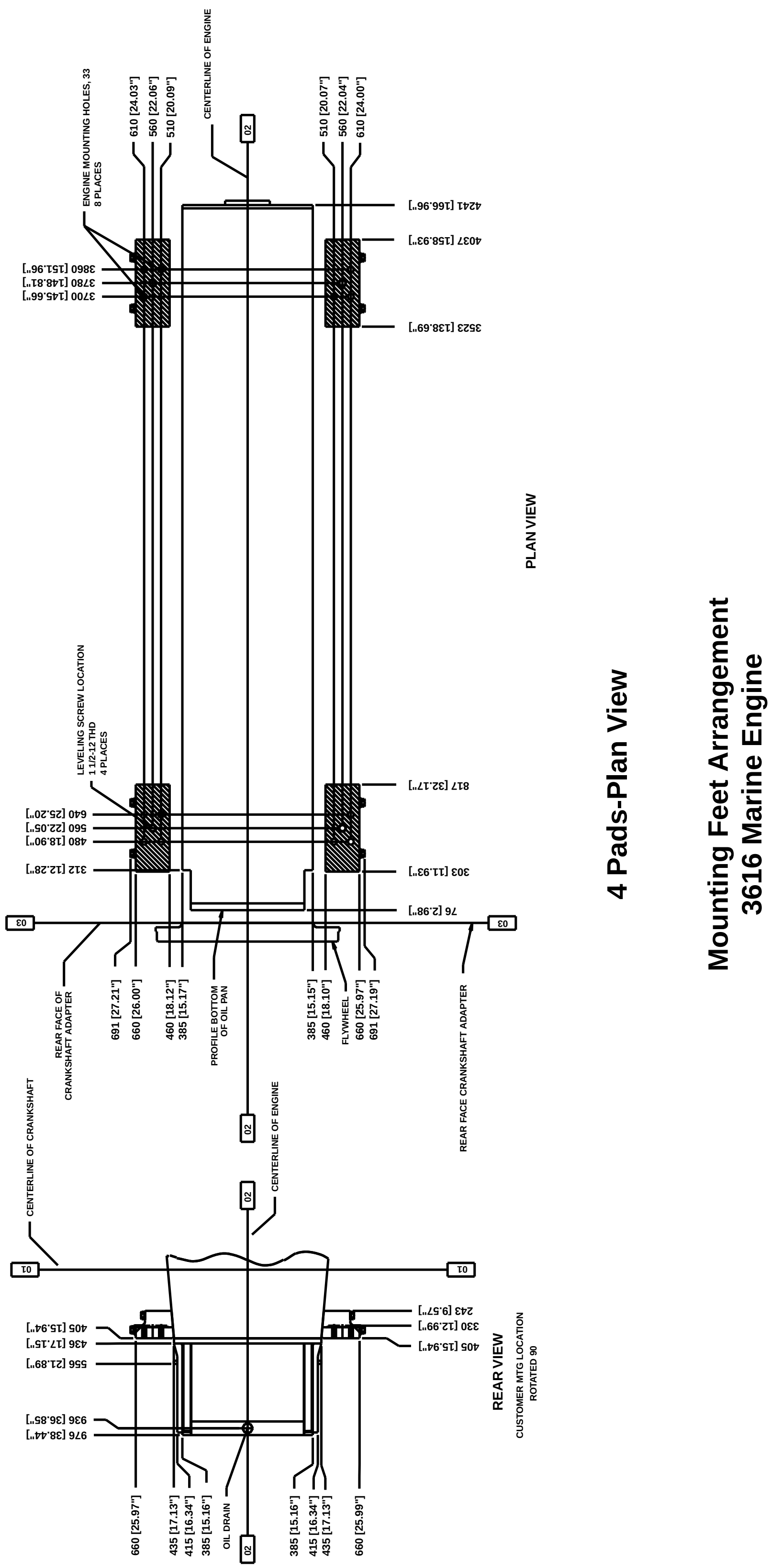
4 Pads-Plan View



6 Pads-Plan View

Mounting Feet Arrangement
3612 Marine Engine

Figure 6


4 Pads-Plan View
Mounting Feet Arrangement
3616 Marine Engine
PLAN VIEW
REAR VIEW
CUSTOMER MTG LOCATION
ROTATED 90
ENGINE MOUNTING HOLES, 33
8 PLACES
LEVELING SCREW LOCATION
1 1/2-12 THD
4 PLACES
CENTERLINE OF ENGINE
CENTERLINE OF CRANKSHAFT
REAR FACE OF
CRANKSHAFT ADAPTER
REAR FACE CRANKSHAFT ADAPTER
PROFILE BOTTOM
OF OIL PAN
FLYWHEEL
OIL DRAIN
610 [24.03"]
560 [22.06"]
510 [20.09"]
510 [20.07"]
560 [22.04"]
610 [24.00"]
4241 [166.96"]
4037 [158.93"]
3860 [151.96"]
3780 [148.81"]
3700 [145.66"]
3523 [138.69"]
817 [32.17"]
640 [25.20"]
560 [22.05"]
480 [18.90"]
312 [12.28"]
303 [11.93"]
76 [2.98"]
691 [27.21"]
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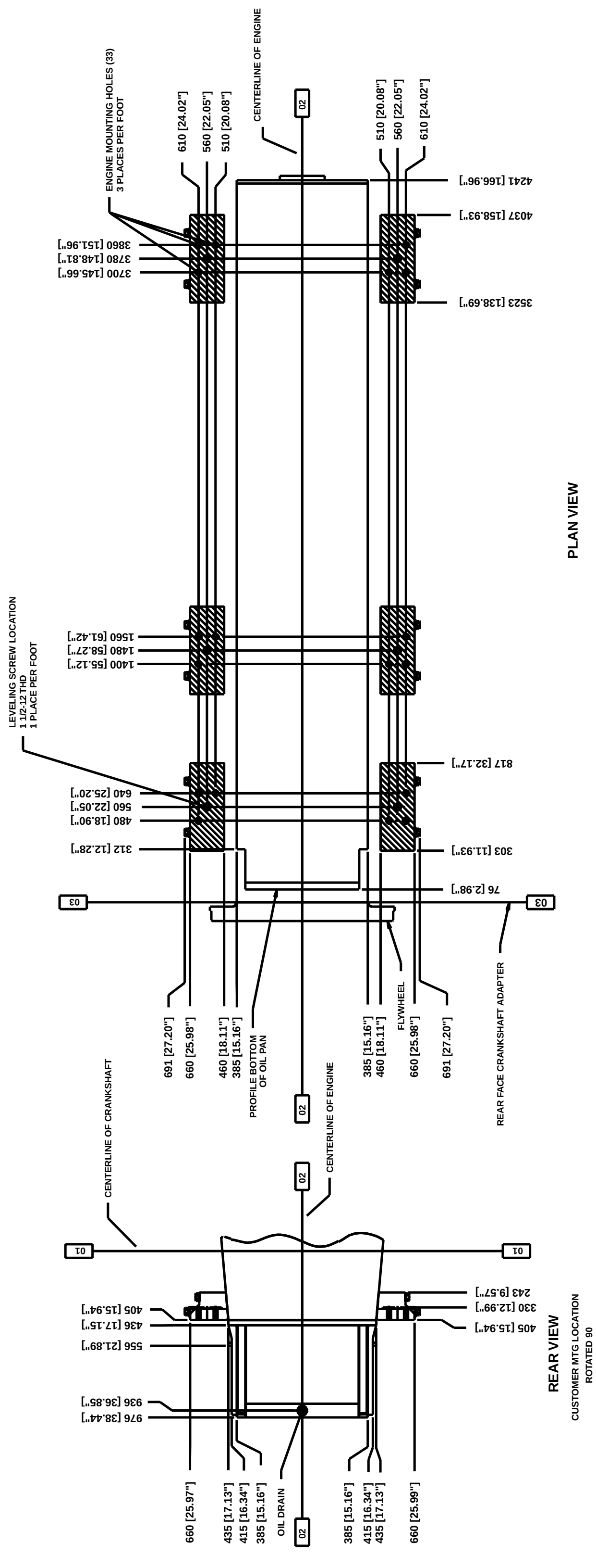
385 [15.16"]
660 [25.99"]
01
02
03

Figure 7



6 Pads-Plan View

Mounting Feet Arrangement
3616 Marine Engine

Figure 8

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

● **Controls**

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CATERPILLAR®

Controls

Control system types and sophistication levels are varied. This section covers common Caterpillar 3600 engine control arrangements and governor features.

The two basic control systems used are electric and pneumatic. A number of variations can be developed from these, but only the more common will be discussed herein.

Pneumatic Control System

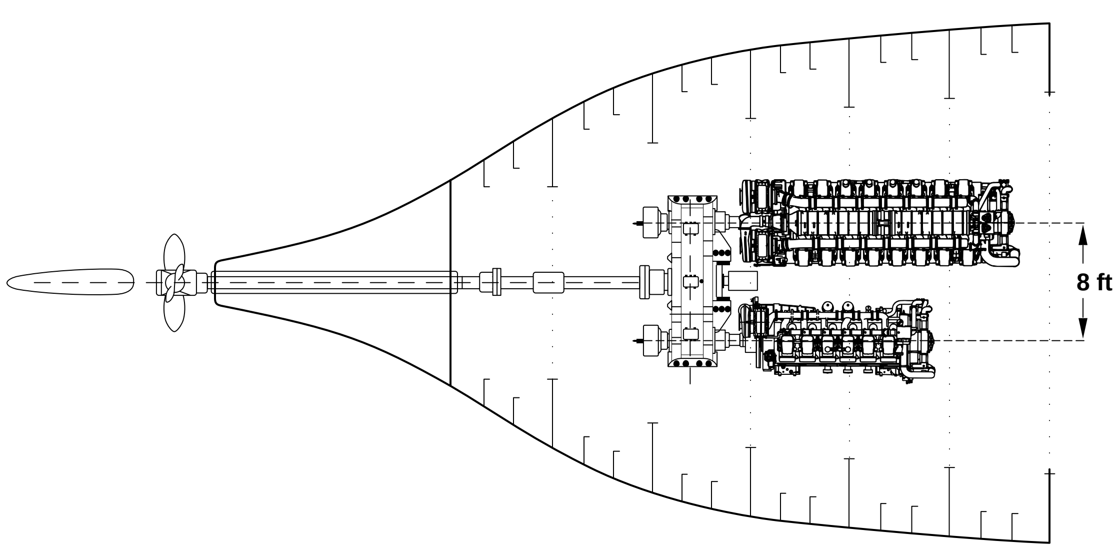
Pneumatic engine control is the most common method of speed setting 3600 marine engines. Control pressures range from 69 to 690 kPa (10 to 100 psi) and 69 to 414 kPa (10 to 60 psi). Valves, switches, and relays are commercially available to allow for multiple station operation. While pneumatic systems allow for installation over longer distances, they are prone to delays in the control signal between the bridge and the engine room. Routine maintenance is required to keep the system leak-free and prevent water and oil contamination. The pneumatic signal can be connected directly to the Woodward 3161 governor with pneumatic speed control. Examples are illustrated in Figures 1 through 3 on pages 27 through 29.

Electronic engine controls with pneumatic ship controls require a pressure-to-current or pressure-to-voltage transducer to convert the pneumatic speed signal to a usable electrical signal.

Electronic Controls

Electronic propulsion controls are becoming more popular. This type of system is typically used for:

- Multiple engines driving a common controllable pitch propeller requiring precise load sharing between engines operated under different conditions. See Figure 6 in the *Drawings* section of this guide.
- Single main engines driving a controllable pitch propeller and a number of different power takeoffs (PTOs). See Figure 6 in the *Other Applications* section of this guide. The PTOs could consist of ship service generators, pumps, and/or compressors.
- Multiple engines of different power ratings driving a controllable pitch propeller (*Father-Son* engine configuration). This arrangement requires load sharing over the operating range of the propulsion system (see Figure 4).



Twin Engine - Single Screw (CPP)
Father - Son Configuration

Figure 4

Engine Governors

There are a few different governors available for 3600 marine engines for use in either pneumatic or electronic control systems.

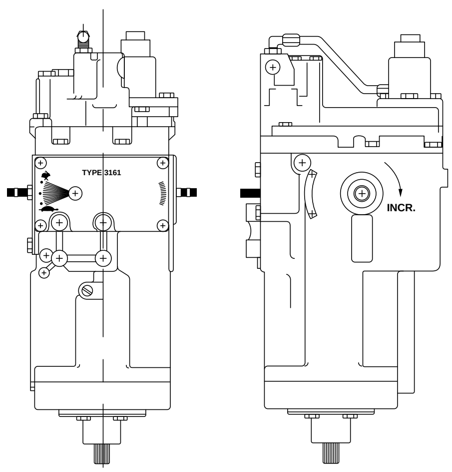
- Woodward 3161 hydra-mechanical governor with pneumatic speed control (Figure 5)
- Heinzmann E30 electronic governor system (Figure 6)
- Woodward 721 digital electronic governor system

The Woodward 3161 governor is most commonly used with a pneumatic control system, the Heinzmann E30 governor can be used with either a pneumatic or electronic control system, and the Woodward 721 governor is most commonly used with an electronic control system. The Woodward 3161 is a stand-alone governor without the need for a separate fuel rack actuator. The electronic governors require a separate fuel rack actuator.

Governor Descriptions

Hydra-mechanical:
Woodward 3161
(Proportional and integral governor)

- Pneumatic speed control, 60-413 kPa (10-60 psi) or 69-690 kPa, (10-100 psi)
- Smoke limiter (standard)
- Drive speed = 1.5 x engine speed
- Manual and electric shutoff standard, pneumatic shutoff optional (Electric shutdown solenoid is required with Caterpillar safety shutoff system). The options are ETR or ETS.
- Self-contained oil supply
- Droop available: 0-5% factory set, non-adjustable
- Low idle offset (LIO) to prevent stalling from full load to no load
- Reference SENR3028, 3161 Governor Service Manual



Outline of 3161 Governor with Pneumatic Speed Setting Device

Figure 5

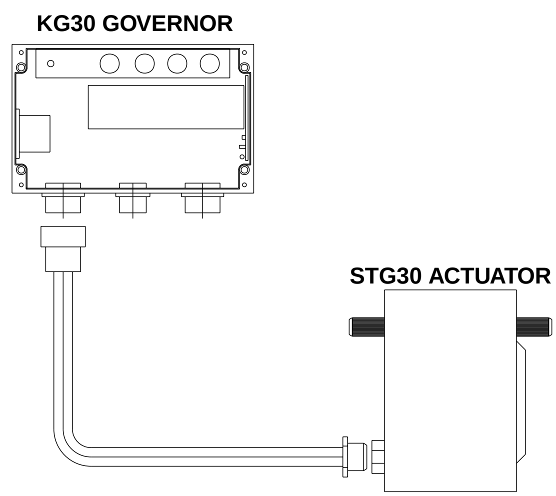


Figure 6

Electronic:
Heinzmann KG30 governor with STG30 Actuator
(Proportional, integral, and derivative governor)

- Remote speed setting potentiometer standard, optional mA or VDC speed setting transducer or pneumatic speed setting with pressure transducer
- Optional smoke limiter with pressure transducer
- Actuator is all electric without ballhead backup, no oil required
- 0-8% adjustable droop
- Actuator is spring loaded to shutoff and is energized-to-run (ETR)
- Requires 20-35 VDC (24 VDC nominal) @ 8 amps, optional power supply/battery backup available
- Equal rack load sharing available for multiple engine applications
- Setup/trouble shooting hand tool provided
- Reference SENR4661, Heinzmann Marine Governor Service Manual

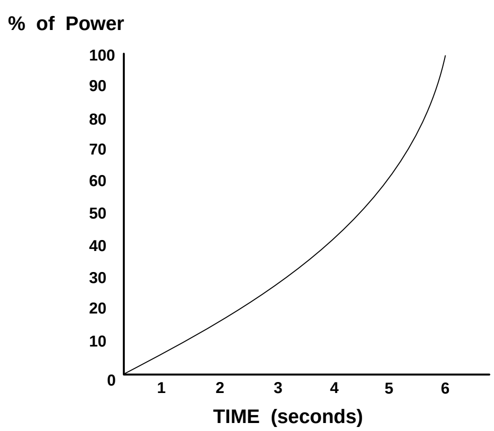
Electronic:
Woodward 721 digital governor
(Proportional, integral, and derivative governor)

- Remote and local electronic speed inputs
- Fuel limiting feature available for boost pressure, speed, and starting
- Fuel indexing control
- Torsional filtering and alarm (requires additional magnetic pickup)
- Multiple ramp rates
- Gain slope and gain windows
- Choice of actuators: UG-18 with no ballhead backup, EGB-13P (in-line) or EGB29P (vee) with ballhead backup, or PGA-EG with tracking ballhead, all require oil
- UG actuator is forward acting and ETR only, forward/reverse acting and ETR/ETS combination available with EGB and PGA-EG actuators
- Isochronous or adjustable droop operation
- Requires 18-40 VDC (24 VDC nominal) power supply
- Equal rack load sharing available for multiple engine applications
- 8 discrete inputs, 4 analog inputs, 3 relays, and 3 analog outputs
- Rough sea mode
- Clutch inputs and clutching logic
- Soft loading and unloading
- Parameters set by hand-held programmer

Clutches

Selection of marine gear clutches is important to propulsion system operation. Clutch characteristics directly affect how rapidly the propulsion system can respond to maneuvering demands of the vessel.

The 3600 Family of Engines' low load torque rise characteristics exceed most similar engines (including two stroke design). Their ability to develop low rpm power depends on how quickly the exhaust gas turbocharger can increase the combustion air mass flow rate. This is inherent in all high bmep four stroke diesel engines. It becomes more important when the main engine is operating at a low load/idle rpm condition and a high torque demand is placed on the engine. Figure 7 illustrates the time required for an unloaded/idled engine to achieve rated horsepower at a specific rpm. The reduction gear clutches must be capable of providing a smooth transition from a no load to high load condition. This is directly related to clutch slip capability.



Approximate Time Required For Turbocharger Acceleration

Figure 7

The duration of clutch slip is limited by the heat rise (thermal horsepower) the clutch materials can withstand. The heat generated during slip is a function of instantaneous driveline torques, driveline inertia, and the difference in velocity of the clutch's driven and driving elements. Matching a clutch's slip ability to the engine's torque rise characteristics is an iterative process. The engine may stall if the slip duration is too brief. If the slip duration is too great, the resulting frictional heat load will exceed the thermal capacity of the clutch, resulting in clutch failure. The clutch manufacturer must be consulted in the early project stages.

The control system must precisely time and sequence ahead and astern clutch engagement during *all* maneuvering conditions.

Shaft Brake

A propeller shaft brake is beneficial in applications where frequent maneuvering is required, or if full speed reversals may be encountered. A properly controlled shaft brake will stop the rotation of the propeller when the reduction gear clutches are disengaged. This action reduces the heat loading of the clutches and the amount of torque required from the engine/clutch to complete a shaft directional change.

Several advantages are gained with the use of shaft brakes:

- Reduce vessel maneuvering time. Vessel speed is reduced quickly due to increased drag of a stopped propeller versus a windmilling propeller. The propeller back torque is also reduced as vessel speed diminishes.
- The shaft brake brings the propeller to a stop with the propeller back torque and driveline momentum transmitted directly into the hull. The main engine is only required to develop the torque associated with a stopped propeller shaft rather than a windmilling propeller. Because thermal loading on the engaging clutch is greatly reduced, clutch life is extended.
- The propeller shaft brake will reduce the chance of engine stall when attempting crash stops, or when attempting high vessel speed shaft reversals.

Consider a propeller shaft brake on any fixed pitch marine propulsion system where repetitive high speed maneuvering is a requirement.

Both disc and drum type brakes are available. The brake and structural supports must be sized for full rated shaft torque, and should stop the shaft quickly during all maneuvering scenarios. Shaft brake size requirements will vary with the propeller type, driveline inertia, vessel speed, and vessel application.

Consult the clutch manufacturer for sizing and application guidelines.

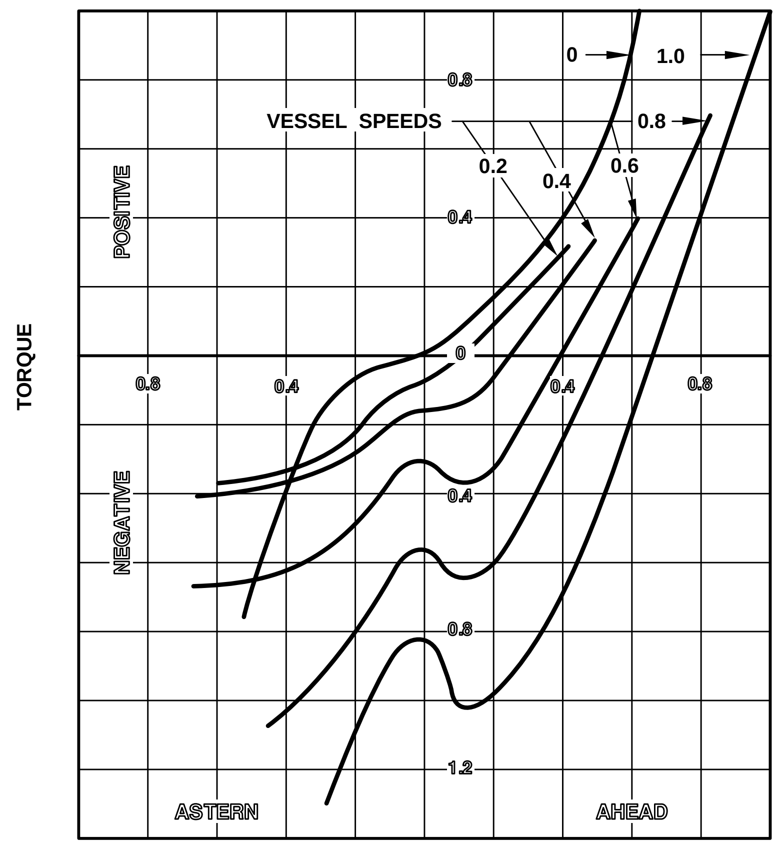
Fixed Pitch Propeller Systems

Pneumatic or electronic control systems require proper sequencing of shaft brake engagement, clutch engagement, and engine speed to ensure safe vessel operation and driveline component protection.

Sufficient engine torque must be available at engagement engine speed when shifting from forward to reverse, or vice versa, to overcome driveline inertia and propeller back torque. The engine will stall or operate in reverse if sufficient torque is not available.

It is important to review the propeller characteristics during the preliminary design phase of the vessel. This includes propeller torque during deceleration and reversing. These values are graphically represented on a Robinson Diagram, Figure 8.

Propeller back torque is generated by a free-wheeling propeller being turned by water flowing past the hull.
Engine stalling and reversal problems can be predicted with a Robinson diagram of the propeller. Inform the propeller designer of the ship's intended maneuvering characteristics.



Shaft rpm
Robinson Diagram
Figure 8 Propeller Torque During Deceleration and Reversing

Recommended Control System

A control system with flexible sequencing and timing of engine speed and signals for clutch and shaft brake engagement is the optimum in maneuvering capability as well as protection of driveline machinery.

Proper sequencing and timing of the controls is necessary to:

- Reduce vessel maneuvering time
- Prevent excessively low engine speed
- Prevent excessive loading of driveline components
- Reduce the possibility of engine stalling

One or more of the following features may be required to minimize the possibility of engine stall during normal and emergency maneuvers:

- Raised low idle speed setting
- Engine throttle boost control
- Shaft brake
- Flexible control system timing

Raised Low Idle Speed Setting

To increase the engine's low speed torque, the low idle setting may be increased providing the vessel's low speed maneuvering is not jeopardized. This will help prevent the engine from stalling or being reversed during maneuvering. *The setting should only be changed by an authorized Caterpillar Dealer. Low speed engine torsionals must be considered.* Excessive shock loading and transmission clutch wear can occur if the engine low idle speed is too high.

Engine Throttle Boost

Throttle boost momentarily raises the idling speed setting of the engine. The engine speed increase should occur just prior to engagement of the clutch. The momentary speed increase occurs only during maneuvering; the engine's normal idle speed is unaffected. Keep throttle boost as low as possible because it tends to increase the load on clutches during maneuvering. With air clutches, increased throttle boost will increase centrifugal forces on the clutch pads, causing very rapid clutch lockup. The control system should permit adjustment of the amount, duration, and rate of throttle boost. As a safety feature, some application controls will not allow throttle boost to be applied until marine gear oil pressure reaches a preset level.

Shaft Brake

Proper control and sequencing of the shaft brake is extremely important. Improper adjustment of the brake and clutch sequencing will manifest itself in two ways - clutch/brake overlap or underlap. Overlap can occur if the clutch engages before the brake is released. This would be realized as an additional load on the engine imposed by the engaged brake. Conversely, underlap represents releasing the brake prior to clutch engagement. In this case, the propeller will quickly begin to windmill, and much of the advantage of the brake is lost.

Overlap is desired in some applications to allow the engine torque to rise prior to brake release.

Flexible Control System Timing

The sequencing and timing of the engine governor, clutches, and shaft brake are critical. Consider only control systems with the following capabilities:

Event Sequences (Adjustable)

1. Governor move to low idle

1a. Engine used as a dynamic brake, (coast down with engine absorbing propeller torque)

2. Clutch disengaged

3. Shaft brake applied, propeller shaft stops

4. Shaft brake released

5a. Throttle boost applied

5b. Clutch fill

5c. Clutch contact*

5d. Clutch lockup*

6. Throttle boost off, governor to full fuel position

* The time between contact and lockup represents clutch slip.

The timing sequence from shaft brake off to clutch lockup should result in only one quarter revolution of the propeller shaft. This ensures no overlap between brake release and clutch engagement. With the above sequencing and timing, the shaft brake will engage any time the pilot house control lever is in the neutral position. Throttle boost will activate each time the pilot house control lever is shifted from neutral to a clutch-engaged position. The boost timing must be precise in multiple engine installations to prevent one engine from attempting to provide required power before the others become active.

Without a propeller shaft brake, a longer pause in neutral in place of Steps 3 and 4 will normally be required to allow vessel speed to diminish.

A proportional neutral delay-type control system is highly recommended to allow a variable time delay between steps 3 and 4 when the shaft brake is applied. This delay is proportional to the last-called-for engine speed signal (indirectly related to vessel speed at the time of maneuver). A crash reversal from full speed causes the brake to be applied longer than when slow speed maneuvering. In full speed reversal, adjust the neutral delay to be just long enough to slow the vessel speed, so propeller back torque won't reduce engine speed 100 rpm below low idle setting when engaging the astern clutch.

For adequate lubrication and to prevent engine stall during vessel maneuvers, it is imperative that engine speed not drop 100 rpm below the low idle rpm. Engines equipped with the Woodward 3161 governor will shut off fuel if subjected to engine reversal. Engines equipped with electronic speed governors need extra protection to prevent the engine from firing and starting in reverse.

Set the control system timing as fast as the propulsion system can safely be operated. Set and permanently lock-wire the timing adjustments after the completion of sea trials. Record the sequence timing and adjustment settings in the control box for future reference.

Suggested Initial Timing Sequence:

- 50 to 75 rpm throttle boost
- Less than one second initial pressure to clutch touch point
- Six seconds from clutch touch to full lock
- One second hard fill time
- Proportional delay of one second per each 100 engine rpm

Typical Pneumatic Control System

The Rexroth Logicmaster Pneumatic Control System is an example of a flexible sequencing propulsion control system. *Other manufacturers may also provide similar suitable systems.*

The system provides interlocked and sequenced operation of proportional timing in ahead and astern clutch engagement and engine speed control. This ensures proper operation of the propulsion machinery as the operator manipulates the remotely mounted control lever. The control system incorporates the following interlocks and the optional features:

- Positive cross engagement interlocks ensure that one clutch is vented before the opposite clutch can be engaged.
- The clutch engagement system incorporates a three stage clutch fill as shown in Figure 9.

1. An initial quick-fill to bring the clutch pads into contact with the drum, (or hydraulic clutch plate initial movement).
2. A controlled (adjustable) rate of fill of approximately 6 seconds.
3. Hard fill inflation at a maximum rate up to supply pressure.

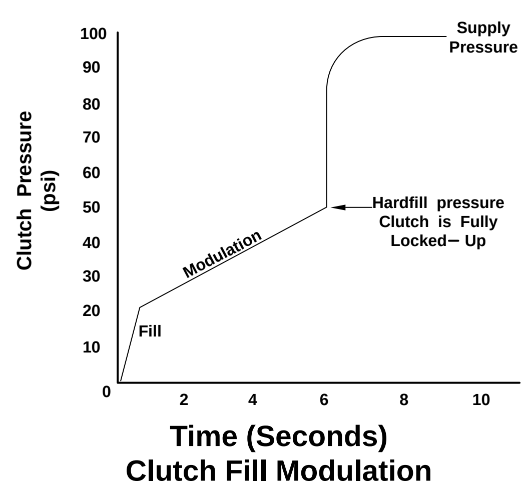


Figure 9

The *initial* quick-fill assures the clutch will move just to the point of contact as soon as possible to reduce the overall clutch engagement times.

Note: For dry type drum clutches, the higher the throttle boost the faster the clutch spins and the greater the centrifugal force exerted on the clutch pads. High engine rpm with the clutch disengaged will result in the pads engaging too fast. As a result, centrifugal force will tend to hold the clutch pads away from the hub until the air pressure overcomes the centrifugal forces. If the throttle boost is too high the actual clutch lock-up times can be cut to less than 1/4 the *clutch fill* times because of the influence of centrifugal forces.

- Governor speed boost is applied during initial clutch engagement to prevent engine stalling. This boost is adjustable in magnitude, duration, and rate.
- A clutch-pressure-engine speed signal interlock is used to ensure the clutch is inflated to lockup pressure prior to an engine speed increase.
- Proportional neutral time delay occurs in both ahead and astern directions. The delay is adjustable and provides a neutral time proportional to vessel speed. Normal low speed maneuvers are accomplished with a minimum delay.
- The ahead clutch hold-in function shortens the reversing time by holding the ahead clutch while the vessel coasts down in speed. This procedure uses the engine's compression to absorb torque from the propeller.
- A shaft brake signal (optional) is provided to actuate a shaft brake in synchronization with the clutch engage/disengage control system. The brake is released when clutch engagement is initiated and is applied when both clutches are disengaged. When a brake is used, the *interlocks* provide a neutral hold to permit the brake to be applied and the shaft stopped before reversal is initiated.

Controllable Pitch Propeller Systems

Controllable pitch propellers have blades separately mounted on the hub. The pitch can be changed or reversed to suit vessel operating conditions. The two basic propulsion systems are:

- Single or multiple main engines with auxiliary power takeoffs (PTOs) requiring main engine load control.
- Multiple main engines with power takeoffs (PTOs) requiring main engine load control and load sharing.

Single Engine

With a single main engine the engine controls are required to:

- Interface with the controllable pitch propeller (CPP) system's engine speed demand signal. This component typically converts the CPP system speed demand signal to a signal that is usable by the engine speed governor.
- Generate a signal representative of the engine's power output to the CPP control system. This component's output is electrical in nature. It is utilized by the CPP control system to protect the engine from overload. If an overload condition is detected, the propeller pitch is reduced until the engine is no longer overloaded.

The Woodward 3161 can be used in this application. An additional interface device is required to convert a voltage or current speed signal to a pneumatic speed signal acceptable to the governor. A rack position indicator is required for an electrical engine load signal.

The Heinzmann E30 electronic governor system is capable of interfacing directly with CPP control systems. An SG02 rack position indicator is required to provide an electrical engine load signal (either 4-20 mA, 1-5 VDC or 1-10 VDC) to the CPP control system. It is mechanically connected to the fuel system linkage and outputs a signal directly to the CPP control system.

A speed setting potentiometer is provided standard with the Heinzmann E30 governor system, but the governor can receive a remote electrical or pneumatic speed signal from the CPP control system with the addition of a SW09 speed setting transmitter or BG03 pressure converter. The SW09 speed setting transmitter receives a 1-5 VDC or 4-20 mA signal from the CPP control system and sends a signal to the governor to match speed demand. The BG03 pressure converter receives either a 1-5 bar or 1-10 bar pneumatic pressure signal from the CPP control system and converts it to an electrical signal that is sent to the governor for speed demand.

Caterpillar provides a Heinzmann control panel that encloses the governor, rack position amplifier, speed setting potentiometer and remote speed setting transmitter all pre-wired and ready for customer installation. A local/remote switch is mounted on the front of the panel for choosing governor control from the local speed setting potentiometer or from the remote speed setting signal. An optional power supply/battery backup box is also available since the governor does not have a ballhead backup. See Figure 10, on page 30, for a typical wiring schematic of the Heinzmann E30 governor system.

The Woodward 721 governor is also capable of interfacing directly with CPP control systems. As with the other two governors previously discussed, a rack position signal is required from the governor to the CPP control system to indicate engine load. An electrical engine speed demand signal is required from the CPP control system to the 721 governor.

Multiple Engines

With several main engines driving a single propeller the controls are required to:

- Interface with the controllable pitch propeller (CPP) control system's engine speed demand signal. This component typically converts the CPP system speed demand signal to a signal usable by the engines' speed governors.
- Generate an electrical signal representative of the engines' power output to the CPP control system. It is utilized by the CPP system to protect the engines from overload. It provides a reference for a proper diversion of load during load sharing operation.

Either the Heinzmann E30 or Woodward 721 electronic governor can be used for multiple engine loadsharing applications. The Heinzmann system uses an SW50 marine control unit for each engine, along with the STG30 actuator, KG30 governor and SG02 rack position indicator, that provides the following features (see Figure 11 on page 31):

- Equal fuel rack load sharing
- Direct interface capability for volts or milliamps speed setting (SW09 not needed)
- Adjustable speed ramping between idle and rated speed
- Fuel limiting proportional to boost pressure
- Smoke limiting (requires an optional pressure transducer)
- Power supply and battery backup provided as standard

The Woodward 721 governor also provides equal fuel rack loadsharing between multiple engines. A rack position indicator is required for each engine along with a choice of fuel rack actuators previously discussed.

Instrumentation and Monitoring Systems

Wiring Routing - Preferred Practices

Wiring for D.C. circuits, magnetic pickups, thermocouples, and resistance temperature detectors (RTDs) can be routed in common conduits. They must not be in the same conduit with A.C. circuits. Separate A.C. circuits greater than 600 Volts from A.C. circuits less than 600 Volts.

Always use 100% shielded wire for magnetic pickups as well as wiring for the electronic governor actuator.

The RTDs supplied by the factory are 100 Ohm platinum, and all factory supplied thermocouples are type K with chromel alumel material. *Care must be taken when attaching additional wiring at the job site. The wrong material, incorrect fastening, or different lengths can result in erroneous temperature readings.*

Instruments (also see Alarm/Shutdown section)

The Caterpillar supplied engine protection, alarms, and instrumentation systems are strongly recommended. Installations not using recommended systems must have factory approval.

The functions below are listed in their order of desirability for operator station instrument panel placement.

A = Highly Desirable Instrumentation (Caterpillar, Caterpillar dealer, installer, or user supplied)

B = Desirable Instrumentation

C = Useful Instrumentation

A **Engine Speed (rpm)**
Observing the relationship between engine speed and governor (or rack) can allow the operator to make engine operation and maintenance judgments. Manual shutdown for an overspeed fault is not possible as an engine will overspeed too quickly for operator reaction.

A **Lube Oil Pressure**
Loss of oil pressure is likely to result in severe engine damage. Quick action in reducing engine speed and load or stopping the engine can minimize damage. Engine oil pressure must be continuously monitored and recorded, either manually or automatically.

A **Lube Oil Temperature**
Much like all modern diesel engines, 3600 Engines rely on piston cooling with lubricating oil. Oil temperature is a good indicator of cooling system operation as well as oil cooler condition.

A **Jacket Water Temperature**
Jacket water temperature increase is almost as serious as loss of lube oil pressure and is more likely to occur. Similar quick action can minimize engine damage.

A **Intake Manifold Air Temperature**
High technology diesel engines rely on efficient turbocharger and aftercooler operation to produce the required output within safe operating limits. Air inlet temperature is a good indication of the turbocharger and air inlet system operation.

A **Exhaust Manifold Temperature**
Changes from normal exhaust manifold temperatures give useful information concerning air filter restriction, aftercooler restriction, valve problems, turbocharger fouling, and engine speed and load.

A **Clock Hour Meter**
Operating hours are essential for determining required maintenance intervals.

A **Fuel Pressure**
Low fuel manifold pressure to the unit injectors can result in poor performance, reduced power, poor starting characteristics, and misfire.

B **Differential Pressure Gauges**
Oil, fuel, and air filter condition can be accurately monitored with the differential pressure gauges. The instrumentation is helpful in determining service periods.

B **Crankcase Pressure (or vacuum)**
High crankcase pressure can indicate crankcase breather malfunctions or problems in the piston and piston ring belt areas. Changing trends in crankcase pressure will normally detect impending problems. Continued operation of an engine with severe problems can result in significant damage to the engine. In these rare instances, the damage occurs much too rapidly to detect by normal gauge observation. Automatic engine shutdown for high crankcase pressure is essential. See *Alarm / Shutdown* section.

B **Inlet Manifold Air Pressure**
This measurement is helpful in determining the condition of the turbocharger, aftercooler, and air intake system as well as being an indicator of engine load.

B **Oil Scavenge Pump Outlet Pressure**
Large engines can be applied in installations requiring very large external oil sumps in addition to the engine oil pan (dry sump configuration). In those instances the oil pressure measured at the scavenge pump outlet can detect oil system problems prior to low pressure detection in the main engine lube oil supply.

B **Air Start Pressure**
Low air tank pressure can prevent engine starting until tank pressure is raised to the required level.

C **Individual Cylinder Exhaust Temperature**
While these instruments will give warning of individual injector failure, the inevitable wide tolerance on the standard temperature (± 42°C (75°F)) often causes undue operator concern. Advantages gained can be overshadowed by cost (thermocouples need annual replacement) and need for special operator training.

C **Sea Water Pressure**
Particularly when using an engine driven sea water pump, it is important to insure that sufficient sea water pressure is delivered to the engine cooler. Engine overheating may result from loss of sea water pressure. In many single engine applications, an electric emergency sea water pump will be used to automatically start upon loss of engine driven pump pressure.

C **Jacket Water Pressure**
It is important to maintain jacket water pressure to the engine to prevent overheating. Single engine applications may use an electric emergency jacket water pump to automatically start upon loss of engine driven pump pressure.

C **AC/OC Water Pressure**
Loss of AC/OC water pressure will result in high inlet manifold air temperature and lube oil temperature, which can quickly cause engine damage. An electric emergency AC/OC water pump may be installed to automatically start upon loss of engine driven pump pressure.

C **AC/OC Water Temperature**
It is beneficial to monitor AC/OC water temperature to help determine operating efficiencies of the aftercooler and oil cooler. Impending problems with the inlet regulator may be detected with a gradual rise in water temperature.

C **Fuel Temperature**
The temperature of the fuel delivered to the engine may be useful for determining the fuel viscosity and power limitations of the engine. Fuel at higher temperatures causes a reduction in maximum available engine power and lower fuel viscosity which may lead to seized injectors.

Alarms and Shutdowns

A wide variety of preset contactors (switches), transducers, and RTD's are available to activate a specified alarm, light, or engine shutdown. Any equipment operating function can be monitored depending on individual installation requirements.

Alarm switches available from Caterpillar operate at various voltages (refer to Form No. LEBQ5043, 3600 Engine and Attachment Selection Guide). They are single-pole, double-throw type.

Minimum engine protection includes automatic shutdowns for overspeed, low lubricating oil pressure (at both low and high engine speeds), and high crankcase pressure. Additional shutdowns are available for cooling water loss, high lubricating oil temperature, high jacket water temperature, and oil mist detection.

A = *Mandatory* (Caterpillar supplied). Exceptions to this requirement will only be allowed by agreement from Caterpillar.

B = Highly desirable

C = Useful

A **Overspeed Shutdown**

Overspeed faults occur when some part of the engine fails, causing the fuel control mechanism to lock in a high fuel flow condition. When the engine load goes to a low level the engine will continue to receive a high fuel flow. Without the load, the engine speed increases rapidly to a dangerously high level. Generally, the engine's air and fuel supply must be cut off to stop the engine. The air shutoff requires a 552 kPa (80 psi) minimum air supply pressure for activation force. Overspeed contactors are set 13% nominally over rated engine speed to avoid nuisance engine shutdowns during sudden reductions in engine load.

A **Low Lube Oil Pressure Alarm And Shutdown**

Two operating conditions require alarms and shutdowns: low oil pressure at low engine speed (idle conditions) and low pressure at high engine speed and/or load. A safe oil pressure while operating at very low loads and/or speeds is too low at full load/speed conditions. The system includes two pressure-sensitive contactors for alarm, two for shutdown and one speed (rpm) switch to decide which pressure switch has the authority to initiate the alarm or shutdown for the engine.

A **High Crankcase Pressure Shutdown**

High crankcase pressure indicates problems occurring in the piston and piston ring belt areas. Continued operation of an engine with severe problems can result in significant damage.

A **Oil Mist Detector Shutdown**

An oil mist detector may be required by marine societies on engines with a rating of 2250 bkW and higher. Oil mist can be an immediate indication of an impending bearing failure, and the engine should be shutdown for inspection.

A **High Oil Temperature Alarm**

Oil temperature measured near the supply to the engine oil manifolds and piston cooling jets indicates the lube oil cooling system's condition. Higher than normal oil temperatures can result in bearing and/or piston problems.

A **Cooling Water Loss Alarm**

Warning of coolant loss can allow the operator to save an engine which would otherwise be lost to overheat failure. If the high water temperature sensors discussed below are not immersed in water they will not activate. This coolant detection switch is installed on the engine at the highest location in the jacket water system.

A **High Jacket Water Temperature Alarm**
Set the high coolant temperature contactors to activate within 2.8°C (5°F) of the highest normal engine temperature at the time of installation.

A **Intake Manifold Air Temperature Alarm**
Excessive intake air temperature indicates problems in the turbo/aftercooler/air intake system.

A **Exhaust Manifold Temperature Alarm**
Excessive temperatures indicate a variety of impending engine problems, see the previous section on *Instruments*.

B **Fuel Temperature Alarm**
High fuel temperature can present performance, power loss, and injector durability problems. This is even more significant when operating on heavy fuel.

B **Oil Level Alarm**
Oil temperatures and pressures are not the complete picture of an engine's lubrication system condition. An alarm to signal low oil level in the sump can also warn of impending danger.

B **Low Fuel Pressure Alarm**
Low fuel pressure in the fuel manifold supplying the unit injectors can result in poor performance, reduced power, poor starting characteristics, and misfire.

B **High Injector Coolant Temperature Alarm**
For use with heavy fuel.

B **Expansion Tank Level Alarm**
While coolant temperatures and pressures are important indicators of cooling system operation, an expansion tank level alarm can indicate loss of system coolant.

C **Low Starting Air Pressure Alarm**
Time saving feature to alert the operator of impending starting problems prior to attempting to start the engine.

C **Low Injector Coolant Pressure Alarm**
Lack of adequate injector tip cooling can result in injector problems when using heavy fuel.

C **Low Sea Water Pressure Alarm**
Can warn of impending problems with an engine mounted sea water pump.

C **Low Jacket Water Pressure Alarm**
Can warn of impending problems with an engine mounted jacket water pump.

C **Low AC/OC Water Pressure Alarm**
Can warn of impending problems with an engine mounted AC/OC water pump.

C **Low AC/OC Water Temperature Alarm**
Set the AC/OC water temperature alarm at 65°C (149°F) for distillate fuel engines and 38°C (100°F) for heavy fuel engines.

C **Differential Pressure Alarms**
Oil and fuel filter condition should be monitored with differential pressure alarms to prevent low oil and fuel pressure delivery to the engine.

C **Exhaust Temperature Deviation Alarm**
An individual injector failure may be detected with an exhaust port temperature deviation alarm.

Protection System Settings

The chart below lists required protection system settings. See the chart below for alarm function settings. The settings should be used for the protection and monitoring system, regardless of source (attachment, special order, or customer provided).

Function	Protection System Alarm System Settings		Shutdown	
	Metric	U.S.	Metric	U.S.
Engine Overspeed (% Rated)	—	—	113%	
Maximum Speed (Before Shutdown)	—	—	120%	
Jacket Water Temperature	103°C	217°F	109°C	228°F
Coolant Loss Detector	Non-adjustable Coolant Level Sensor			
Oil Temperature To Bearings and Cooling Jets	92°C	198°F	98°C	208°F
Oil Pressure 650-1000 rpm	320 kPa	46 psi	260 kPa	38 psi
Oil Pressure 0-650 rpm	120 kPa	17 psi	105 kPa	15 psi
Crankcase Pressure	–	–	101.6 mm H_20	4.0 in. H_20
Fuel Temperature	Fuel Viscosity Dependent			

Note: *Low sea water pump pressure, low JW pump pressure, and low aftercooler pump pressure alarms are normally connected to the 650 rpm speed switch contacts. Pump pressures below 650 rpm will not result in an alarm. The alarm contactor can therefore be set at 140 kPa to protect the engine at high speeds and loads without getting nuisance alarms at low engine speeds.*

Alarm Settings

The chart below lists alarm system settings. Fuel temperature and injector coolant temperature alarm settings are dependent on fuel viscosity and the fuel conditioning requirements to maintain the viscosity at the unit injector between 15 and 20 cSt.

Function	Alarm System Settings	
	Metric	U.S.
Exhaust Manifold Gas Temperature		
(Distillate Fuel)	630°C	1166°F
(Heavy Fuel)	550°C	1025°F
Low Water Level	Variable- dependent on expansion tank volume	
Low Oil Level (Vertical distance above oil suction inlet while operating)	50 mm	2 in.
Low Fuel Pressure	260 kPa	38 psi
Low Sea Water Pump Pressure	35 kPa +static head	5 psi +static head
Low Starting Air Pressure (Vane starter)	750 kPa	110 psi
Low Injector Coolant Pressure	35 kPa	5 psi
High Air Manifold Temperature		
(Diesel Fuel)	92°C	198°F
(Heavy Fuel)	72°C	162°F
High Injector Coolant Temperature	Fuel Viscosity Dependent	
Low Fuel Temperature	Fuel Viscosity Dependent	
High Fuel Temperature	Fuel Viscosity Dependent	

Note: *Low sea water pump pressure, low JW pump pressure, and low aftercooler pump pressure alarms are normally connected to the 650 rpm speed switch contacts. Pump pressures below 650 rpm will not result in an alarm. The alarm contactor can therefore be set at 140 kPa to protect the engine at high speeds and loads without getting nuisance alarms at low engine speeds.*

Alarm and Protection Probe Location	
Function	**Location**
Engine Overspeed	Flywheel Ring Gear
Jacket Water Temperature	Water Manifold Outlet
Oil Temperature to bearings	Oil Temperature Regulator Outlet
Oil Pressure to bearings 650-1000 rpm	Priority Valve
Oil Pressure to bearings 0-650 rpm	Priority Valve
Crankcase Pressure	Side Cover With Oil Filter Neck
Exhaust Manifold Gas Temperature	Exhaust Manifold
Low Water Level	Expansion Tank
Low Oil Level	Side Cover with Oil Filler Neck
Low Fuel Pressure	Fuel Filter Housing
Low Sea Water Pump Pressure	Sea Water Pump Outlet
Low Starting Air Pressure	Air Supply
Low Injector Coolant Pressure	Coolant Manifold
Low Jacket Water Pressure	Cylinder Block Inlet
High Air Manifold Temperature	Air Manifold
High Injector Coolant Temperature	Fuel Module Dependent
Low Fuel Temperature	Fuel Inlet to Engine
High Fuel Temperature	Fuel Inlet to Engine

Caterpillar Protection Systems

Caterpillar offers two types of engine protection systems, the Marine Monitoring System (MMS) and the standard relay based protection system.

Marine Monitoring System

The Caterpillar MMS is a microprocessor based engine control, protection and monitoring system designed specifically for marine applications. The control features of the system enable the operator to start and stop the engine locally from the MMS panel or remotely. The minimum protection features enable the system to shutdown the engine if overspeed, low oil pressure, crankcase pressure, or oil mist detector (if applicable) parameters exceed the set points. The monitoring features allow the operator to view current operating temperatures and pressures of various engine parameters. A 10" touch screen computer display screen displays the information, and shows when a parameter is in alarm condition.

The MMS utilizes all engine mounted sensors so there are no customer pressure connections or temperature capillary connections. All sensors are wired to an engine mounted terminal box. The entire system is enclosed in a single panel for ease of installation. The MMS can also communicate with other shipboard alarm systems via an industry standard data link connection. The system has been designed to meet ABS, Lloyd's and DNV unmanned engine room requirements. The MMS has some flexibility built in to allow customers to add additional monitoring and alarm parameters such as marine gear oil temperature and pressure, bilge level alarms, etc. See Figure 12 for one line drawing of the MMS system layout.

Standard Relay Based Protection System

Caterpillar also has a standard relay based protection system that uses separate panels for control, protection, and monitoring. A start/stop control panel provides these functions for the engine. A customer mounted junction box contains the relay protection logic and a separate contactor panel provides the required switches for alarm and shutdown parameters. Flexible hoses must be used to connect the pressure switches from the contactor panel to the engine and the temperature switch capillaries must also be connected to the engine. A separate relay based alarm annunciation panel is also available with this system.

Alarm Panel

Caterpillar recommends the following minimum features in alarm panels:

- Fault light lock-in circuitry keeps the fault light on when intermittent faults occur.
- Lockout of additional alarm lights prevents subsequent alarm lights from going on after the activated engine shutoff stops the engine. This aids in troubleshooting.
- Alarm silence allows the operator to acknowledge the alarm without the need to continually listen to the alarm horn. The alarm light is left on until the fault is corrected.
- If more than one engine is connected to an alarm panel, a fault in a second engine should activate the alarm even though the alarm horn may have been silenced after a fault on another engine.
- Circuit test provides for periodic checking of alarm panel functions.

Electrical Systems

Caterpillar Wiring Diagrams

The following are generic comments applicable to Caterpillar wiring diagrams:

- SR1 is used to activate the fuel shutoff for any fault reason. This relay can also be used to trip a circuit breaker.
- SR2 is used to activate the air shutoff due to an emergency or overspeed fault.
- The position of all switches are shown *at rest*.
- Crank termination (CT) comes on at 170 rpm and stays on for two seconds after the engine shuts down.
- The engine electrical system uses less than 1 amp during normal operation with no faults. About 40 milliamps are used when the engine is stopped. About 7 amps is used during an overspeed fault until the engine comes to a complete stop.
- The annunciator panel has its own power supply. Once a light is turned on it stays on (latched in) until the reset button is pressed.
- The water level low alarm switch (WLLA) and the oil level low alarm switch (OLLA) are shown in the no fluid condition.

Electrical Speed Switch

The Caterpillar *electrical engine speed switch* is located inside the MMS panel or junction box as applicable. The power supply to this switch can be 8-40 VDC, but is typically 24 VDC. It receives its speed input signal from a magnetic pickup which senses speed from the flywheel ring gear teeth. All contacts are single pole, double throw, “C” form. *The engine speed switch provides three functions:*

- **Overspeed:** Provides an adjustable overspeed setting. The overspeed recognition point is typically set at 113% of rated speed for engines rated at 720, 750, 900 and 1000 rpm. This gives a shutdown before 120% overspeed is reached. The switch trips using a latching contact on increasing speed. A manual reset button on the switch is used to clear the fault. The switch also has a 75% verify feature which provides an electrically simulated overspeed shutdown at 75% of the true overspeed setting (rpm).
- **Crank Termination:** Senses if engine is running. This contact becomes energized when engine speed reaches 170 rpm on increasing speed and stays energized for two seconds after the engine stops. It automatically disengages the starter and energizes the safeties after a 9 second delay on startup.
- **Oil Step:** Used to arm the high speed oil pressure alarm and shutdown contactors. It is preset to arm when engine speed reaches a preset function of rated engine speed. The unit has a 9 second delay on increasing speed and no time delay on decreasing speed. It allows time for pressure to develop to the alarm and shutdown contactors before checking for faults.
- **Miscellaneous:** *The air shutoff and governor fuel shutoff solenoids trip for overspeed or emergency shutdowns.* The air shutoff and speed switch must be manually reset for restarts. The air shutoff is connected as an energized to shutdown solenoid. Only the governor fuel shutoff solenoid trips in other shutoff modes. 24 VDC is standard for both the fuel and air shutoff solenoids.

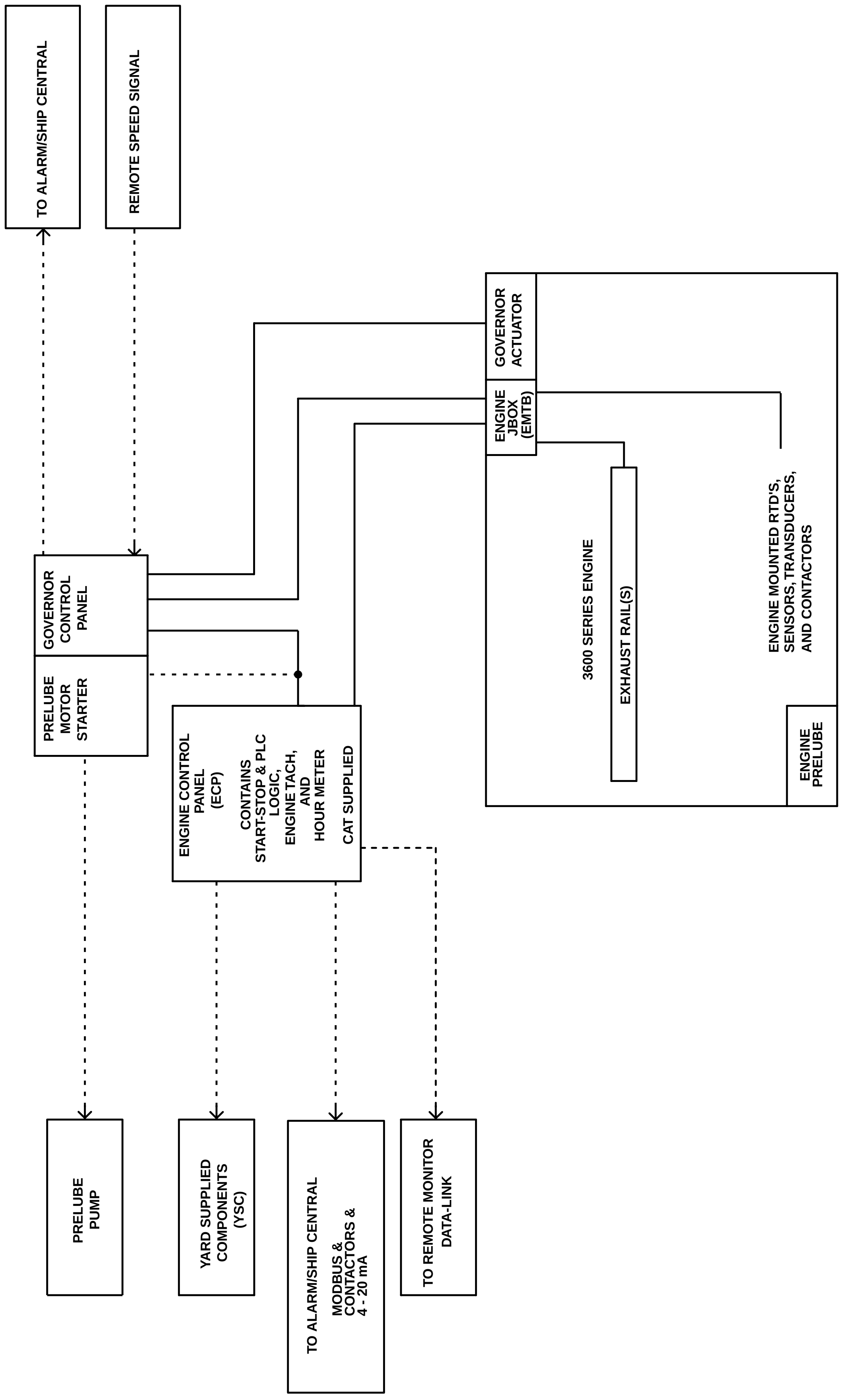

TO ALARM/SHIP CENTRAL
REMOTE SPEED SIGNAL
GOVERNOR ACTUATOR
ENGINE JBOX (EMTB)
GOVERNOR CONTROL PANEL
PRELUBE MOTOR STARTER
ENGINE CONTROL PANEL (ECP)
CONTAINS START-STOP & PLC LOGIC, ENGINE TACH, AND HOUR METER
CAT SUPPLIED
3600 SERIES ENGINE
EXHAUST RAIL(S)
ENGINE MOUNTED RTD'S, SENSORS, TRANSDUCERS, AND CONTACTORS
ENGINE PRELUBE
PRELUBE PUMP
YARD SUPPLIED COMPONENTS (YSC)
TO ALARM/SHIP CENTRAL
MODBUS & CONTACTORS & 4 - 20 mA
TO REMOTE MONITOR DATA-LINK

Figure 12

Commissioning

Recommended Instrumentation

Because of the need for precise sequencing of the control system, use an event logger during the commissioning of the propulsion system. The instrumentation points are:

Fixed Pitch

- Engine speed
- Shaft speed
- Shaft brake pneumatic signal
- Astern clutch pressure
- Engine pneumatic speed signal
- Ahead clutch pressure
- Engine fuel rack position
- Turbocharger boost pressure

Controllable Pitch

- Engine speed
- Shaft speed
- Engine pneumatic speed signal
- Propeller pitch position
- Engine fuel rack position
- Turbocharger boost pressure

3161 (LIO) Marine Governor Setup Recommendations

The seven areas of recommendations covered for the 3161 with air head control are:

A. Governor Installation and Engine Synchronization

B. Governor Angle Indicator Setting

C. Air Fuel Ratio Control Adjustment

D. Compensation Screw Adjustment

E. Idle Adjustment

F. Matching Ship's Controls

G. Clutch/Control adjustment

A. Governor Installation and Engine Synchronization Procedure

- Install governor with linkage to the rack control housing disconnected.

Note: *Use caution — the governor drive can fall inside the engine.*

- Rotate the allen head *rig pin* on the governor and move the governor output lever to fuel on. Hold the lever against the pin with a force of approximately 20 N•m (15 lb ft). The *governor* is now in the *sync* position (about 50% fuel).

- Install the engine *sync* bolt (without the washer) and rotate the racks in the fuel on direction. Hold the racks against the *sync* bolt with a force of approximately 20 N•m (15 lb ft). The *engine racks* are now in their *sync* position.

- Adjust the engine-to-governor rod until the bolts on the rack control housing and governor can be installed freely. Install the bolts, remove the tension from the governor and rack, remove the sync pin, and rotate the rig pin back to its normal position.

B. Governor Angle Indicator Setting

Note: *An angle indicator is available from Woodward to indicate engine rack travel.*

- With the engine off move the governor to full fuel (rack control touching the rack screw). Adjust the angle indicator to read a round number, approximately 30° for river boat engines.

- Return the governor to the fuel-off position and recheck governor angle. It should be approximately 0°.

The operator can use the angle indicator to get an approximate indication of fuel rack.

C. Air/Fuel Ratio Control Adjustment

- Start the engine and allow the governor oil to warm. A final adjustment may be required after the governor is at normal operating temperature. This can take up to 6 hours.
- From step B, note the angle position for idle and *dead* rack (fuel rack stop position) — typically 10° at idle and 30° at *dead* rack.
- Blip the throttle toward full fuel. Note where the air/fuel ratio control is holding the rack. Adjust the control to give about 50% (approximately 20°) of maximum fuel.

Note: *Speeds above approximately 450 rpm are not needed. Only a blip of the throttle is needed to find the air/fuel ratio control setting.*

Note: *Setting the air/fuel ratio control too much under 50% will cause the engine to accelerate slowly, particularly in flanking and crash maneuvers. Setting it to a higher (richer setting) will allow the engine to accelerate faster, but with pronounced smoke.*

D. Compensation Screw Adjustment

The LIO governor is isochronous above 450 rpm but has approximately 10% droop at idle (200 to 450 rpm). Therefore, the compensation screw can be turned out considerably when the engine is at 350 rpm, but can only be turned out about 1/2 turn above 450 rpm. More turns causes the engine to become unstable unless there is a load on the engine.

When the governor is warm and at idle, turn the compensation in until it softly seats. Then turn the screw out between 1/2 to one turn. More turns will increase engine response but the engine will surge if operated without load.

E. Idle Adjustment

- Move the governor speed handle from low idle to high idle. Check that both speeds are within specifications.

Note: *The low idle setting should be 350 rpm and the high idle setting is dependent upon the governor's droop setting. Both low and high idle settings are part of the engine's 2T specification and they are stamped on the engine nameplate. The following formula can be used to calculate the high idle speed based on the governor's droop setting:*

$$\text{rpm}_{\text{high idle}} = \text{rpm}_{\text{rated}} \left(1 + \frac{\%\ \text{Droop}}{100}\right)$$

- Make adjustments as necessary.

F. Matching Ships Controls

Note: *The governor operates with ship service air between 69 kPa (10 psi) at idle and 414 kPa (60 psi) at rated rpm.*

- Check the ship service air by plugging off the air clutches and moving the pilot house air controls from neutral to idle and then to full speed. Note the following pressures to the governor.

Neutral	0 kPa (0 psi)
Idle	69 kPa (10 psi)
Full speed	414 kPa (60 psi)

- After setting the ship controls to the 69-414 kPa (10-60 psi) signal, move the throttle lever to idle. Adjust the air head to obtain approximately 365 rpm and move the throttle to within 13 mm (1/2 in.) of full throttle. Rotate the bellows to get high idle rpm.

- Shut off the engine, reconnect the air lines to the clutches, and restart the engine. Move the throttle to idle and adjust the air head to 350 rpm with the prop turning. Some customers may want the idle rpm to be higher when the prop is engaged to prevent gear box noise. Adjustment on the air head can accommodate the customer's wishes. The in-gear rpm should not be below 350 rpm for engine oil pressure and engine response reasons.

Note: *Because of the high droop of the governor in the 200-450 rpm range, the load of the prop will affect the rpm of the engine. Water depth, rudder position, and water flow will affect the load on the engine and, therefore, will affect the rpm of the engine. This is a normal situation for the LIO governor.*

G. Clutch/Control Adjustment

Note: *Clutch fill occurs in three phases.*

- Initial filling of the cavities.
- Actual engagement and transfer of power from the engine to the gear.
- A hard clutch fill to maintain clutch engagement at higher rpm. The following recommendations reduce clutch abuse and provide acceptable engine response:

1. Clutch fill times/rates
   The first phase (initial fill) occurs between 0 kPa (0 psi) and 138 kPa (20 psi). This phase should occur as quickly as possible. The second phase (transfer of power) occurs between approximately 138 to 345 kPa (20 to 50 psi) and this should be set between 5 to 7 seconds. The third phase (hard fill and lock up) occurs at approximately 414 kPa (60 psi), and should occur as quickly as possible to fully hold the clutch in at the higher rpm.

2. Throttle boost
   Just before clutch engagement throttle boost should bring the engine to a speed acceptable to the marine gear manufacturer, typically 400 - 500 rpm. Excessive boost will cause the centrifugal forces of the clutch to hold the clutch away from the drum for a longer time. This causes the clutch to *grab* and either lock up too fast, thereby stalling the engine, or creating excessive heat in the clutch. The throttle boost should remain on until the clutch has fully engaged.

   If the boost is too low, reduced engine rpm, low engine oil pressure, and acceleration problems occur during normal vessel maneuvers. This can cause engine stalling and/or running in reverse during a crash reversal maneuver.

   Additional information of shaft brakes, proportional time delays, clutch *hold-in*, etc., is available from the air control manufacturer.

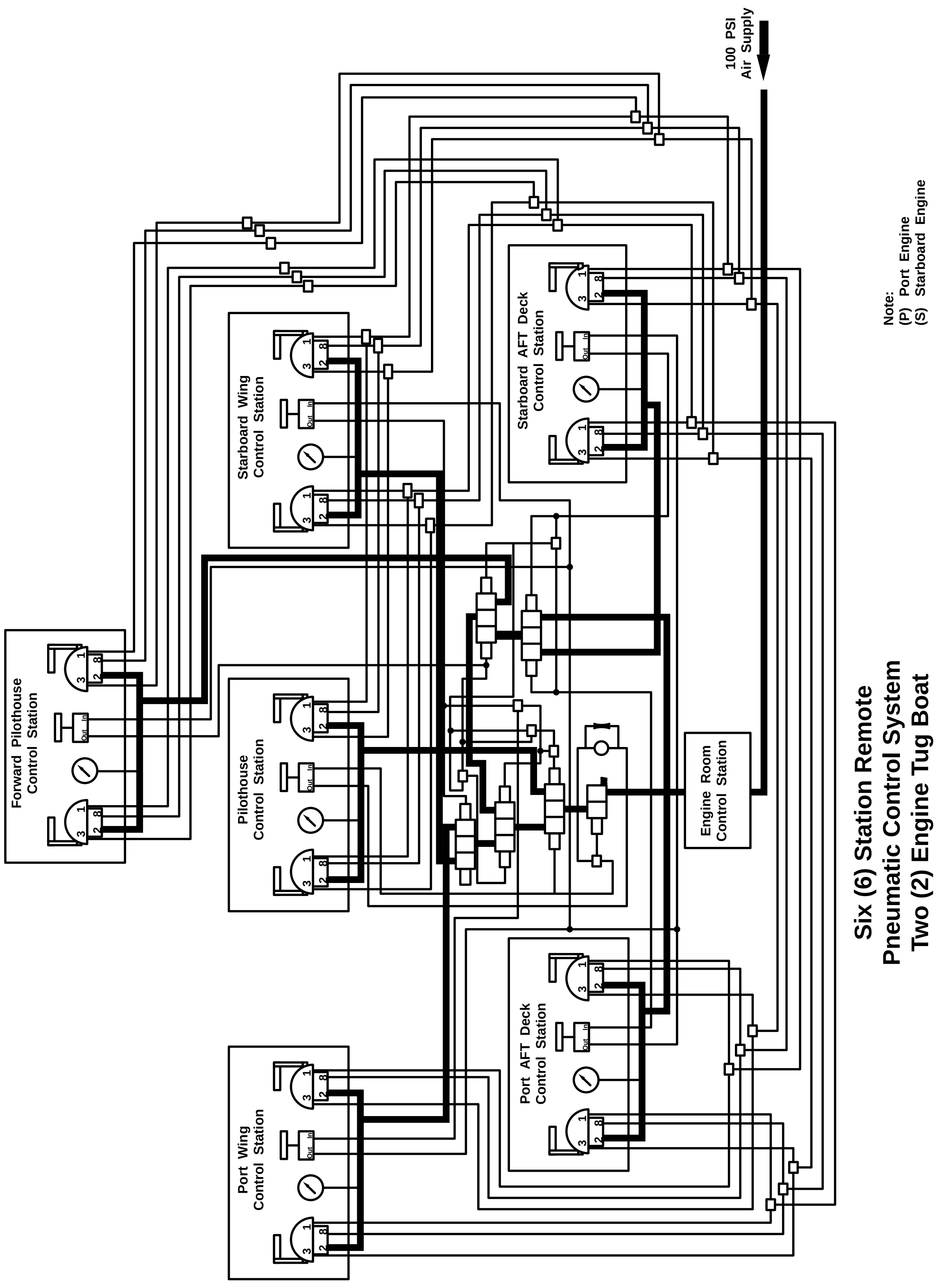

100 PSI
Air Supply
Forward Pilothouse
Control Station
Starboard Wing
Control Station
Starboard AFT Deck
Control Station
Pilothouse
Control Station
Engine Room
Control Station
Port Wing
Control Station
Port AFT Deck
Control Station
Note:
(P) Port Engine
(S) Starboard Engine
Six (6) Station Remote
Pneumatic Control System
Two (2) Engine Tug Boat

Figure 1

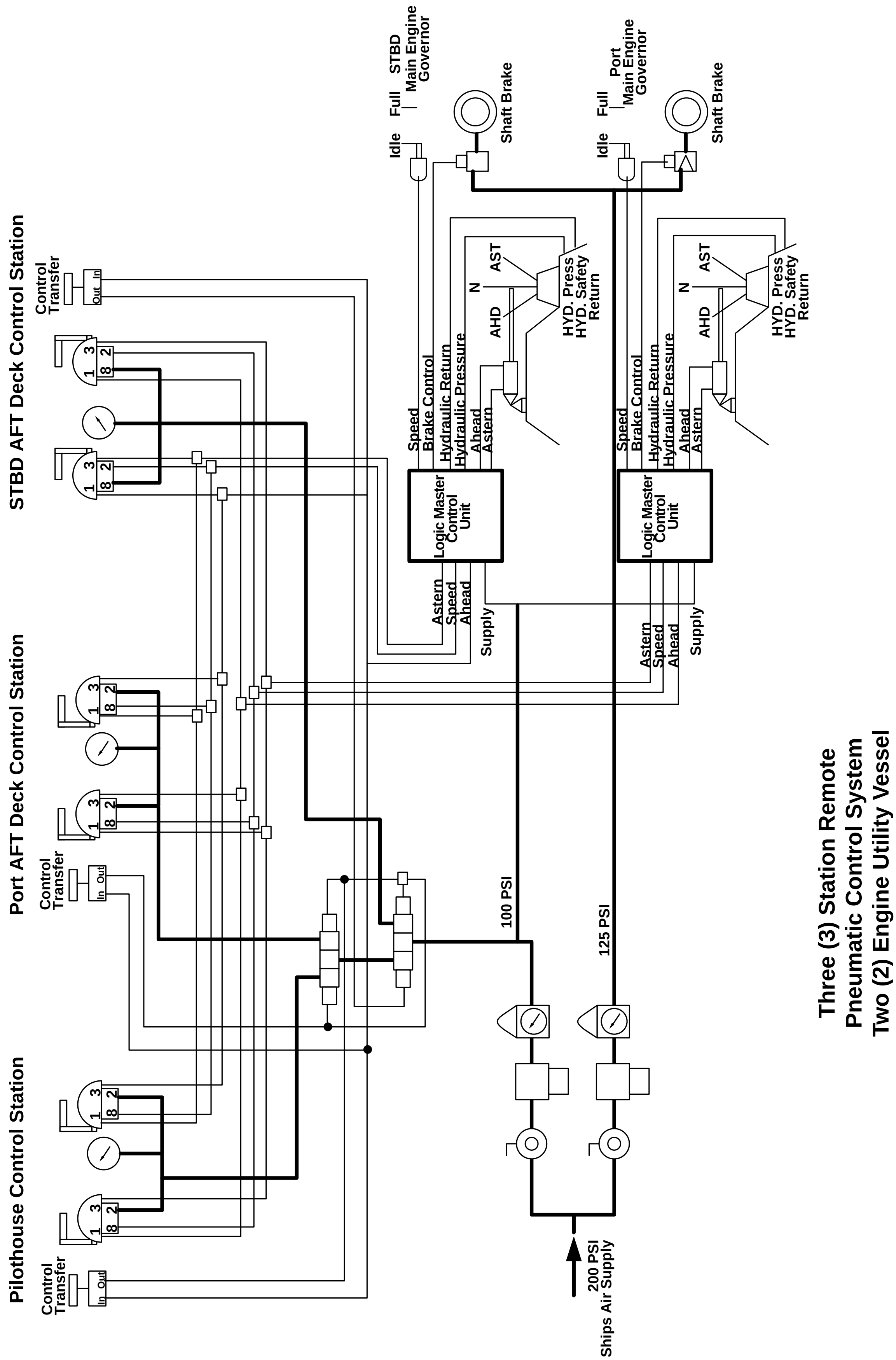
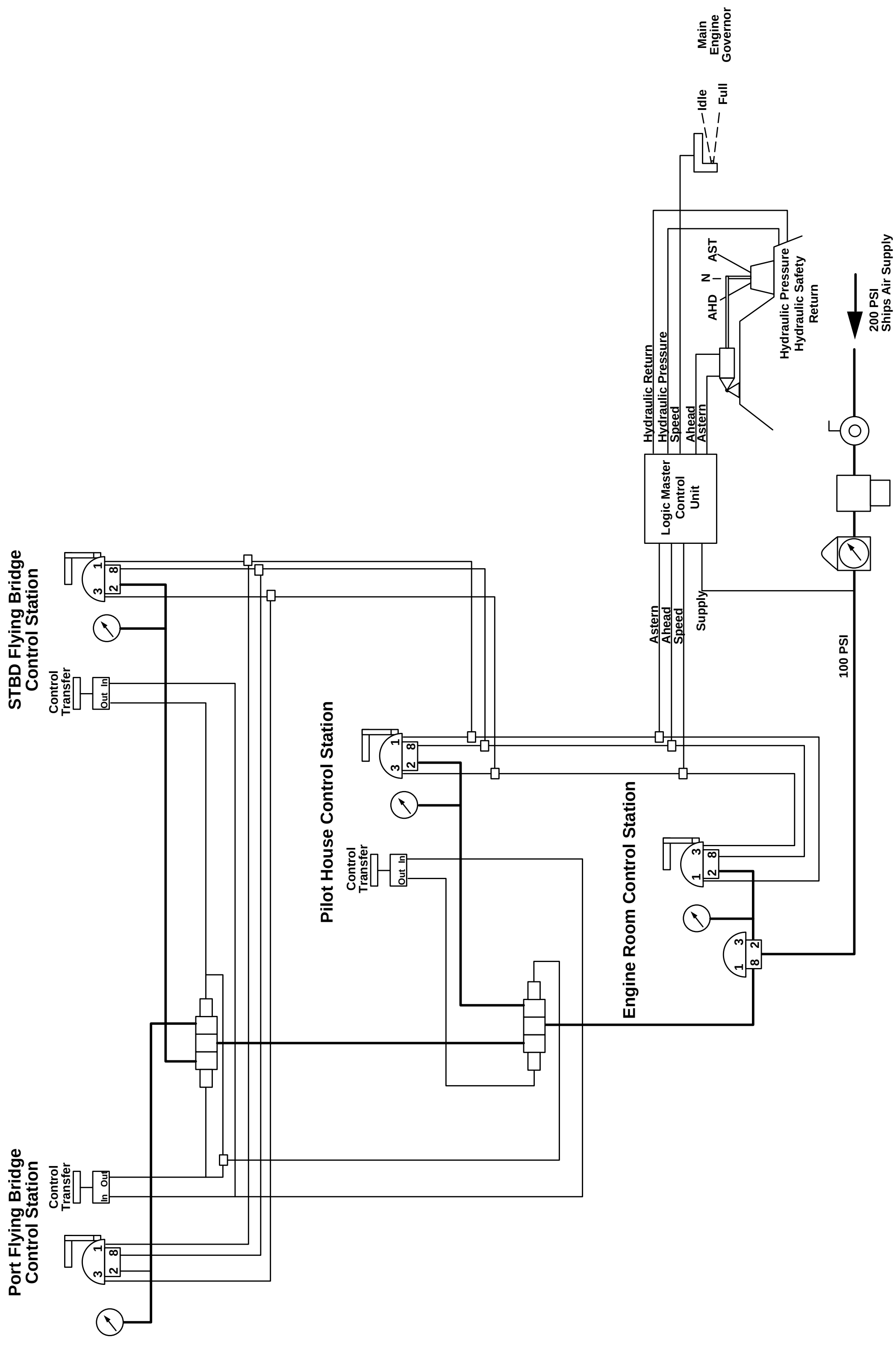

Three (3) Station Remote
Pneumatic Control System
Two (2) Engine Utility Vessel
Pilothouse Control Station
Port AFT Deck Control Station
STBD AFT Deck Control Station
Control Transfer
In Out
1 3
8 2
Logic Master Control Unit
Speed
Brake Control
Hydraulic Return
Hydraulic Pressure
Ahead
Astern
Supply
AHD
N
AST
HYD. Press
HYD. Safety
Return
Idle
Full
STBD Main Engine Governor
Port Main Engine Governor
Shaft Brake
100 PSI
125 PSI
200 PSI
Ships Air Supply

Figure 2



Four (4) Station Remote Pneumatic Control System Single Main Engine Fishing Vessel

Figure 3

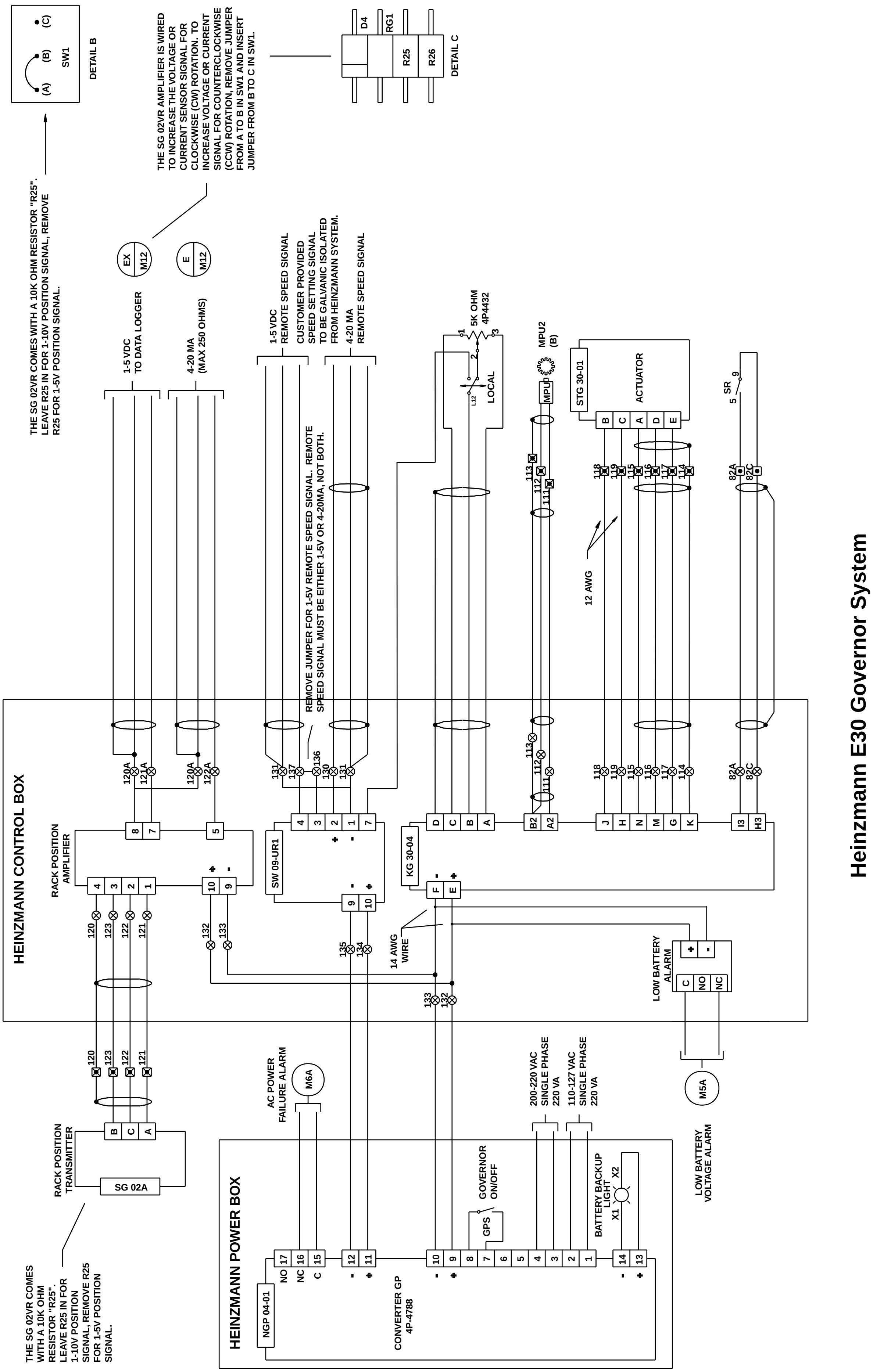

Heinzmann E30 Governor System
HEINZMANN CONTROL BOX
HEINZMANN POWER BOX
RACK POSITION AMPLIFIER
RACK POSITION TRANSMITTER
SG 02A
SW 09-UR1
KG 30-04
NGP 04-01
CONVERTER GP 4P-4788
GOVERNOR ON/OFF
GPS
BATTERY BACKUP LIGHT
LOW BATTERY ALARM
LOW BATTERY VOLTAGE ALARM
AC POWER FAILURE ALARM
200-220 VAC SINGLE PHASE 220 VA
110-127 VAC SINGLE PHASE 220 VA
14 AWG WIRE
12 AWG
ACTUATOR
STG 30-01
MPU2 (B)
5K OHM 4P4432
LOCAL
1-5 VDC TO DATA LOGGER
4-20 MA (MAX 250 OHMS)
1-5 VDC REMOTE SPEED SIGNAL
CUSTOMER PROVIDED SPEED SETTING SIGNAL TO BE GALVANIC ISOLATED FROM HEINZMANN SYSTEM.
4-20 MA REMOTE SPEED SIGNAL
REMOVE JUMPER FOR 1-5V REMOTE SPEED SIGNAL. REMOTE SPEED SIGNAL MUST BE EITHER 1-5V OR 4-20MA, NOT BOTH.
THE SG 02VR COMES WITH A 10K OHM RESISTOR "R25". LEAVE R25 IN FOR 1-10V POSITION SIGNAL, REMOVE R25 FOR 1-5V POSITION SIGNAL.
THE SG 02VR AMPLIFIER IS WIRED TO INCREASE THE VOLTAGE OR CURRENT SENSOR SIGNAL FOR CLOCKWISE (CW) ROTATION. TO INCREASE VOLTAGE OR CURRENT SIGNAL FOR COUNTERCLOCKWISE (CCW) ROTATION, REMOVE JUMPER FROM A TO B IN SW1 AND INSERT JUMPER FROM B TO C IN SW1.
DETAIL B
SW1
DETAIL C
D4
RG1
R25
R26
THE SG 02VR COMES WITH A 10K OHM RESISTOR "R25". LEAVE R25 IN FOR 1-10V POSITION SIGNAL, REMOVE R25 FOR 1-5V POSITION SIGNAL.

Figure 10

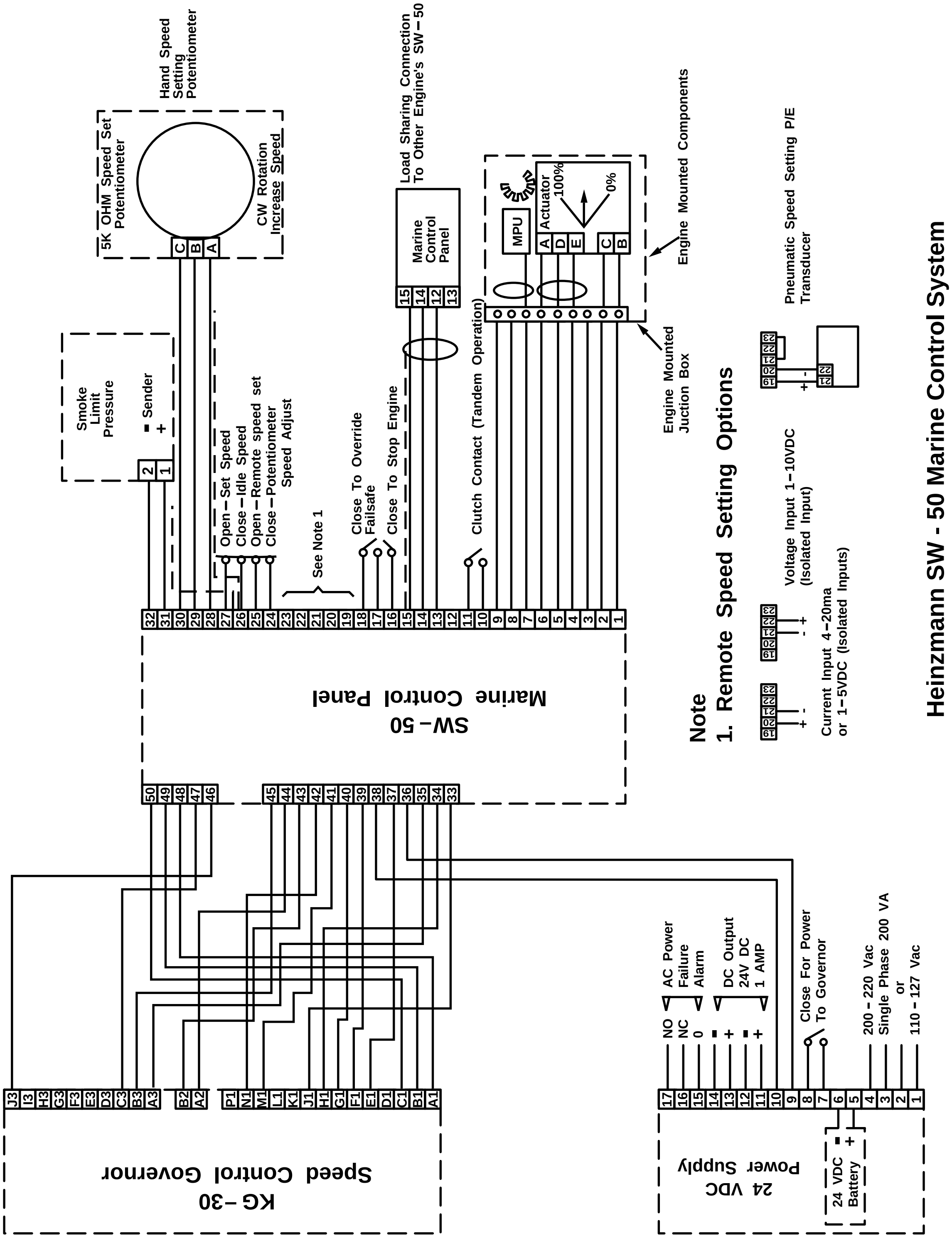

Heinzmann SW - 50 Marine Control System
KG − 30
Speed Control Governor
SW − 50
Marine Control Panel
24 VDC
Power Supply
24 VDC
Battery
5K OHM Speed Set
Potentiometer
CW Rotation
Increase Speed
Hand Speed
Setting
Potentiometer
Smoke
Limit
Pressure
Sender
Open − Set Speed
Close − Idle Speed
Open − Remote speed set
Close − Potentiometer
Speed Adjust
See Note 1
Close To Override
Failsafe
Close To Stop Engine
Load Sharing Connection
To Other Engine's SW − 50
Marine
Control
Panel
Clutch Contact (Tandem Operation)
MPU
Actuator
100%
0%
Engine Mounted Components
Engine Mounted
Juction Box
Note
1. Remote Speed Setting Options
Current Input 4 − 20ma
or 1 − 5VDC (Isolated Inputs)
Voltage Input 1 − 10VDC
(Isolated Input)
Pneumatic Speed Setting P/E
Transducer
NO
NC
0
AC Power
Failure
Alarm
DC Output
24V DC
1 AMP
Close For Power
To Governor
200 - 220 Vac
Single Phase 200 VA
or
110 - 127 Vac

Figure 11

3600 Marine Engine Application and Installation Guide

● Drawings

LEKM8469 8-98

CATERPILLAR®

Drawings

General Drawing Datums and Conventions
Engine Installation Drawings
Engine Room Installations
General
Drawings

General Drawing Datums and Conventions

Caterpillar Drawing Datums And General Conventions

Zero Datum

All dimensions identified on standard Caterpillar General Arrangement Drawings are referenced to three (3) principal datums:

01 Horizontal Centerline Of Engine
02 Vertical Centerline Of Engine
03 Rear Face Of Crankshaft Adapter

The rear of the engine has been established as the flywheel end with right and left identified as looking forward from that location.

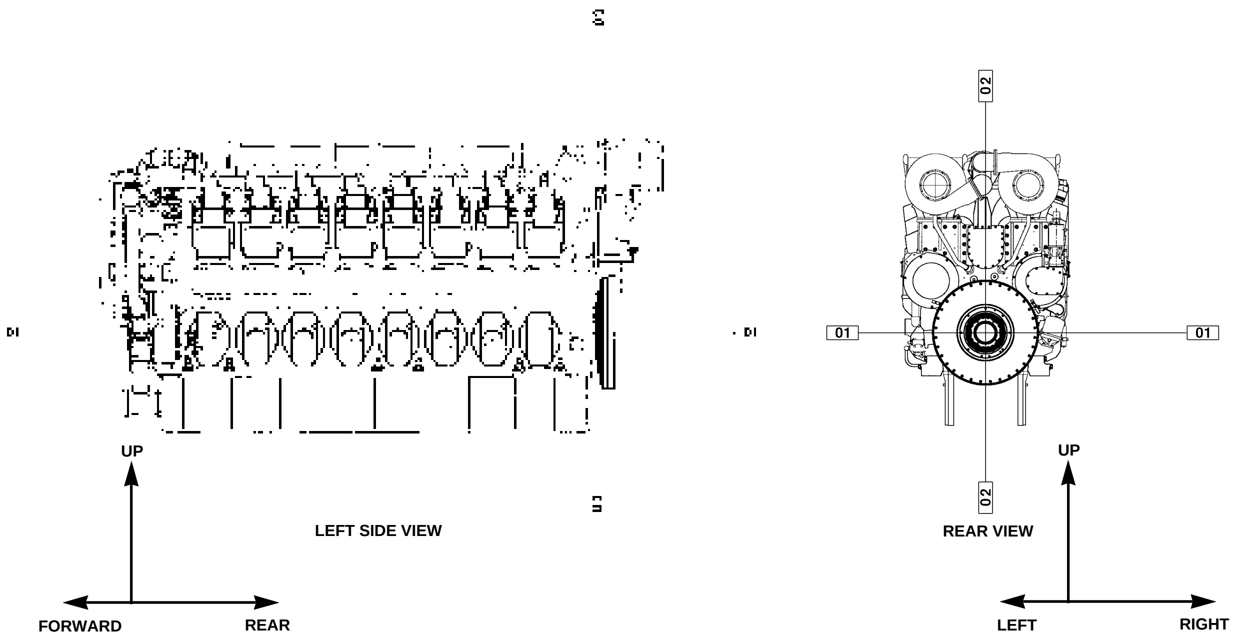


Figure 1

Engine Installation Drawings

Installation Drawings numbered, 3606 MAR, 3608 MAR, 3612 MAR and 3616 MAR represent the 3600 engines with marine propulsion configurations. See LEKX1120 generator set *Technical Data* for drawings of typical marine auxiliary generator set engine configurations.

Engine Room Installations

The engine room machinery layout is normally made by the shipyard and/or the owner and consultant. However, the engine builder requirements must be considered to ensure all systems function properly and service requirements are met. Pumps, coolers, starting air compressors, etc., must be serviceable. Piping attached to equipment such as coolers should allow cooler end bonnets to be removed for tube bundle service. Cooler tubes must be removable without interfering with piping, wiring or machinery. Access covers, grease points, etc., must be accessible.

Provide sufficient floor space or service platforms near the engine and marine gear for major parts removed during service (cylinder heads, pistons, etc.). Reinforce service platform plates subject to heavy loads. All engine and marine gear service and inspection areas must be accessible without removing floorplates, pipes, or wiring.

The engine room should have storage space, preferably near the engine, for major spare parts. Locate a bridge crane above the engine. Provide additional monorails with hoists throughout the engine room to move heavy equipment and spares from the storage area. The ship design must allow movement of heavy parts to and from the engine room.

When two or more engines are connected to the propeller through reduction gears, the center distance between engines must allow access space for servicing each engine. The sketches that follow allow for a 2.44 m (8 ft) between engine centerlines. This is minimum for inspection and service. If closer spacing is required it is considered marginal, and the design should be reviewed with the operator.

The instrument panel, bypass oil filters, lube oil filling connection, fuel and lube filters located on the engine inboard side facilitates inspection and service for twin engine installations.

Engine installation cost can be reduced by factory ordering an auxiliary module (fresh water expansion tank, heat exchanger, etc.). The module comes complete with associated engine auxiliary equipment. It can be mounted at the forward end of the engine as shown in Figure 2.

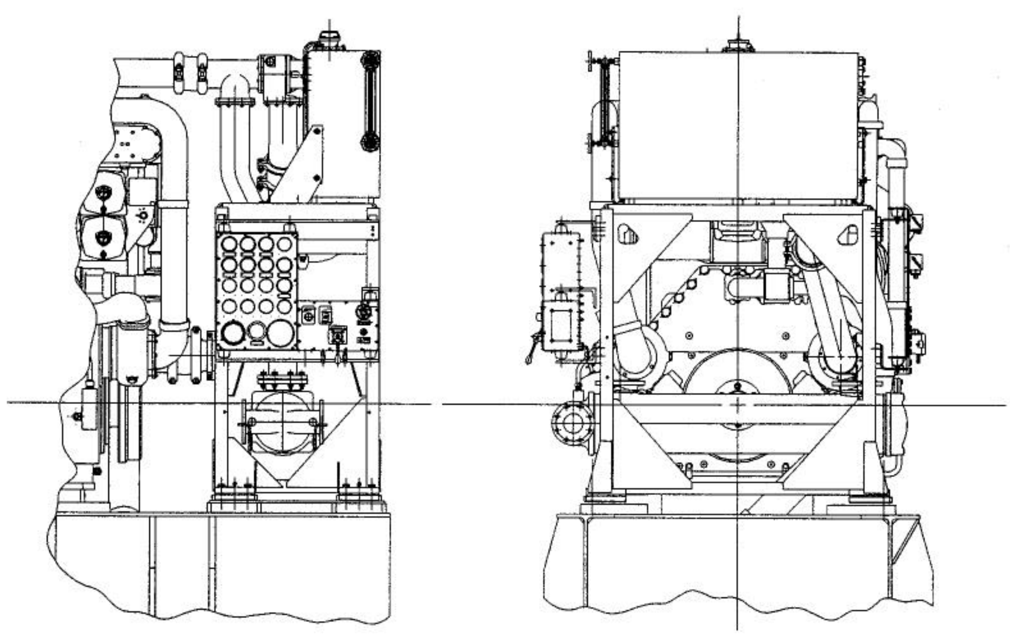


Figure 2 **Typical Accessory Module**

Flexible connections should be used between the module and shipyard piping.

If possible, place the fuel treatment and service equipment within a separate, dedicated room. This allows the majority of fuel handling equipment to be located in one area and confines fire potential areas. Provide separate ventilation and fire extinguishing systems.

Enclose the ship's service generators within a sound proof room to minimize engine room noise. This allows the operators to service the main engines in port at reasonable engine room noise levels.

The machinery casing above the engine room must allow for installation, inspection and maintenance of the engine exhaust piping and silencers, and for ventilation air ducting and air trunks.

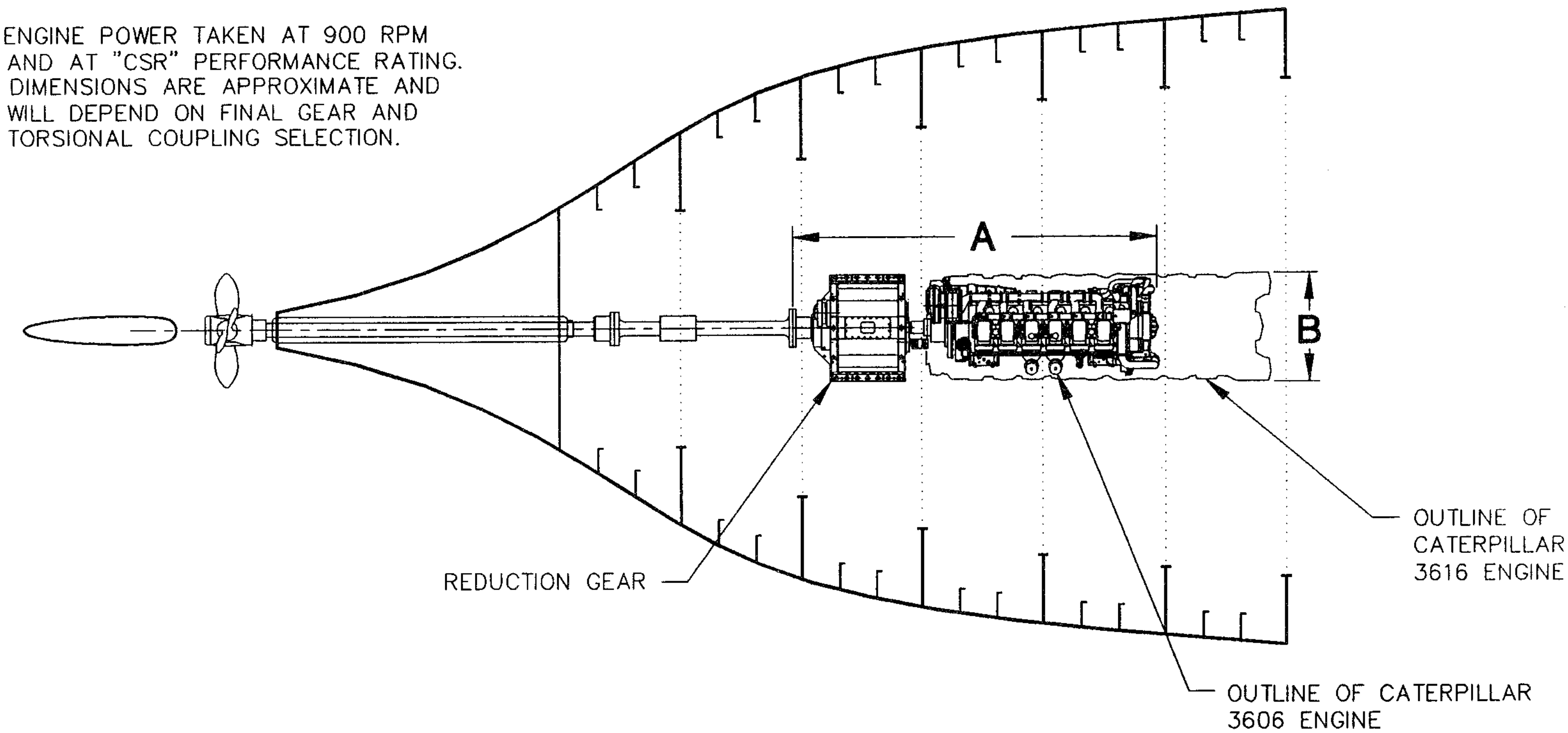
Give consideration to keeping the machinery casings separate from living accommodations to minimize noise and vibration.

The following drawings indicate overall dimensions for various engine/marine gear configurations. The dimensions shown are approximate and can change based on marine gear manufacturer, torsional coupling selected, horsepower and speed of engine, propeller rpm, etc. The dimensions shown can be used for preliminary design and configuration arrangement. The table of horsepower ranges is based on the Continuous Service Rating (CSR) at an engine speed of 900 rpm.

Figure 3

INSTALLED ENGINE POWER AND OVERALL DIMENSIONS				
ENGINE CYLINDERS	KW	H.P.	DIMENSIONS	
			A	B
6	1730	2320	6.1m (20')	1.75mm (5.74')
8	2300	3080	7.0m (23')	1.75mm (5.74')
12	3460	4640	6.7m (22')	1.71mm (5.62')
16	4600	6170	7.6m (25')	1.71mm (5.62')

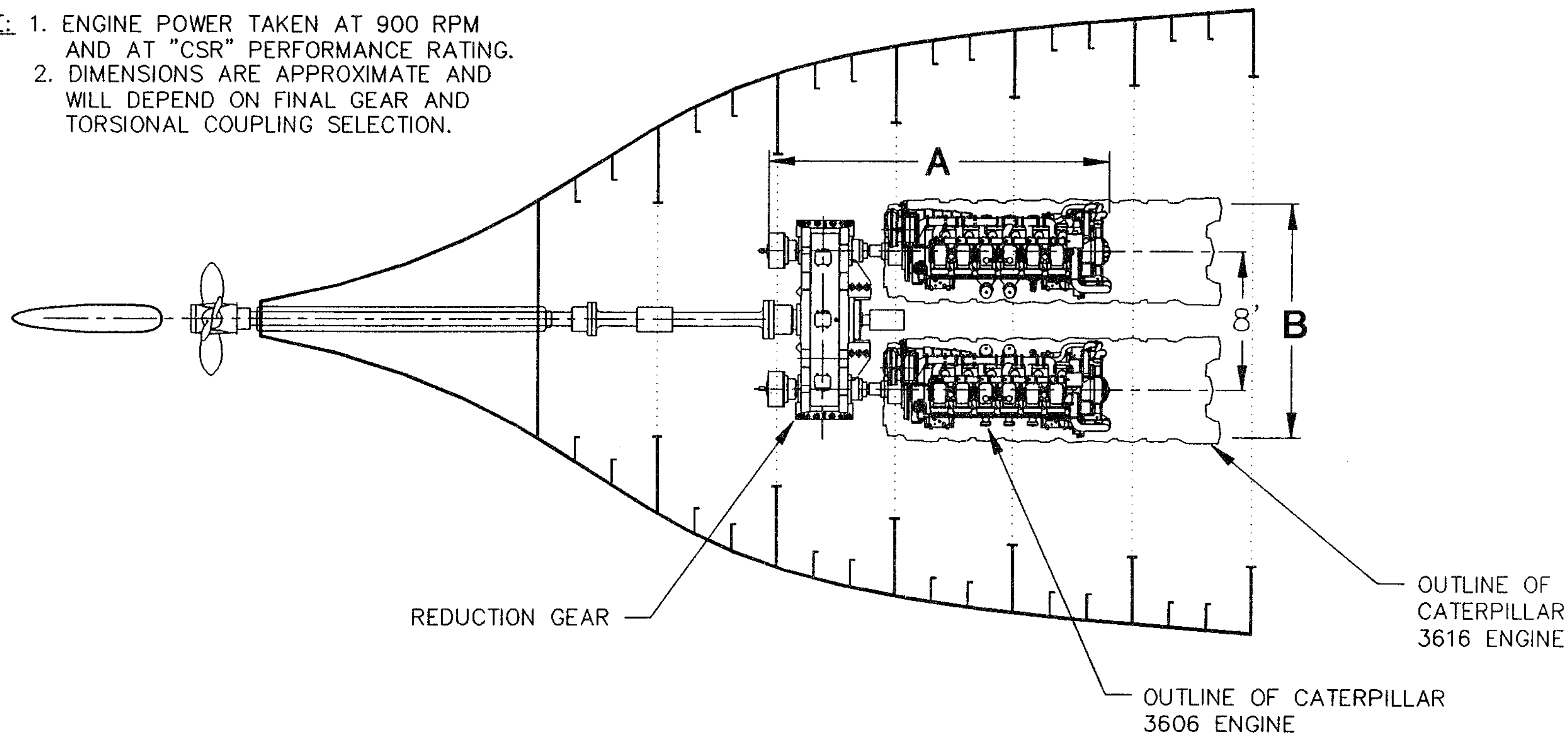
NOTE: 1. ENGINE POWER TAKEN AT 900 RPM AND AT "CSR" PERFORMANCE RATING.
2. DIMENSIONS ARE APPROXIMATE AND WILL DEPEND ON FINAL GEAR AND TORSIONAL COUPLING SELECTION.



Single Engine - Single Screw

INSTALLED ENGINE POWER AND OVERALL DIMENSIONS				
ENGINE CYLINDERS	KW	H.P.	DIMENSIONS	
			A	B
6	3460	4640	6.1m (20')	4.2m (13.7')
8	4600	6160	7.0m (23')	4.2m (13.7')
12	6920	9280	6.7m (22')	4.2m (13.7')
16	9200	12,340	7.6m (25')	4.2m (13.7')

NOTE: 1. ENGINE POWER TAKEN AT 900 RPM AND AT "CSR" PERFORMANCE RATING.
2. DIMENSIONS ARE APPROXIMATE AND WILL DEPEND ON FINAL GEAR AND TORSIONAL COUPLING SELECTION.



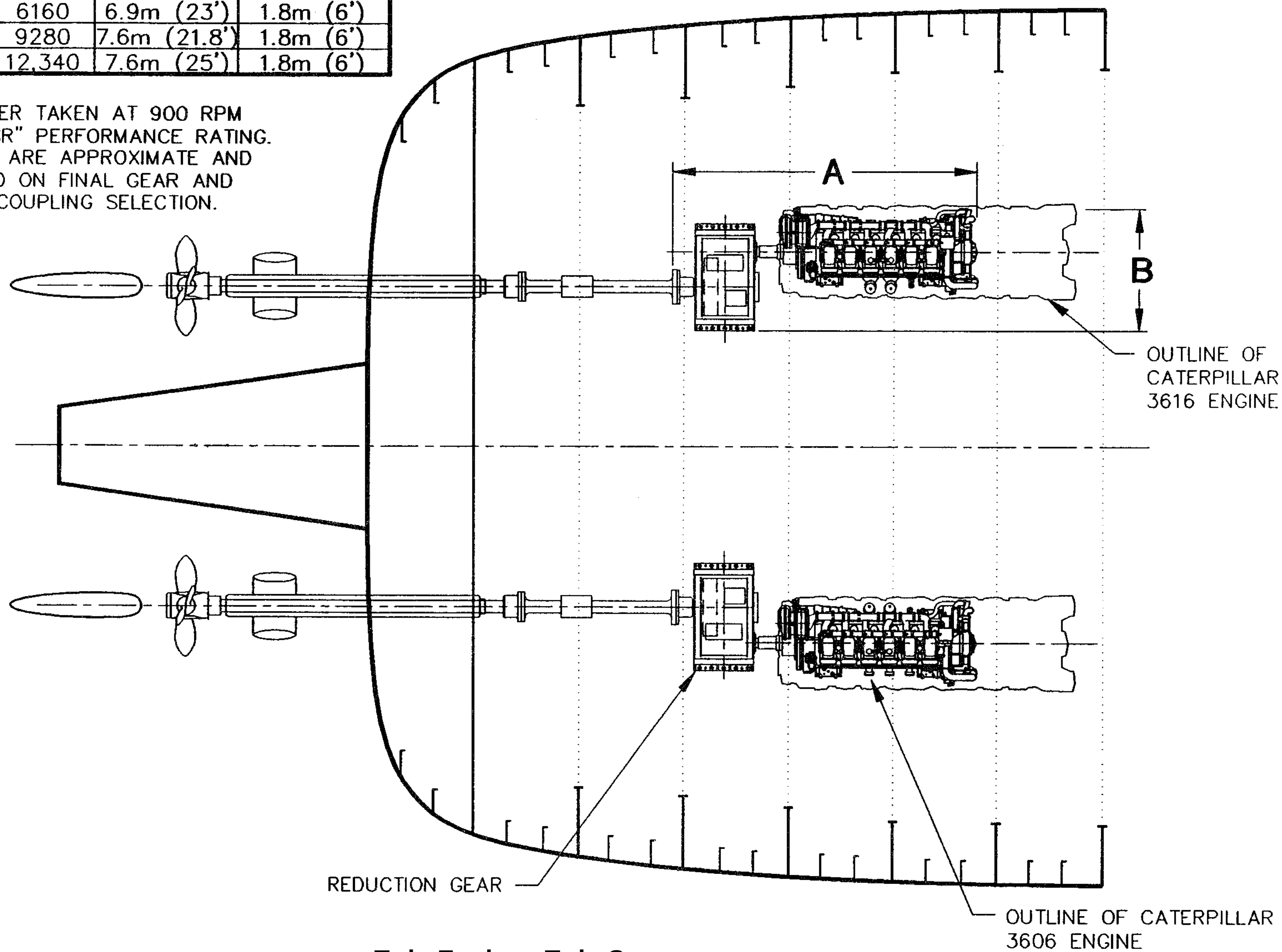
Twin Engine - Single Screw

Figure 4

Figure 5

INSTALLED ENGINE POWER AND OVERALL DIMENSIONS				
ENGINE CYLINDERS	KW	H.P.	DIMENSIONS	
			A	B
6	3460	4640	6.1m (20')	1.8m (6')
8	4600	6160	6.9m (23')	1.8m (6')
12	6920	9280	7.6m (21.8')	1.8m (6')
16	9200	12,340	7.6m (25')	1.8m (6')

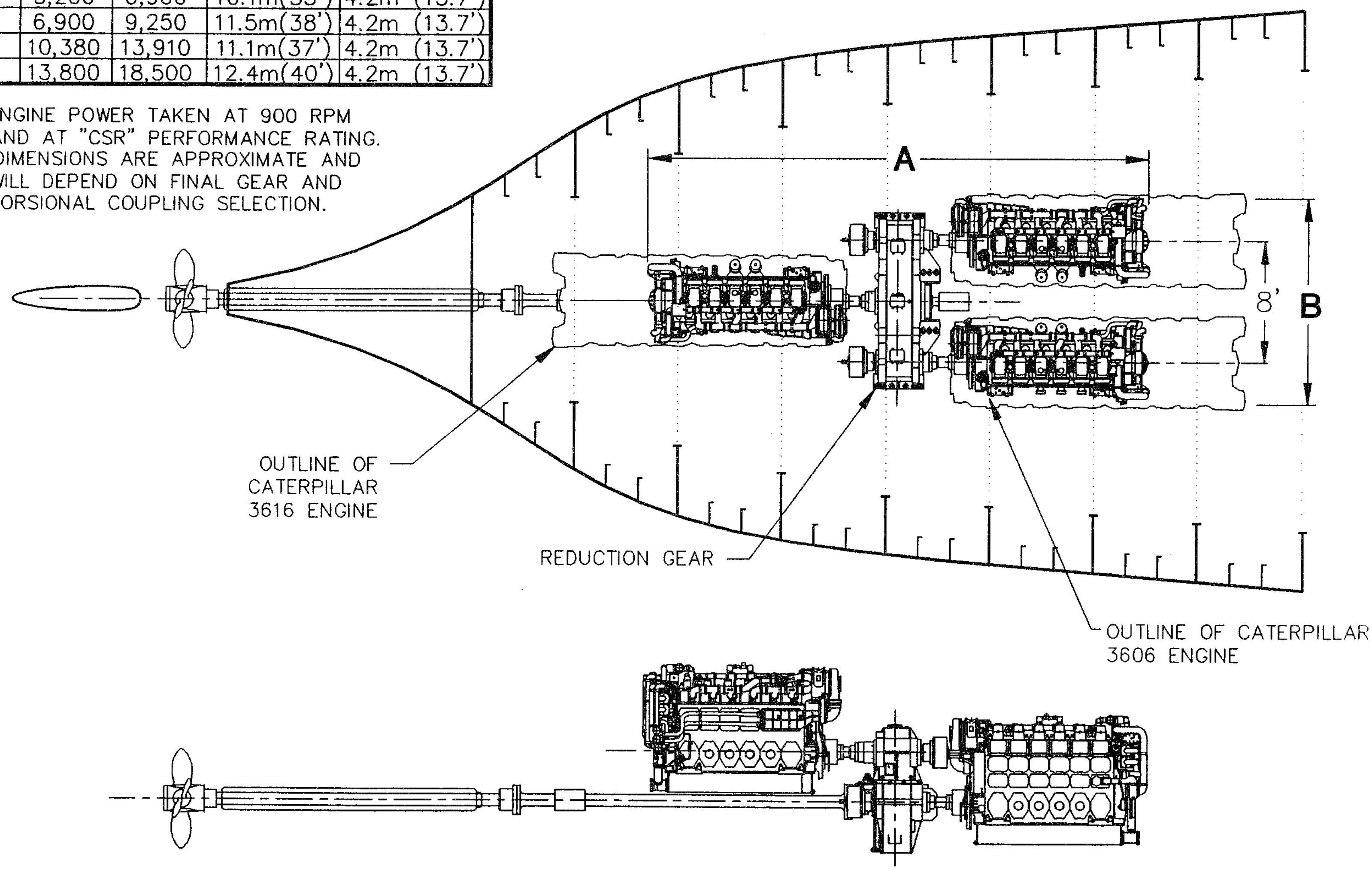
NOTE: 1. ENGINE POWER TAKEN AT 900 RPM AND AT "CSR" PERFORMANCE RATING.
2. DIMENSIONS ARE APPROXIMATE AND WILL DEPEND ON FINAL GEAR AND TORSIONAL COUPLING SELECTION.



Twin Engine - Twin Screw

INSTALLED ENGINE POWER AND OVERALL DIMENSIONS				
ENGINE CYLINDERS	KW	H.P.	DIMENSIONS	
			A	B
6	5,200	6,960	10.1m(33')	4.2m (13.7')
8	6,900	9,250	11.5m(38')	4.2m (13.7')
12	10,380	13,910	11.1m(37')	4.2m (13.7')
16	13,800	18,500	12.4m(40')	4.2m (13.7')

NOTE: 1. ENGINE POWER TAKEN AT 900 RPM AND AT "CSR" PERFORMANCE RATING.
2. DIMENSIONS ARE APPROXIMATE AND WILL DEPEND ON FINAL GEAR AND TORSIONAL COUPLING SELECTION.



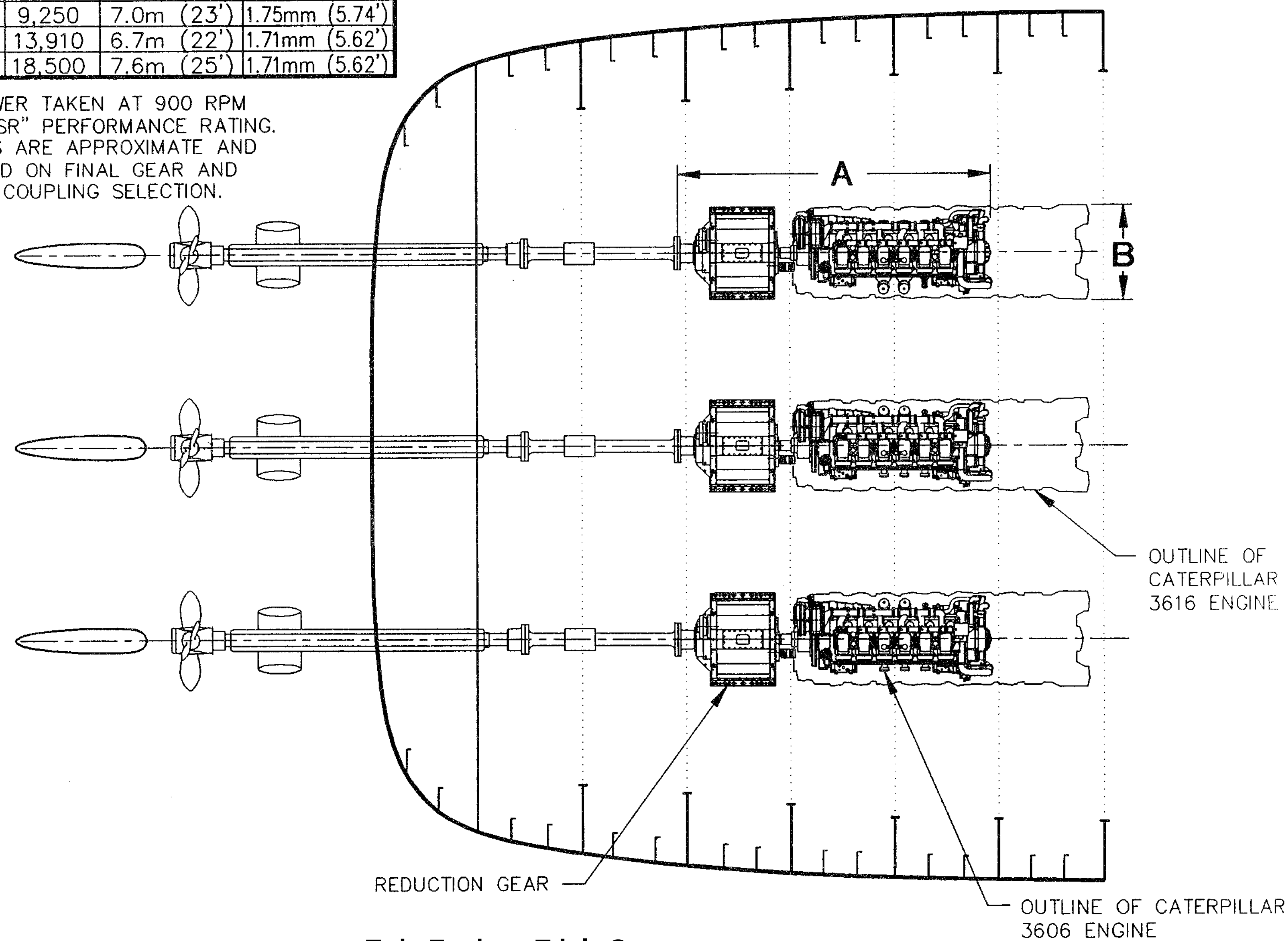
Three Engine - Single Screw

Figure 6

Figure 7

INSTALLED ENGINE POWER AND OVERALL DIMENSIONS				
ENGINE CYLINDERS	KW	H.P.	DIMENSIONS	
			A	B
6	5,200	6,960	6.1m (20')	1.75mm (5.74')
8	6,900	9,250	7.0m (23')	1.75mm (5.74')
12	10,380	13,910	6.7m (22')	1.71mm (5.62')
16	13,800	18,500	7.6m (25')	1.71mm (5.62')

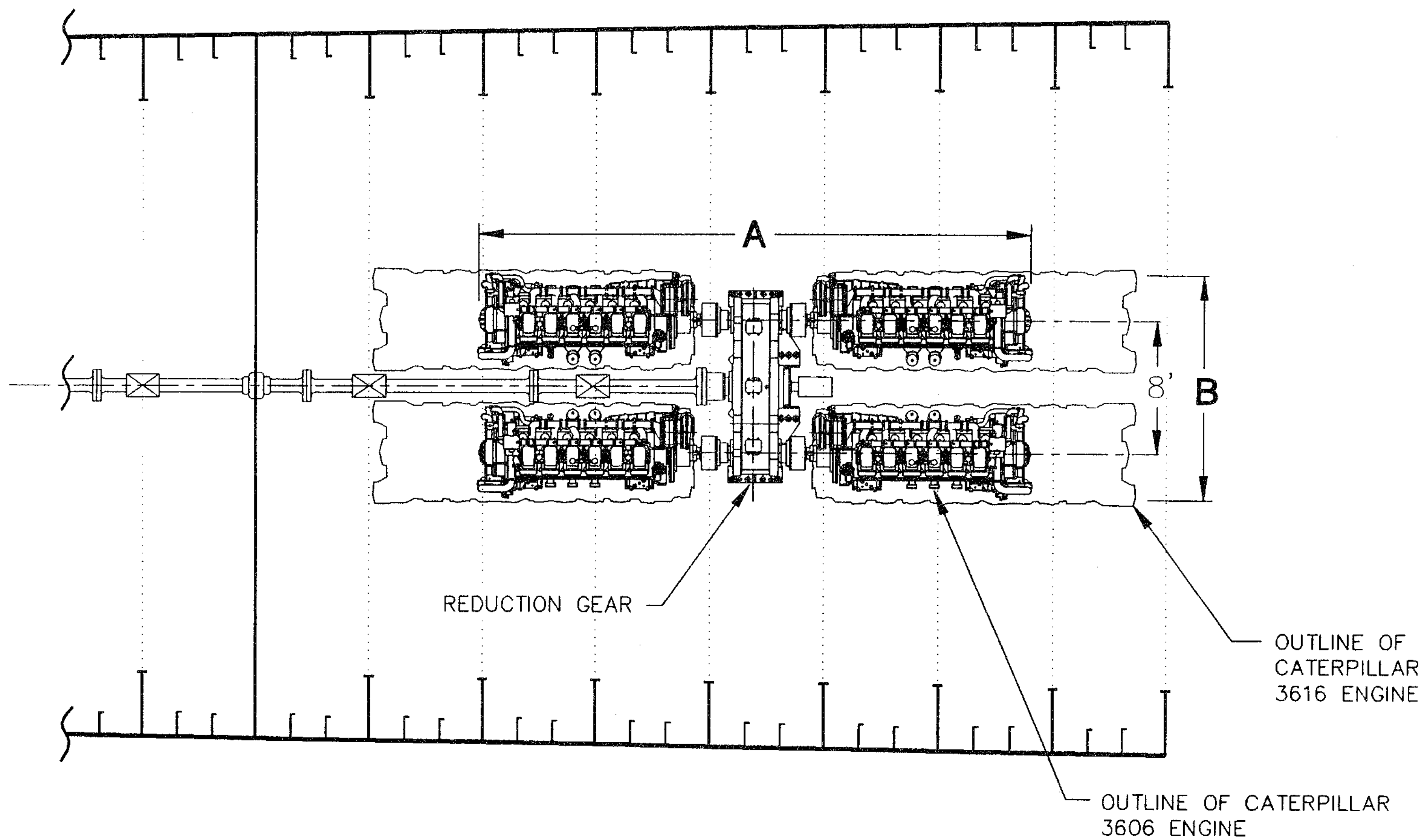
NOTE: 1. ENGINE POWER TAKEN AT 900 RPM AND AT "CSR" PERFORMANCE RATING.
2. DIMENSIONS ARE APPROXIMATE AND WILL DEPEND ON FINAL GEAR AND TORSIONAL COUPLING SELECTION.



Twin Engine - Triple Screw

INSTALLED ENGINE POWER AND OVERALL DIMENSIONS				
ENGINE CYLINDERS	KW	H.P.	DIMENSIONS	
			A	B
6	6,920	9,280	10.1m(33')	4.2m (13.7')
8	9,200	12,320	11.9m(39')	4.2m (13.7')
12	13,840	18,560	11.3m(37')	4.2m (13.7')
16	18,400	24,680	13.0m(43')	4.2m (13.7')

NOTE:
1. ENGINE POWER TAKEN AT 900 RPM AND AT "CSR" PERFORMANCE RATING.
2. DIMENSIONS ARE APPROXIMATE AND WILL DEPEND ON FINAL GEAR AND TORSIONAL COUPLING SELECTION.



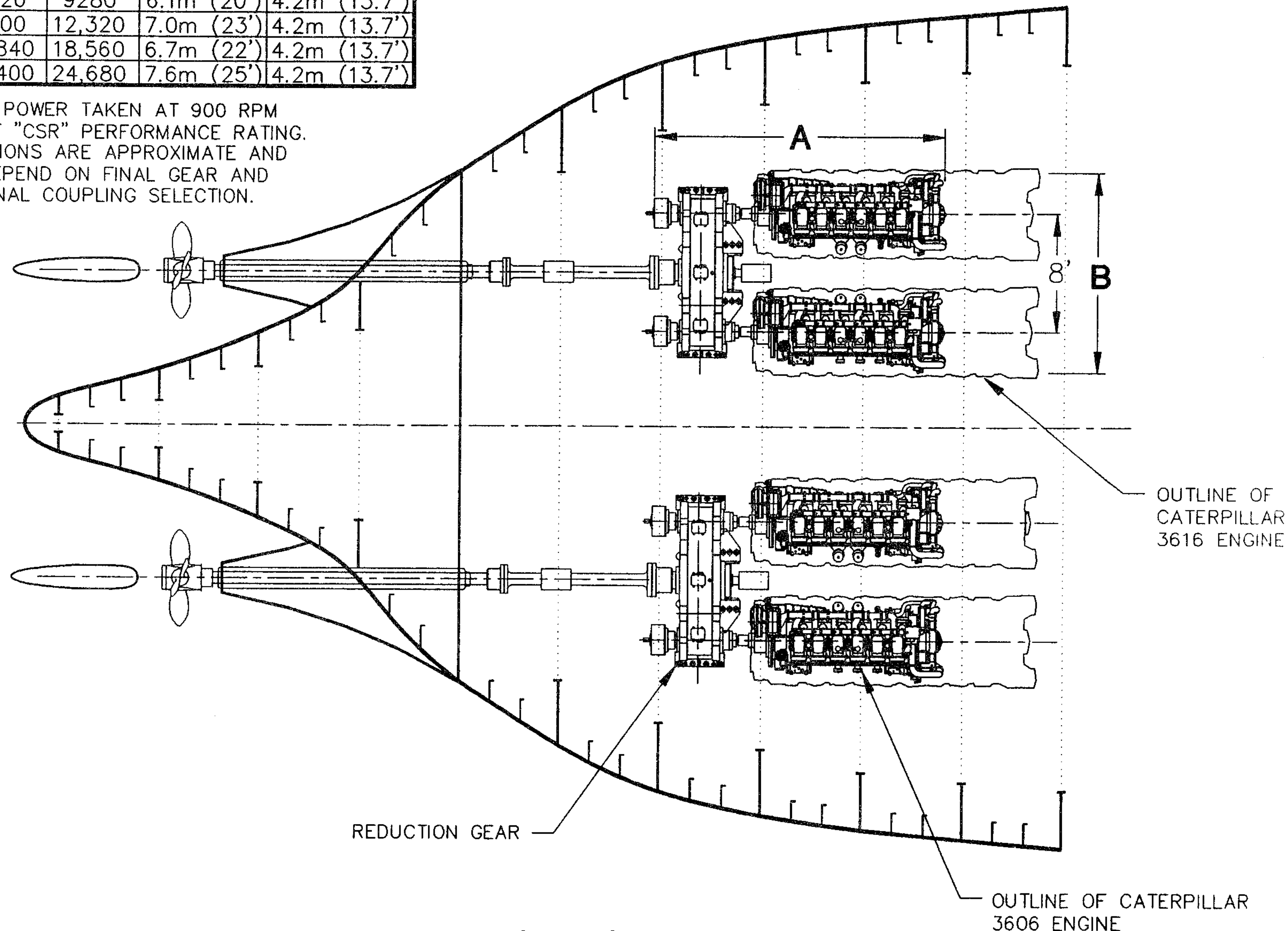
Four Engine - Single Screw

Figure 8

INSTALLED ENGINE POWER AND OVERALL DIMENSIONS

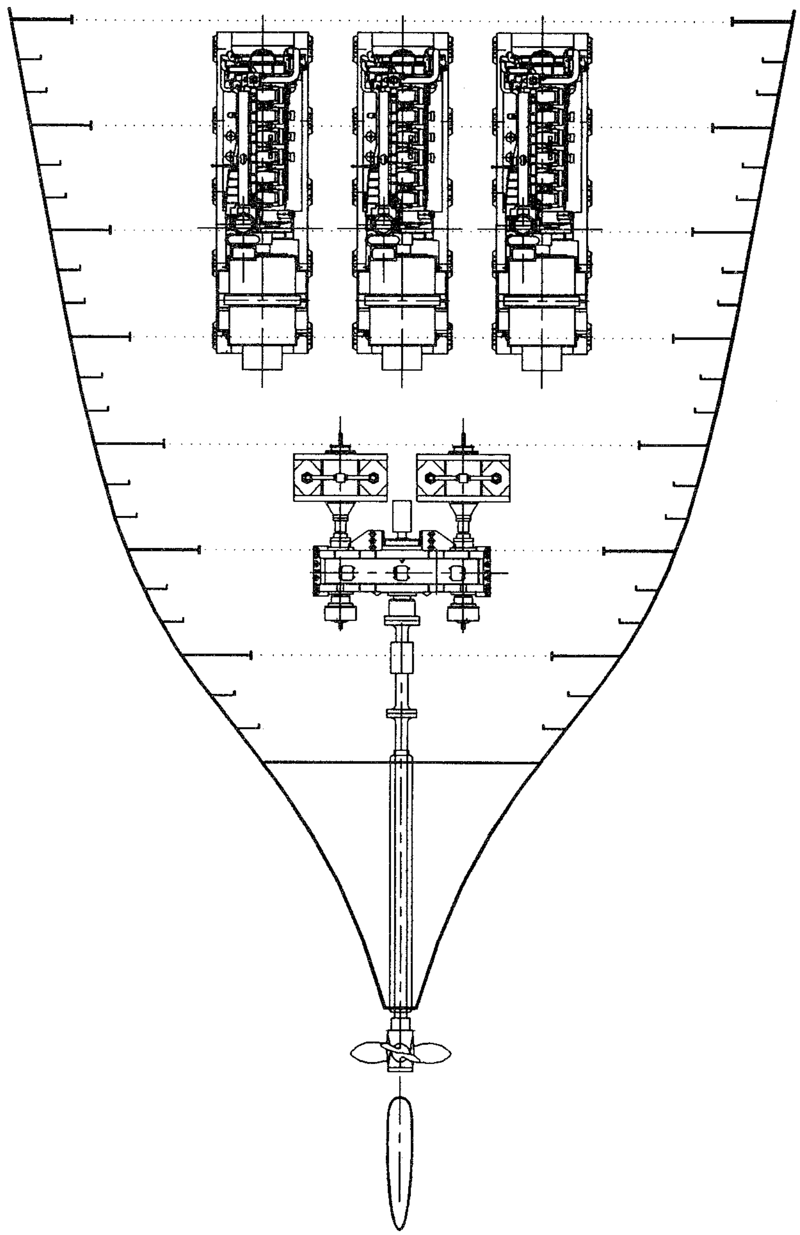
ENGINE CYLINDERS	KW	H.P.	DIMENSIONS A	DIMENSIONS B
6	6920	9280	6.1m (20')	4.2m (13.7')
8	9200	12,320	7.0m (23')	4.2m (13.7')
12	13,840	18,560	6.7m (22')	4.2m (13.7')
16	18,400	24,680	7.6m (25')	4.2m (13.7')

NOTE: 1. ENGINE POWER TAKEN AT 900 RPM AND AT "CSR" PERFORMANCE RATING.
2. DIMENSIONS ARE APPROXIMATE AND WILL DEPEND ON FINAL GEAR AND TORSIONAL COUPLING SELECTION.



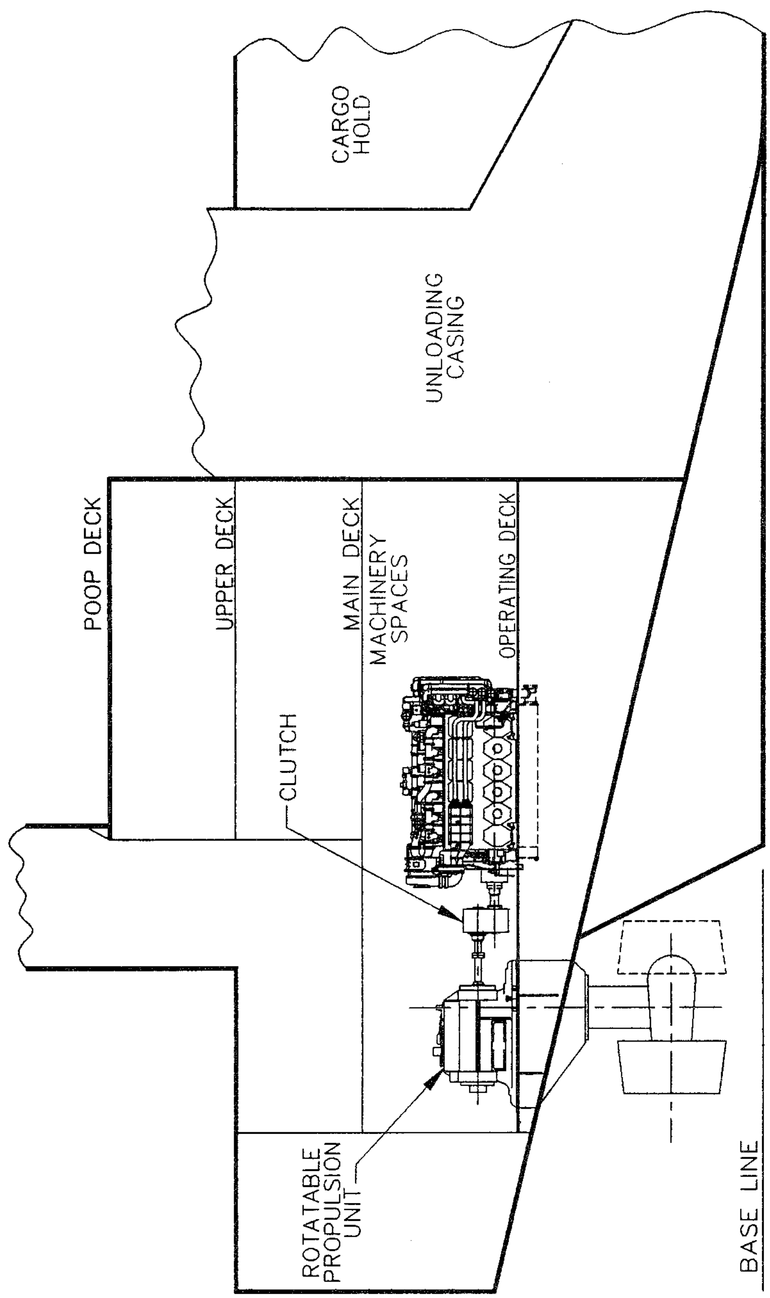
Four Engine - Twin Screw

Figure 9



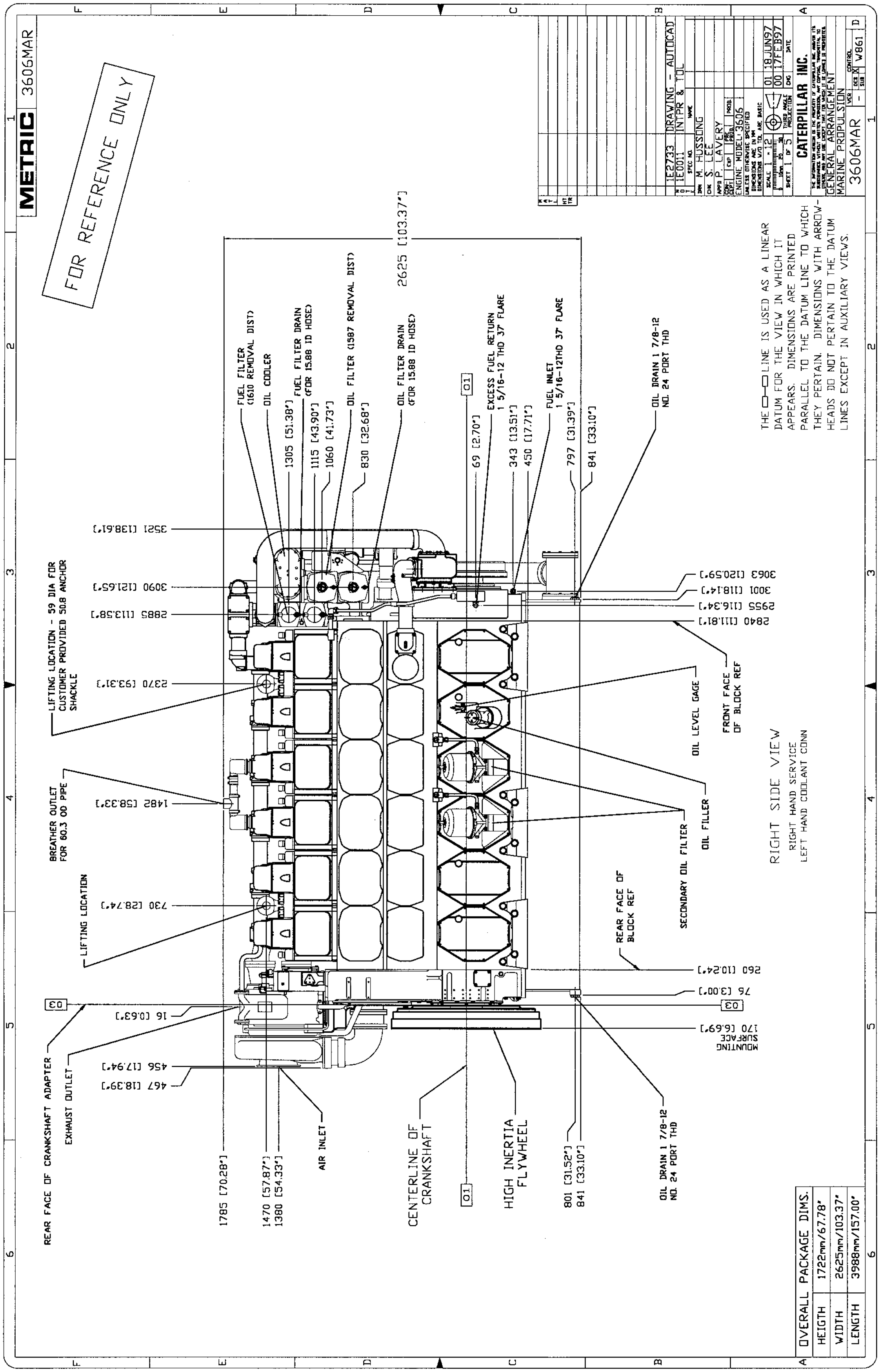
Typical Electric Drive

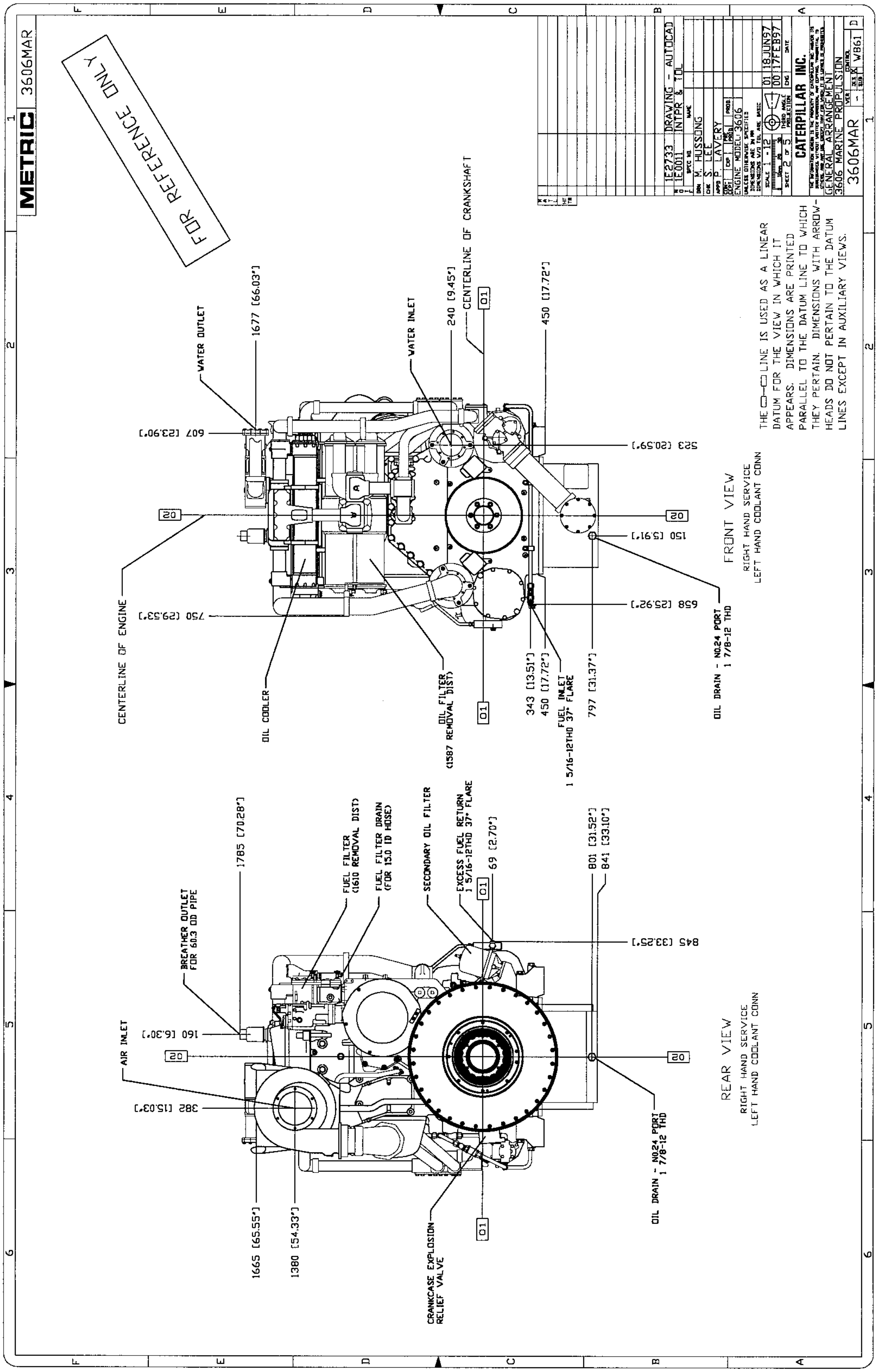
Figure 10

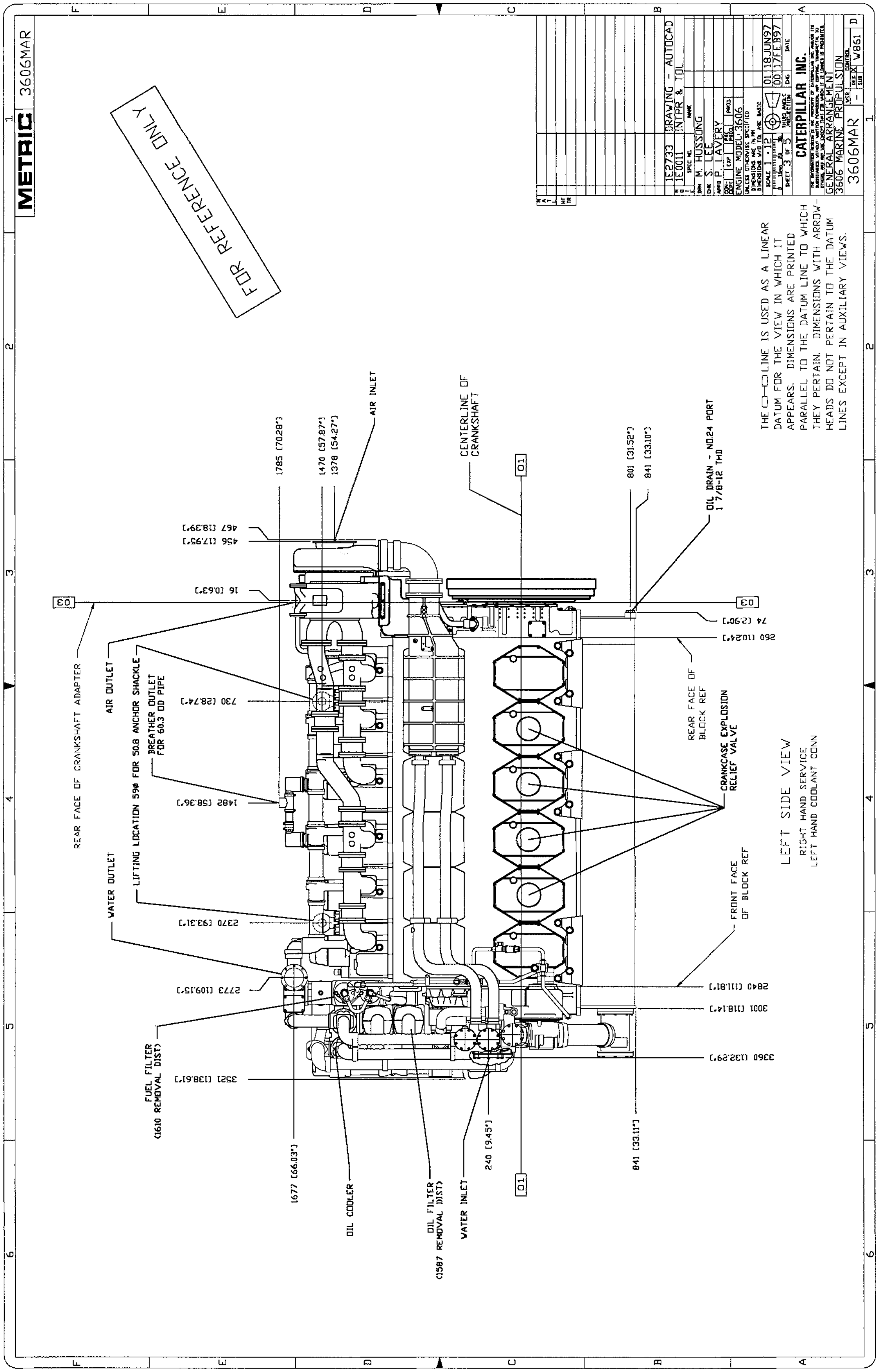


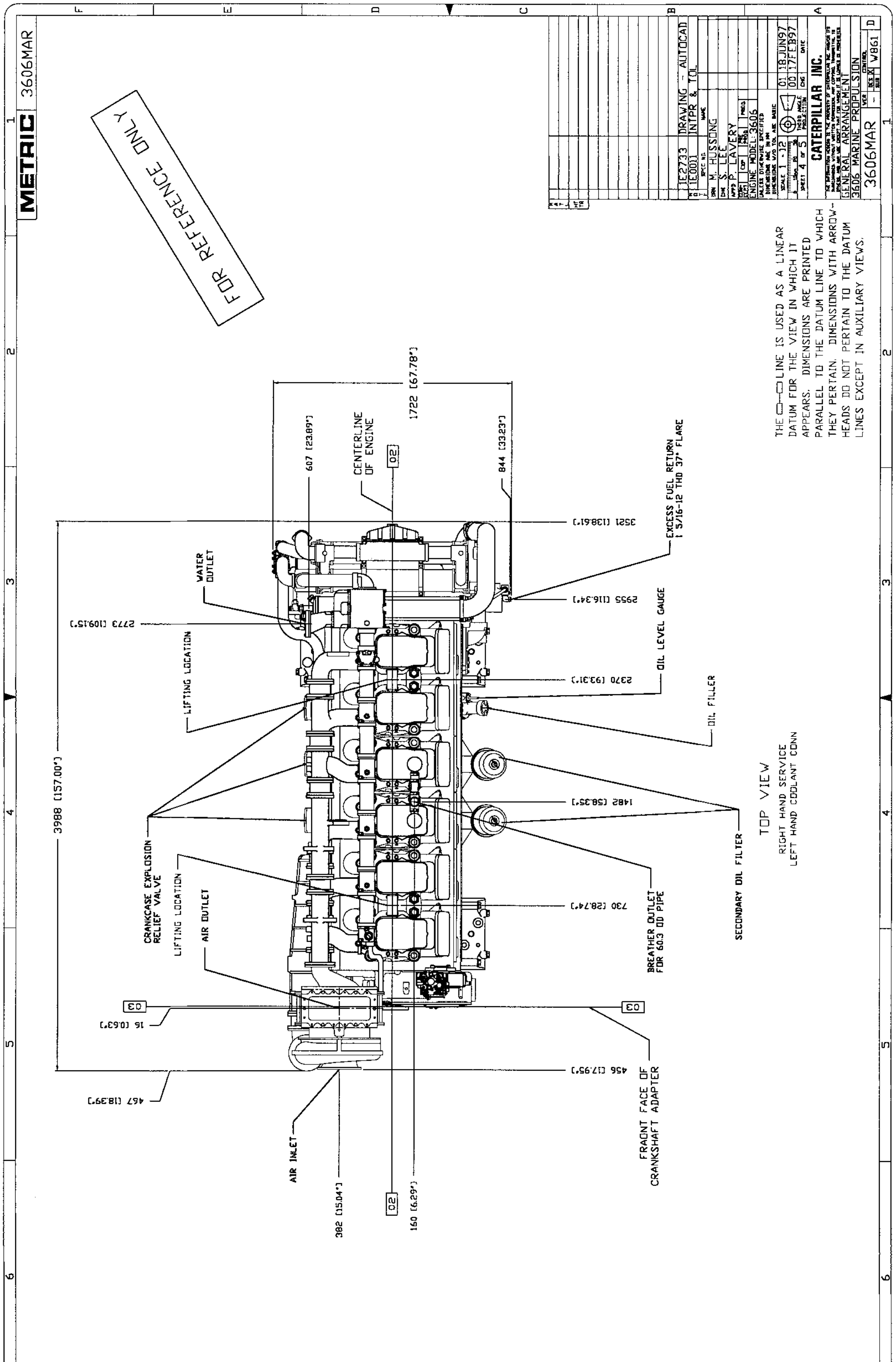
Typical Rotatable Drive

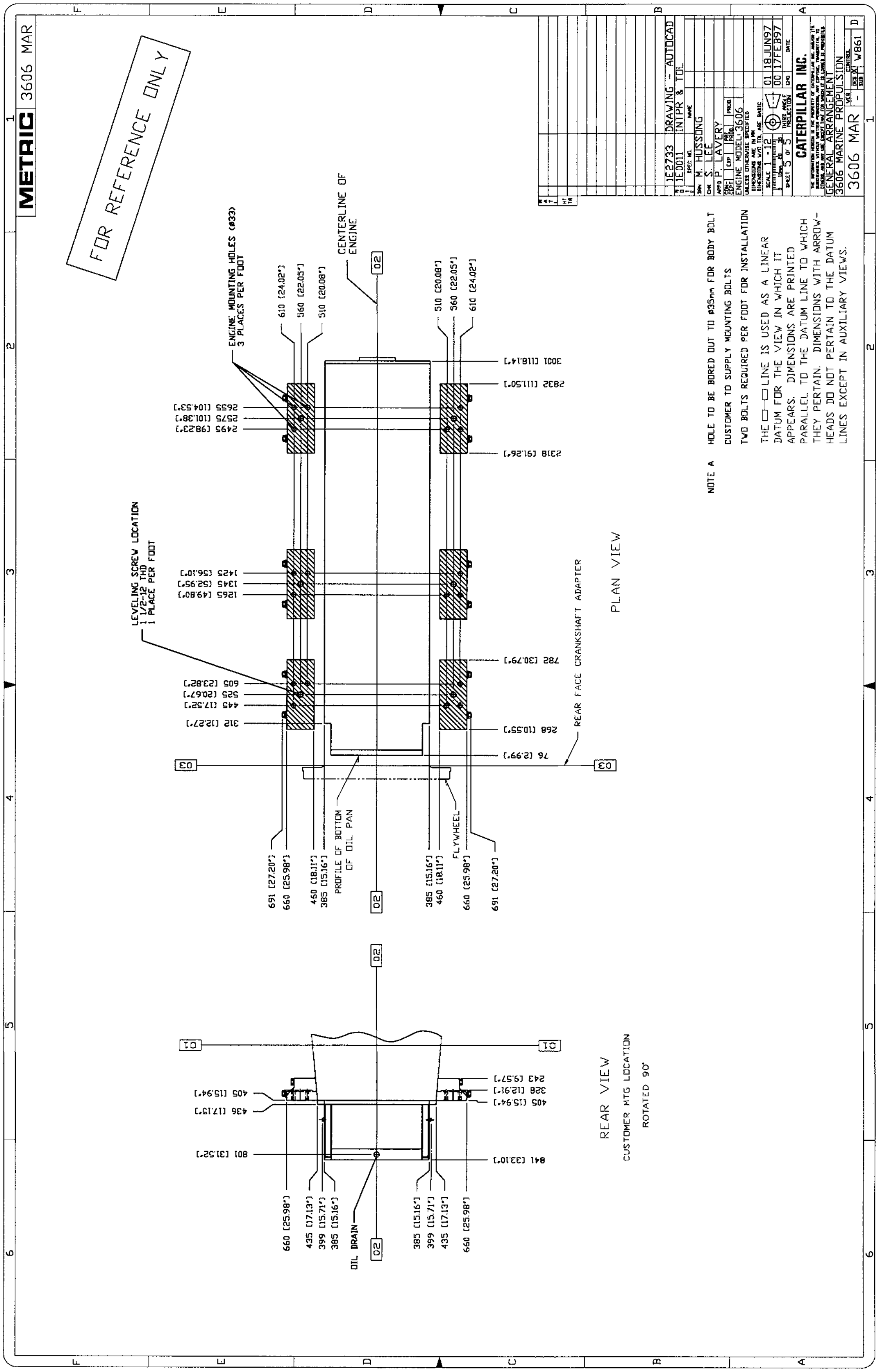
Figure 11

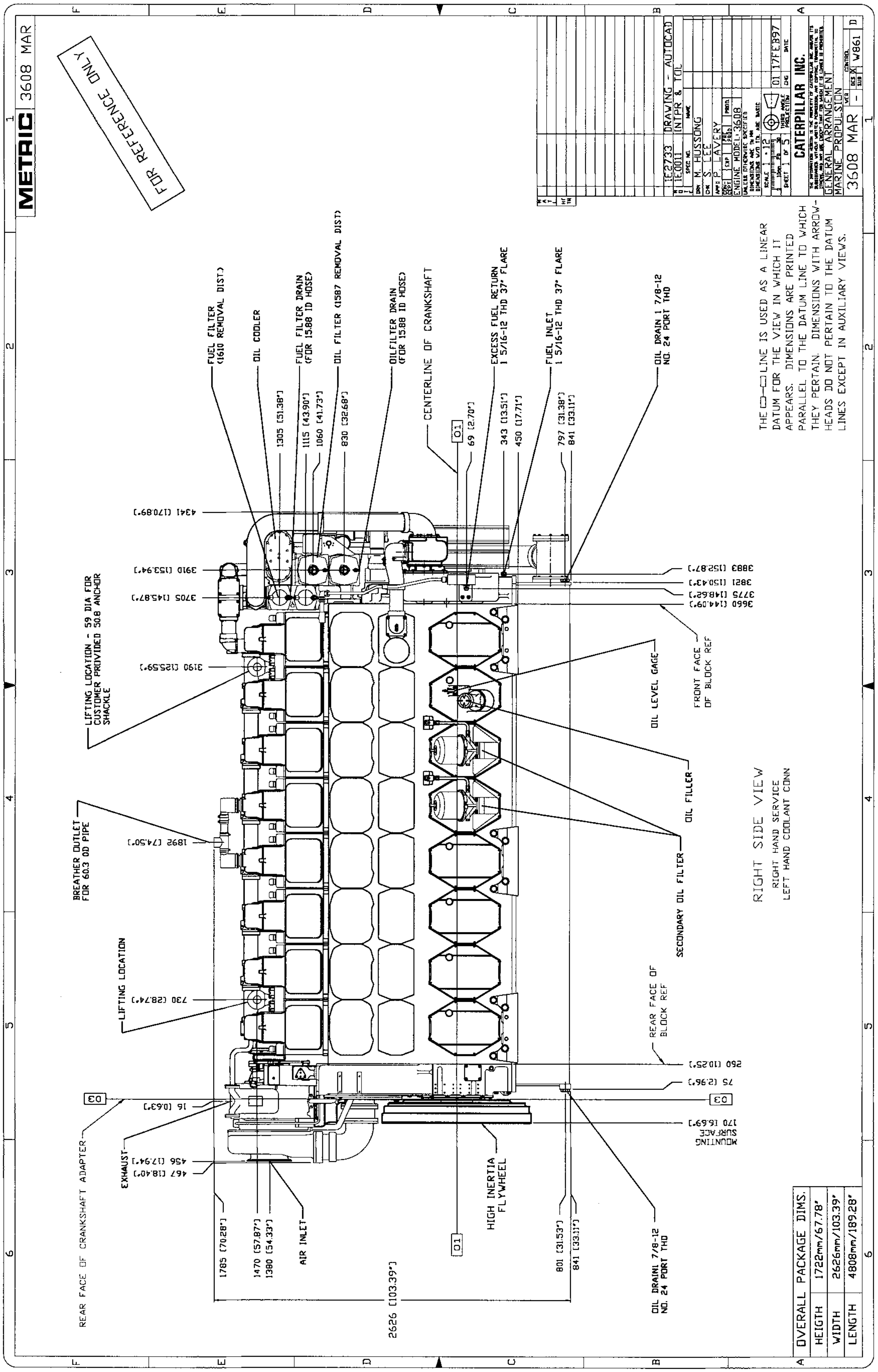

METRIC
3606MAR
FOR REFERENCE ONLY
RIGHT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
FUEL FILTER (1610 REMOVAL DIST)
OIL COOLER
FUEL FILTER DRAIN (FOR 15.88 ID HOSE)
OIL FILTER (1587 REMOVAL DIST)
OIL FILTER DRAIN (FOR 15.88 ID HOSE)
EXCESS FUEL RETURN 1 5/16-12 THD 37° FLARE
FUEL INLET 1 5/16-12THD 37° FLARE
OIL DRAIN 1 7/8-12 NO. 24 PORT THD
2625 [103.37"]
LIFTING LOCATION - 59 DIA FOR CUSTOMER PROVIDED 50.8 ANCHOR SHACKLE
BREATHER OUTLET FOR 60.3 OD PIPE
LIFTING LOCATION
REAR FACE OF CRANKSHAFT ADAPTER
EXHAUST OUTLET
AIR INLET
CENTERLINE OF CRANKSHAFT
HIGH INERTIA FLYWHEEL
REAR FACE OF BLOCK REF
SECONDARY OIL FILTER
OIL FILLER
OIL LEVEL GAGE
FRONT FACE OF BLOCK REF
MOUNTING SURFACE
THE LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
OVERALL PACKAGE DIMS.
HEIGTH 1722mm/67.78"
WIDTH 2625mm/103.37"
LENGTH 3988mm/157.00"
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
ENGINE MODEL 3606


METRIC
3606MAR
FOR REFERENCE ONLY
WATER OUTLET
1677 [66.03"]
WATER INLET
240 [9.45"]
CENTERLINE OF CRANKSHAFT
450 [17.72"]
607 [23.90"]
523 [20.59"]
750 [29.53"]
CENTERLINE OF ENGINE
150 [5.91"]
658 [25.92"]
OIL COOLER
OIL FILTER (1587 REMOVAL DIST)
343 [13.51"]
450 [17.72"]
FUEL INLET 1 5/16-12THD 37° FLARE
797 [31.37"]
OIL DRAIN - NO.24 PORT 1 7/8-12 THD
FRONT VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
BREATHER OUTLET FOR 60.3 OD PIPE
1785 [70.28"]
FUEL FILTER (1610 REMOVAL DIST)
FUEL FILTER DRAIN (FOR 15.0 ID HOSE)
SECONDARY OIL FILTER
EXCESS FUEL RETURN 1 5/16-12THD 37° FLARE
69 [2.70"]
801 [31.52"]
841 [33.10"]
845 [33.25"]
AIR INLET
160 [6.30"]
382 [15.03"]
1665 [65.55"]
1380 [54.33"]
CRANKCASE EXPLOSION RELIEF VALVE
OIL DRAIN - NO.24 PORT 1 7/8-12 THD
REAR VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE □—□ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
3606 MARINE PROPULSION
3606MAR


METRIC
3606MAR
FOR REFERENCE ONLY
AIR INLET
CENTERLINE OF CRANKSHAFT
OIL DRAIN - NO24 PORT 1 7/8-12 THD
REAR FACE OF CRANKSHAFT ADAPTER
AIR OUTLET
LIFTING LOCATION 59Ø FOR 50.8 ANCHOR SHACKLE
BREATHER OUTLET FOR 60.3 OD PIPE
WATER OUTLET
FUEL FILTER (1610 REMOVAL DIST)
OIL COOLER
OIL FILTER (1587 REMOVAL DIST)
WATER INLET
REAR FACE OF BLOCK REF
CRANKCASE EXPLOSION RELIEF VALVE
FRONT FACE OF BLOCK REF
LEFT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
1785 [70.28"]
1470 [57.87"]
1378 [54.27"]
801 [31.52"]
841 [33.10"]
467 [18.39"]
456 [17.95"]
16 [0.63"]
74 [2.90"]
260 [10.24"]
730 [28.74"]
1482 [58.36"]
2370 [93.31"]
2773 [109.15"]
2840 [111.81"]
3001 [118.14"]
3360 [132.29"]
3521 [138.61"]
1677 [66.03"]
240 [9.45"]
841 [33.11"]
THE O1—O1 LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
DRAWING - AUTOCAD
INTPR & TOL
M. HUSSONG
S. LEE
P. LAVERY
ENGINE MODEL 3606
01 18JUN97
00 17FEB97
CATERPILLAR INC.
GENERAL ARRANGEMENT
3606 MARINE PROPULSION
3606MAR


METRIC
3606MAR
FOR REFERENCE ONLY
1722 [67.78"]
607 [23.89"]
CENTERLINE OF ENGINE
844 [33.23"]
3521 [138.61"]
EXCESS FUEL RETURN
1 5/16-12 THD 37° FLARE
WATER OUTLET
2773 [109.15"]
2955 [116.34"]
OIL LEVEL GAUGE
LIFTING LOCATION
2370 [93.30"]
OIL FILLER
3988 [157.00"]
1482 [58.35"]
CRANKCASE EXPLOSION RELIEF VALVE
LIFTING LOCATION
AIR OUTLET
730 [28.74"]
BREATHER OUTLET FOR 60.3 OD PIPE
SECONDARY OIL FILTER
TOP VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
16 [0.63"]
456 [17.95"]
FRAONT FACE OF CRANKSHAFT ADAPTER
467 [18.39"]
AIR INLET
382 [15.04"]
160 [6.29"]
THE LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
1E2733 DRAWING - AUTOCAD
1E0001 INTPR & TOL
M. HUSSONG
S. LEE
P. LAVERY
ENGINE MODEL 3606
01 18JUN97
00 17FEB97
CATERPILLAR INC.
GENERAL ARRANGEMENT
3606 MARINE PROPULSION
3606MAR
W861


METRIC
3606 MAR
FOR REFERENCE ONLY
ENGINE MOUNTING HOLES (Ø33)
3 PLACES PER FOOT
CENTERLINE OF ENGINE
LEVELING SCREW LOCATION
1 1/2-12 THD
1 PLACE PER FOOT
REAR FACE CRANKSHAFT ADAPTER
PROFILE OF BOTTOM OF OIL PAN
FLYWHEEL
PLAN VIEW
REAR VIEW
CUSTOMER MTG LOCATION
ROTATED 90°
OIL DRAIN
NOTE A HOLE TO BE BORED OUT TO Ø35mm FOR BODY BOLT
CUSTOMER TO SUPPLY MOUNTING BOLTS
TWO BOLTS REQUIRED PER FOOT FOR INSTALLATION
THE □—□ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
3606 MARINE PROPULSION
ENGINE MODEL 3606



METRIC
3608 MAR
FOR REFERENCE ONLY
FUEL FILTER (1610 REMOVAL DIST.)
OIL COOLER
FUEL FILTER DRAIN (FOR 15.88 ID HOSE)
OIL FILTER (1587 REMOVAL DIST)
OILFILTER DRAIN (FOR 15.88 ID HOSE)
CENTERLINE OF CRANKSHAFT
EXCESS FUEL RETURN 1 5/16-12 THD 37° FLARE
FUEL INLET 1 5/16-12 THD 37° FLARE
OIL DRAIN 1 7/8-12 NO. 24 PORT THD
LIFTING LOCATION - 59 DIA FOR CUSTOMER PROVIDED 50.8 ANCHOR SHACKLE
BREATHER OUTLET FOR 60.3 OD PIPE
LIFTING LOCATION
REAR FACE OF CRANKSHAFT ADAPTER
EXHAUST
AIR INLET
HIGH INERTIA FLYWHEEL
OIL DRAIN 1 7/8-12 NO. 24 PORT THD
OIL LEVEL GAGE
FRONT FACE OF BLOCK REF
OIL FILLER
SECONDARY OIL FILTER
REAR FACE OF BLOCK REF
MOUNTING SURFACE
RIGHT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE ▭-▭ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
OVERALL PACKAGE DIMS.
HEIGTH 1722mm/67.78"
WIDTH 2626mm/103.39"
LENGTH 4808mm/189.28"
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3608 MAR
4341 [170.89"]
3910 [153.94"]
3705 [145.87"]
3190 [125.59"]
1892 [74.50"]
730 [28.74"]
16 [0.63"]
456 [17.94"]
467 [18.40"]
1785 [70.28"]
1470 [57.87"]
1380 [54.33"]
2626 [103.39"]
801 [31.53"]
841 [33.11"]
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1115 [43.90"]
1060 [41.73"]
830 [32.68"]
69 [2.70"]
343 [13.51"]
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797 [31.38"]
841 [33.11"]
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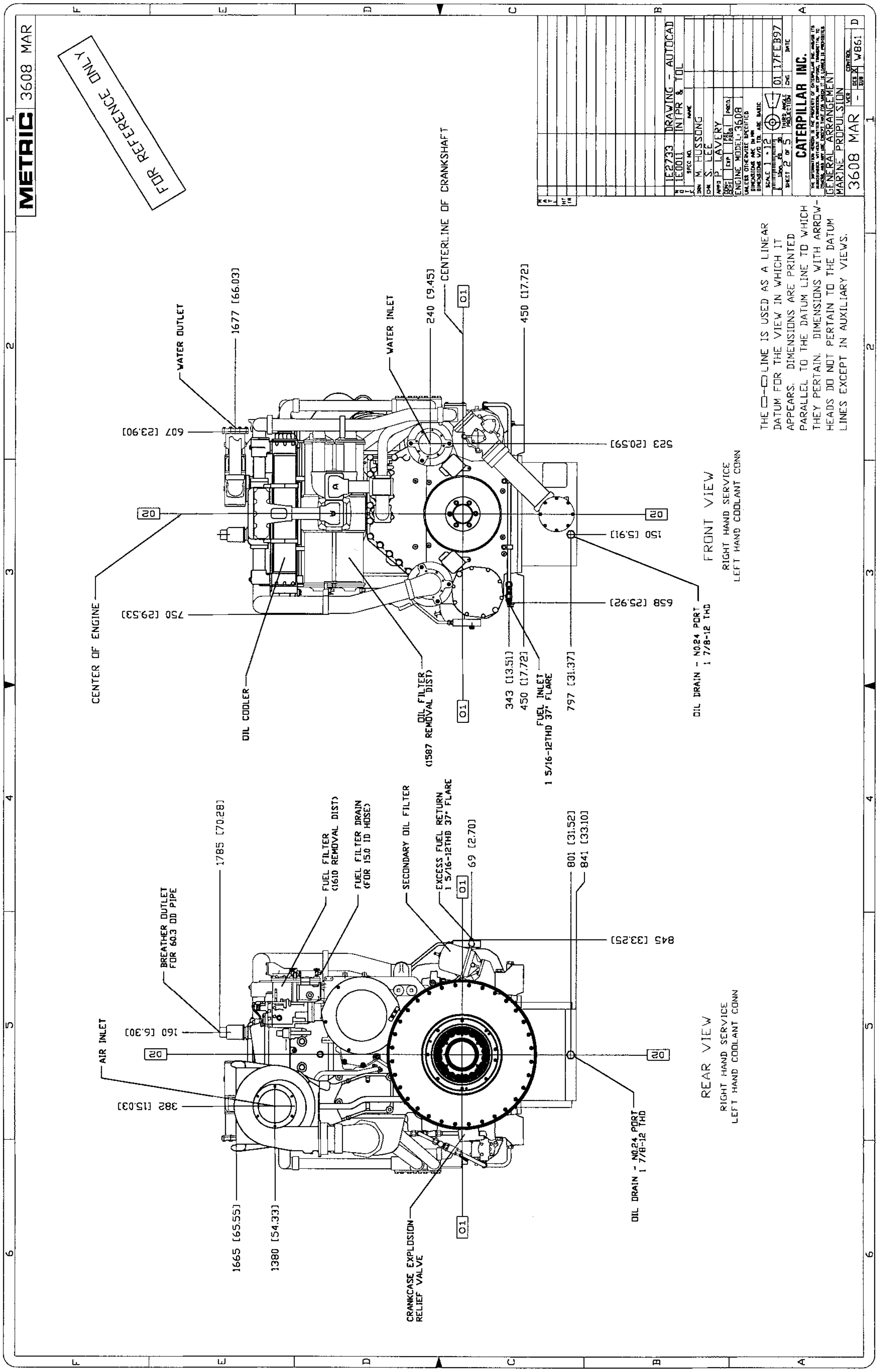
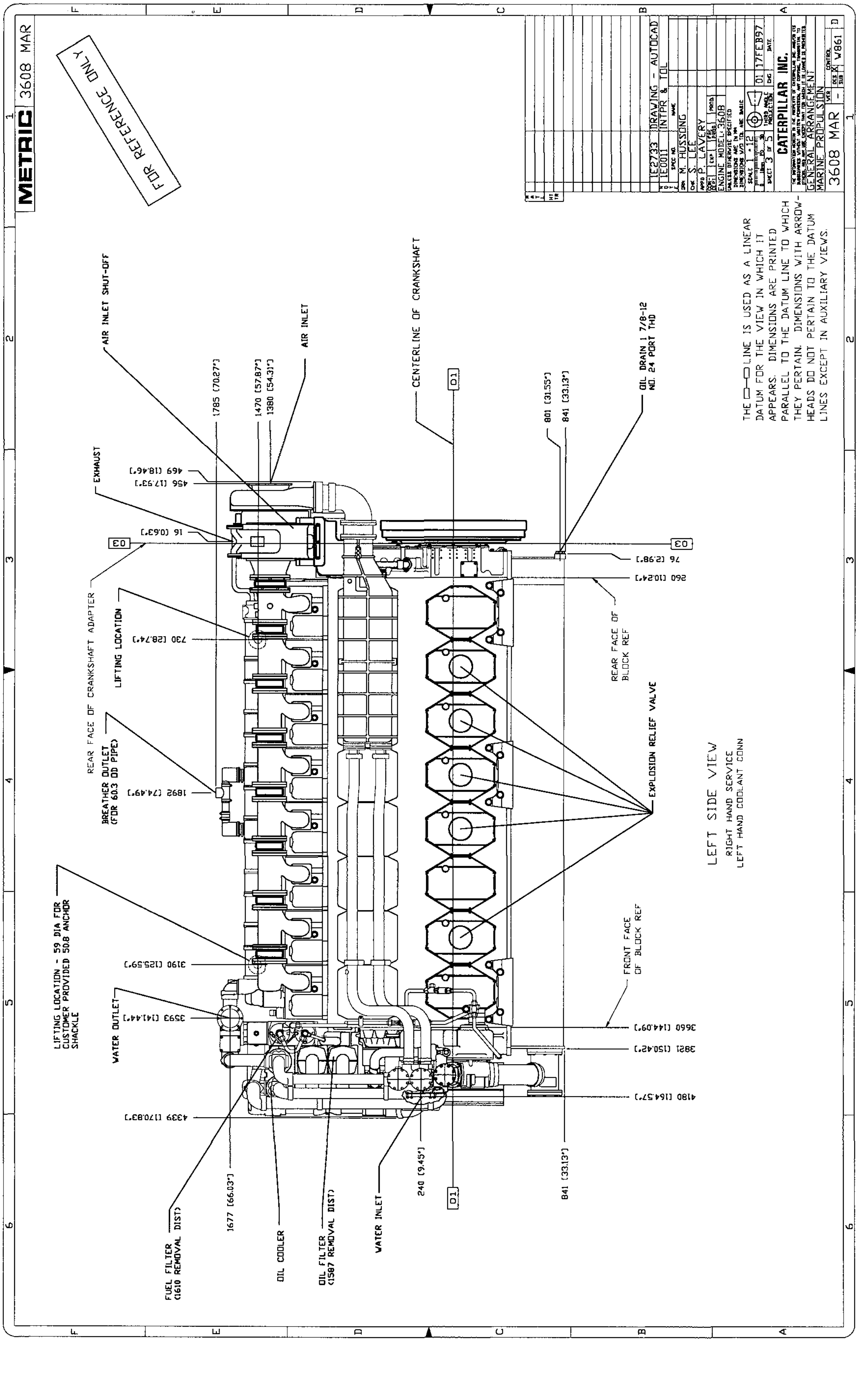
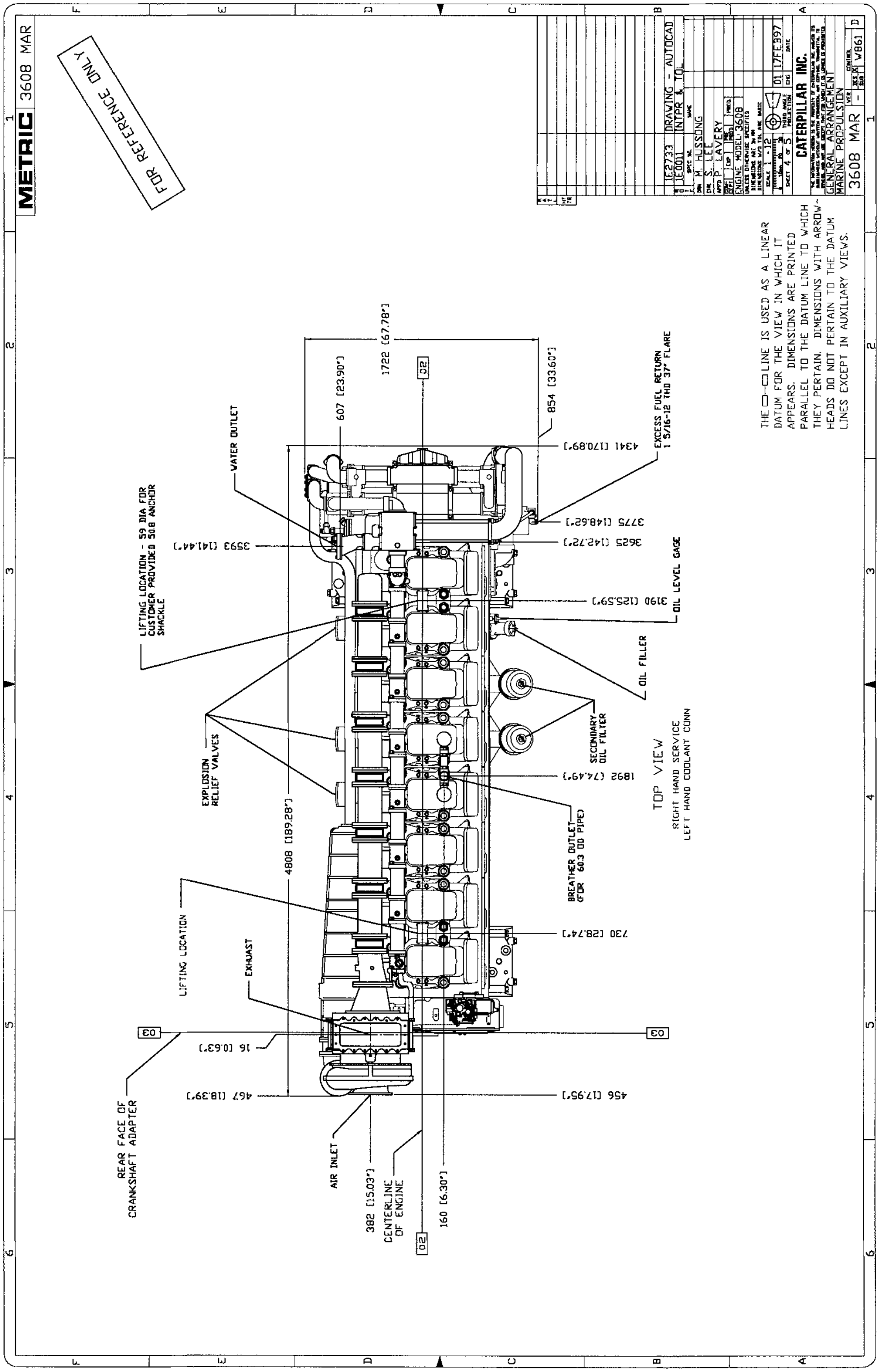
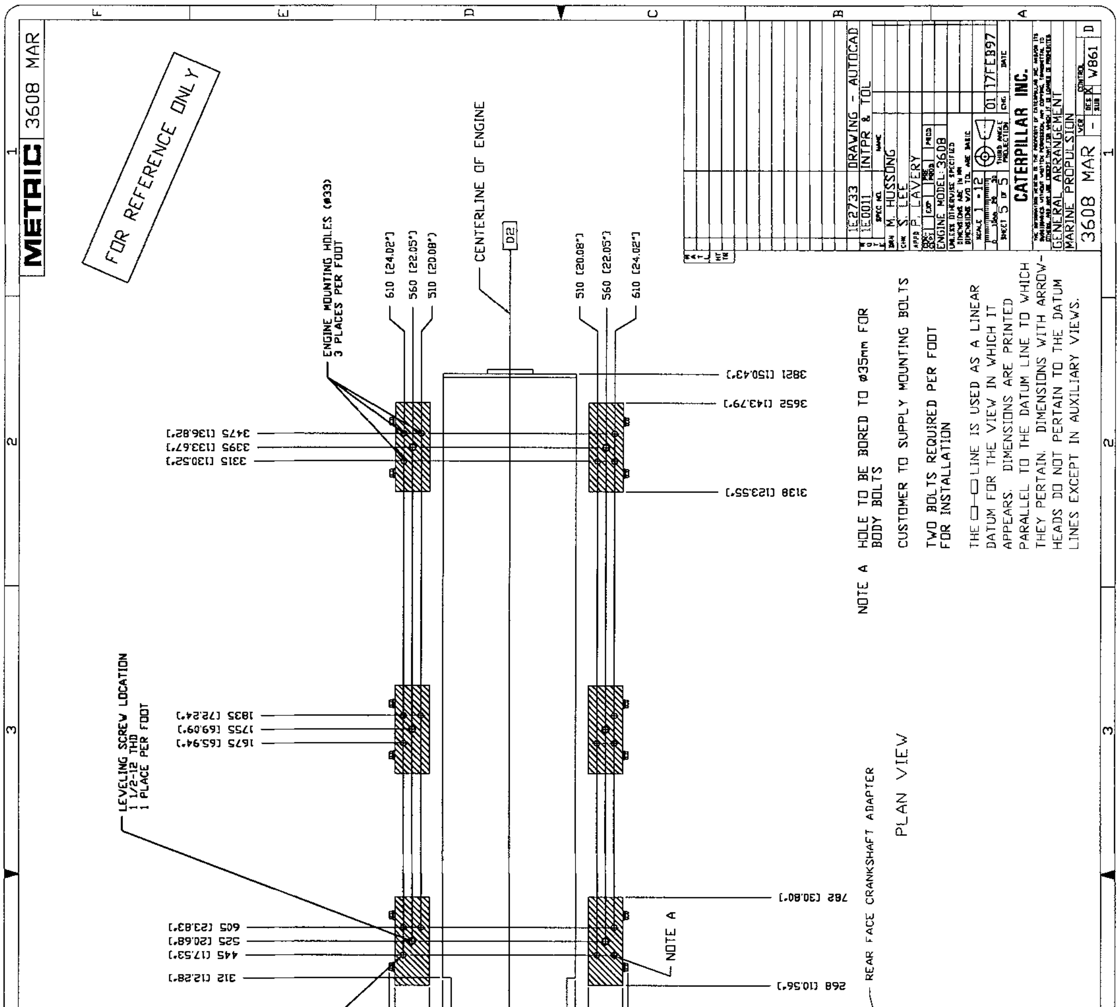
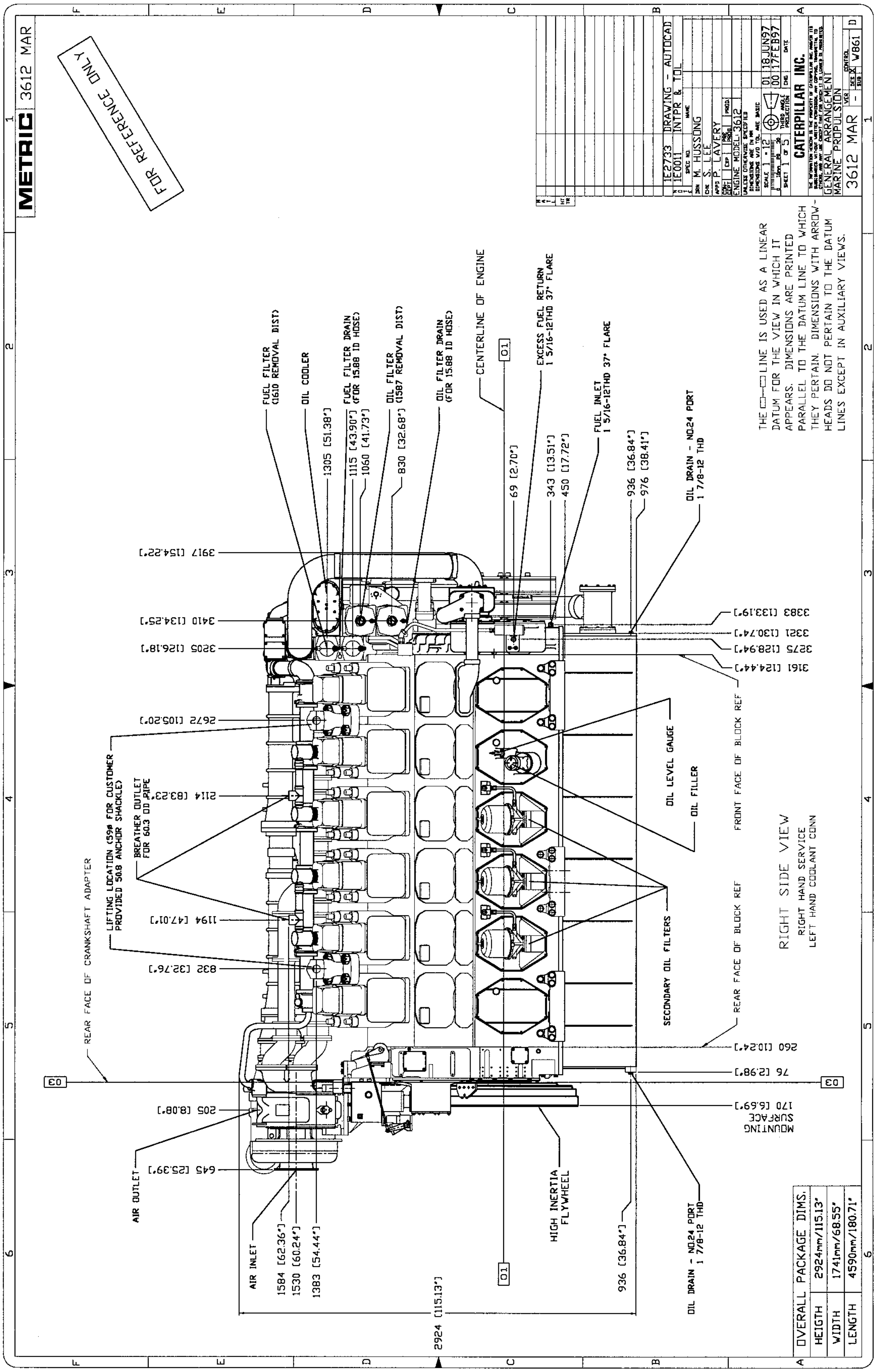
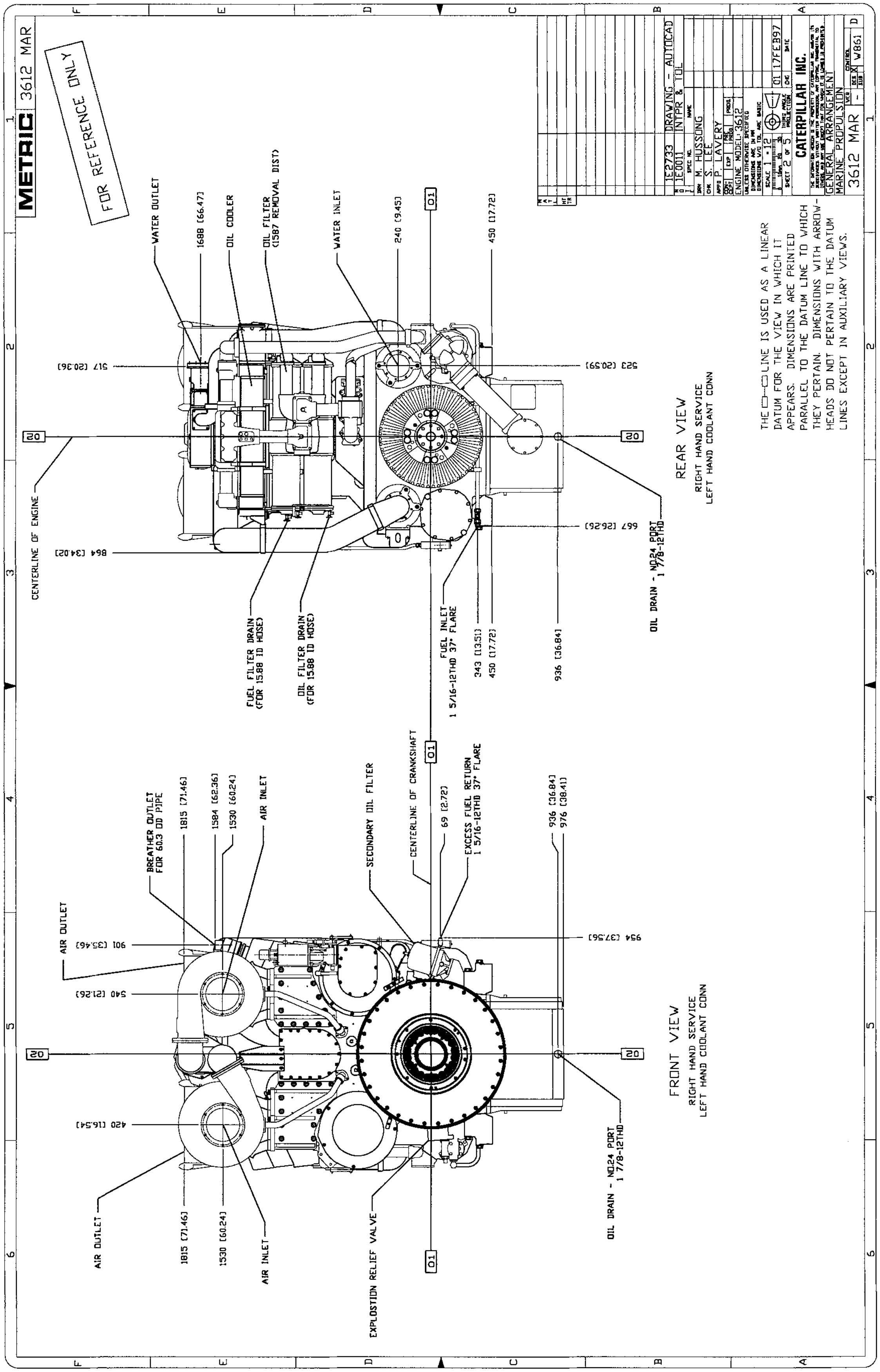

METRIC
3608 MAR
FOR REFERENCE ONLY
FRONT VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
REAR VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
CENTERLINE OF CRANKSHAFT
WATER OUTLET
WATER INLET
CENTER OF ENGINE
OIL COOLER
OIL FILTER (1587 REMOVAL DIST)
FUEL INLET 1 5/16-12THD 37° FLARE
OIL DRAIN - NO24 PORT 1 7/8-12 THD
AIR INLET
BREATHER OUTLET FOR 60.3 OD PIPE
FUEL FILTER (1610 REMOVAL DIST)
FUEL FILTER DRAIN (FOR 15.0 ID HOSE)
SECONDARY OIL FILTER
EXCESS FUEL RETURN 1 5/16-12THD 37° FLARE
CRANKCASE EXPLOSION RELIEF VALVE
1677 [66.03]
607 [23.90]
240 [9.45]
450 [17.72]
523 [20.59]
150 [5.91]
658 [25.92]
750 [29.53]
343 [13.51]
797 [31.37]
1785 [70.28]
160 [6.30]
382 [15.03]
69 [2.70]
845 [33.25]
801 [31.52]
841 [33.10]
1665 [65.55]
1380 [54.33]
THE □-□ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3608 MAR
ENGINE MODEL: 3608
DRAWING - AUTOCAD
01 17FEB97


METRIC
3608 MAR
FOR REFERENCE ONLY
AIR INLET SHUT-OFF
AIR INLET
CENTERLINE OF CRANKSHAFT
OIL DRAIN 1 7/8-12
NO. 24 PORT THD
EXHAUST
REAR FACE OF CRANKSHAFT ADAPTER
LIFTING LOCATION
BREATHER OUTLET
(FOR 60.3 OD PIPE)
REAR FACE OF
BLOCK REF
EXPLOSION RELIEF VALVE
LIFTING LOCATION - 59 DIA FOR
CUSTOMER PROVIDED 50.8 ANCHOR
SHACKLE
WATER OUTLET
FRONT FACE
OF BLOCK REF
FUEL FILTER
(1610 REMOVAL DIST)
OIL COOLER
OIL FILTER
(1587 REMOVAL DIST)
WATER INLET
LEFT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3608 MAR
W861
1785 [70.27"]
1470 [57.87"]
1380 [54.31"]
469 [18.46"]
456 [17.93"]
16 [0.63"]
730 [28.74"]
1892 [74.49"]
3190 [125.59"]
3593 [141.44"]
4339 [170.83"]
1677 [66.03"]
240 [9.45"]
841 [33.13"]
801 [31.55"]
76 [2.98"]
260 [10.24"]
3660 [144.09"]
3821 [150.42"]
4180 [164.57"]
D1
D3

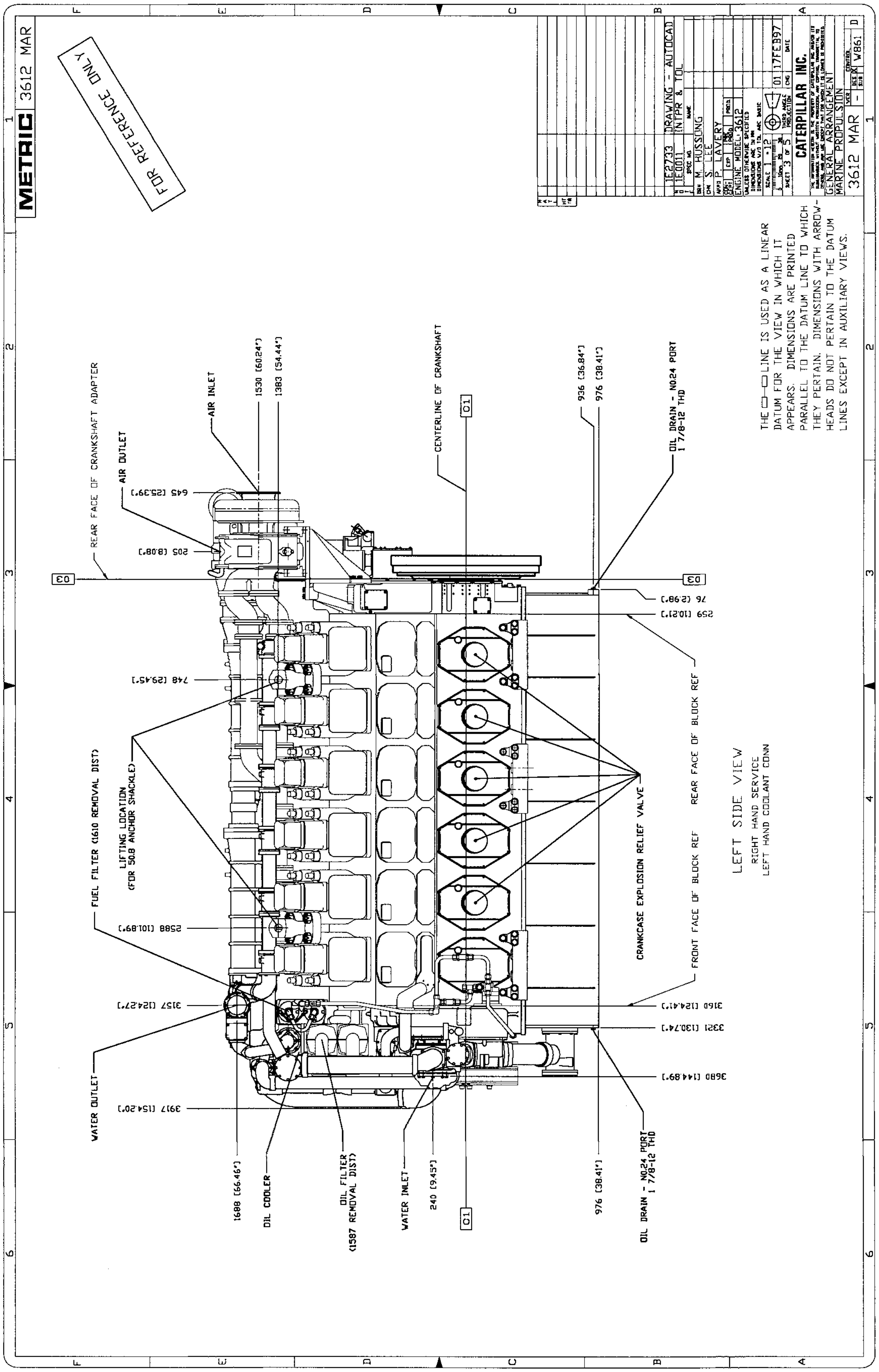

METRIC
3608 MAR
FOR REFERENCE ONLY
TOP VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
WATER OUTLET
607 [23.90"]
1722 [67.78"]
854 [33.60"]
EXCESS FUEL RETURN
1 5/16-12 THD 37° FLARE
4341 [170.89"]
3775 [148.62"]
3625 [142.72"]
3593 [141.44"]
LIFTING LOCATION - 59 DIA FOR
CUSTOMER PROVIDED 508 ANCHOR
SHACKLE
3190 [125.59"]
OIL LEVEL GAGE
OIL FILLER
SECONDARY
OIL FILTER
EXPLOSION
RELIEF VALVES
1892 [74.49"]
BREATHER OUTLET
(FOR 60.3 OD PIPE)
4808 [189.28"]
LIFTING LOCATION
EXHAUST
730 [28.74"]
16 [0.63"]
467 [18.39"]
456 [17.95"]
REAR FACE OF
CRANKSHAFT ADAPTER
AIR INLET
382 [15.03"]
CENTERLINE
OF ENGINE
160 [6.30"]
D2
D3
THE □—□ LINE IS USED AS A LINEAR
DATUM FOR THE VIEW IN WHICH IT
APPEARS. DIMENSIONS ARE PRINTED
PARALLEL TO THE DATUM LINE TO WHICH
THEY PERTAIN. DIMENSIONS WITH ARROW-
HEADS DO NOT PERTAIN TO THE DATUM
LINES EXCEPT IN AUXILIARY VIEWS.
DRAWING - AUTOCAD
ENGINE MODEL: 3608
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3608 MAR
W861

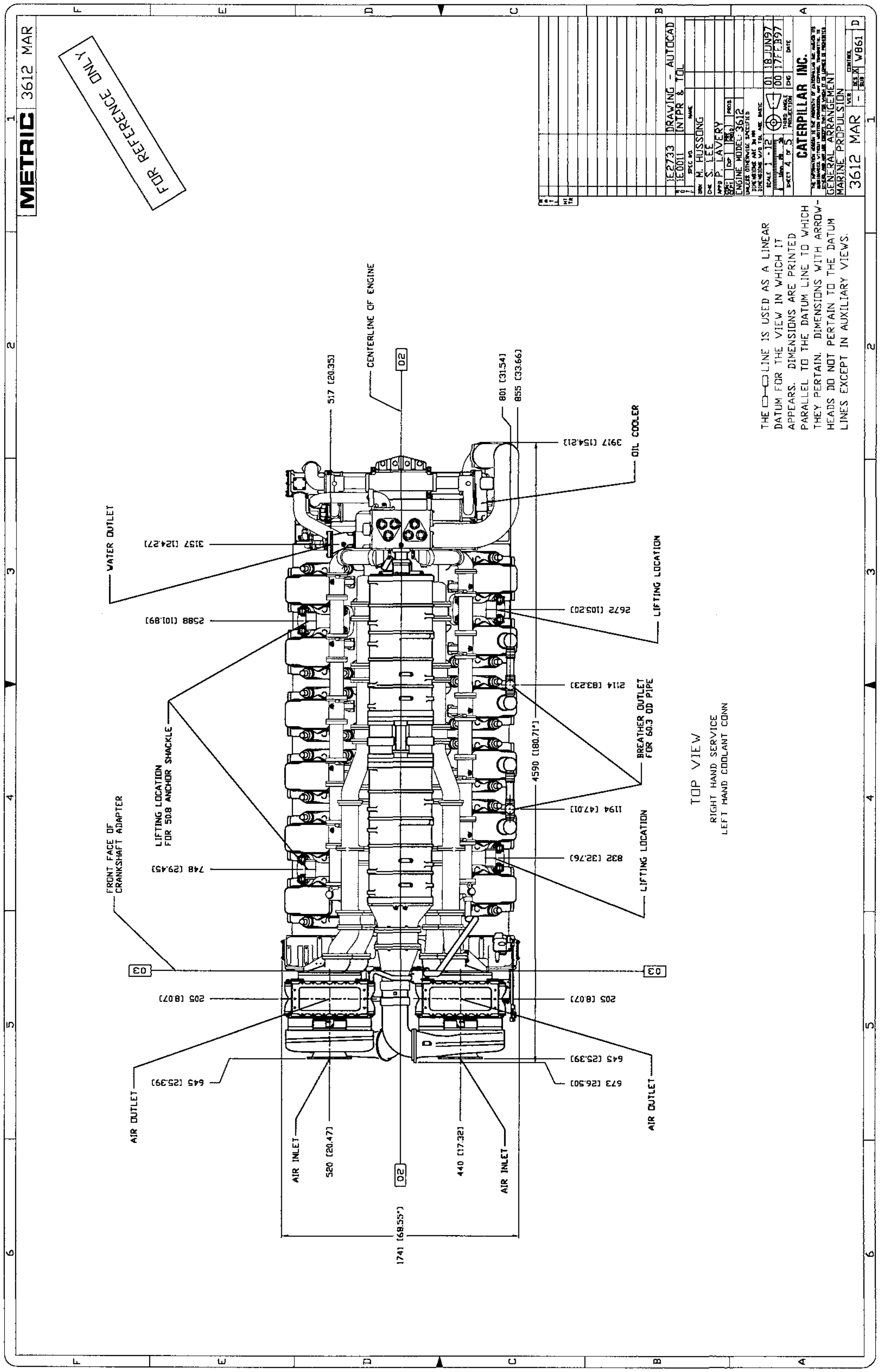

METRIC
3608 MAR
FOR REFERENCE ONLY
ENGINE MOUNTING HOLES (ø33)
3 PLACES PER FOOT
CENTERLINE OF ENGINE
LEVELING SCREW LOCATION
1 1/2-12 THD
1 PLACE PER FOOT
CENTERLINE OF CRANKSHAFT
NOTE A
PROFILE BOTTOM OF OIL PAN
FLYWHEEL
REAR FACE CRANKSHAFT ADAPTER
PLAN VIEW
REAR VIEW
CUSTOMER MTG LOCATION
ROTATED 90°
OIL DRAIN 1 7/8-12 NO. 24 PORT THD
NOTE A HOLE TO BE BORED TO ø35mm FOR BODY BOLTS
CUSTOMER TO SUPPLY MOUNTING BOLTS
TWO BOLTS REQUIRED PER FOOT FOR INSTALLATION
THE ▭—▭ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN IN AUXILIARY VIEWS EXCEPT IN AUXILIARY VIEWS.
DRAWING - AUTOCAD
ENGINE MODEL 3608
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3608 MAR
17FEB97

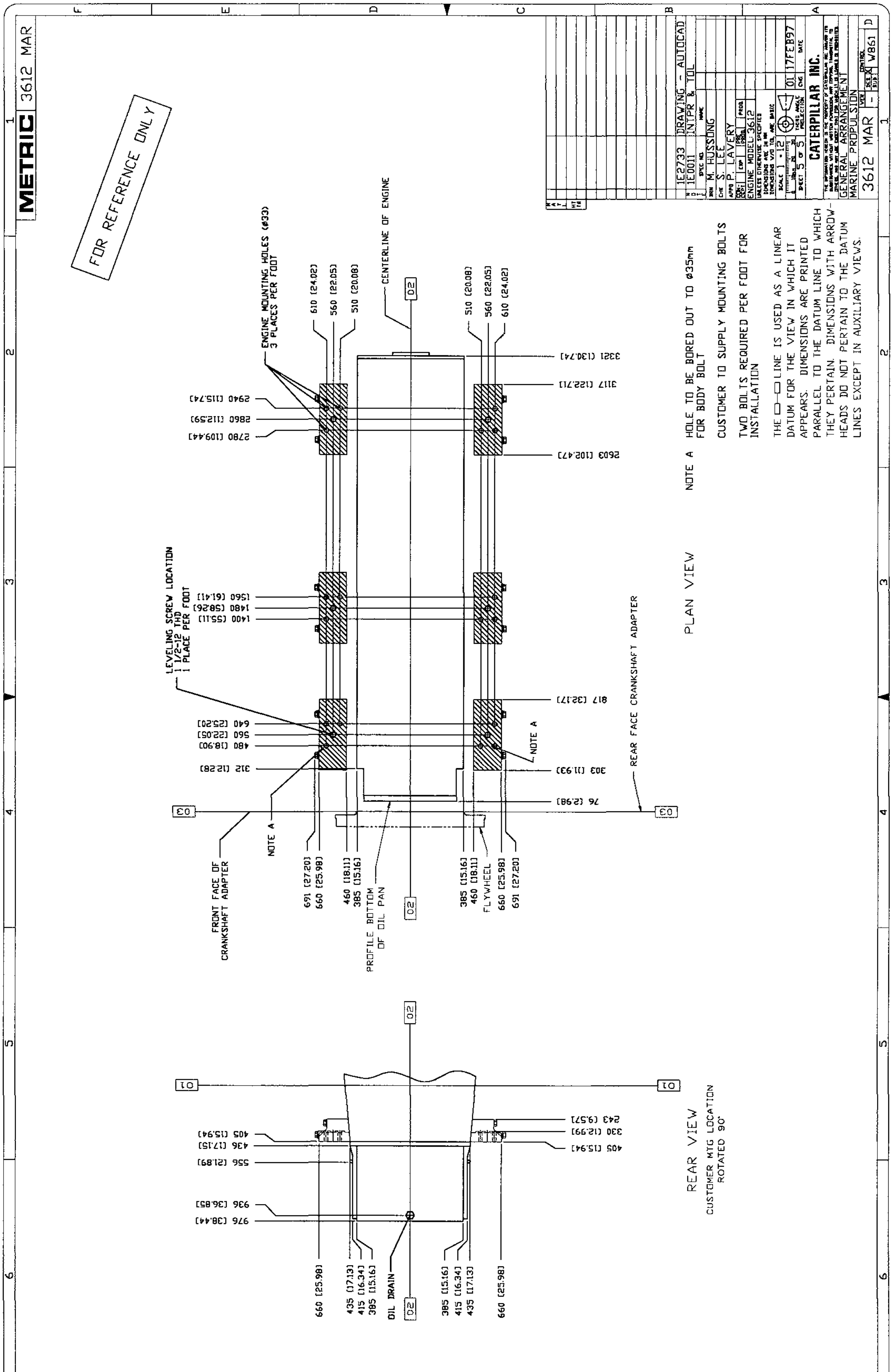

METRIC
3612 MAR
FOR REFERENCE ONLY
RIGHT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
FUEL FILTER (1610 REMOVAL DIST)
OIL COOLER
FUEL FILTER DRAIN (FOR 15.88 ID HOSE)
OIL FILTER (1587 REMOVAL DIST)
OIL FILTER DRAIN (FOR 15.88 ID HOSE)
CENTERLINE OF ENGINE
EXCESS FUEL RETURN 1 5/16-12THD 37° FLARE
FUEL INLET 1 5/16-12THD 37° FLARE
OIL DRAIN - NO.24 PORT 1 7/8-12 THD
OIL LEVEL GAUGE
OIL FILLER
SECONDARY OIL FILTERS
FRONT FACE OF BLOCK REF
REAR FACE OF BLOCK REF
REAR FACE OF CRANKSHAFT ADAPTER
LIFTING LOCATION (59# FOR CUSTOMER PROVIDED 50.8 ANCHOR SHACKLE)
BREATHER OUTLET FOR 60.3 OD PIPE
AIR OUTLET
AIR INLET
HIGH INERTIA FLYWHEEL
MOUNTING SURFACE
1305 [51.38"]
1115 [43.90"]
1060 [41.73"]
830 [32.68"]
69 [2.70"]
343 [13.51"]
450 [17.72"]
936 [36.84"]
976 [38.41"]
3917 [154.22"]
3410 [134.25"]
3205 [126.18"]
2672 [105.20"]
2114 [83.23"]
1194 [47.01"]
832 [32.76"]
205 [8.08"]
645 [25.39"]
3383 [133.19"]
3321 [130.74"]
3275 [128.94"]
3161 [124.44"]
260 [10.24"]
76 [2.98"]
170 [6.69"]
1584 [62.36"]
1530 [60.24"]
1383 [54.44"]
2924 [115.13"]
THE □—□ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
OVERALL PACKAGE DIMS.
HEIGTH 2924mm/115.13"
WIDTH 1741mm/68.55"
LENGTH 4590mm/180.71"
1E2733 DRAWING - AUTOCAD
1E0011 INTPR & TOL
DRN M. HUSSONG
CHK S. LEE
APPD P. LAVERY
ENGINE MODEL: 3612
SCALE 1 = 12
SHEET 1 OF 5
01 18JUN97
00 17FEB97
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3612 MAR
V861

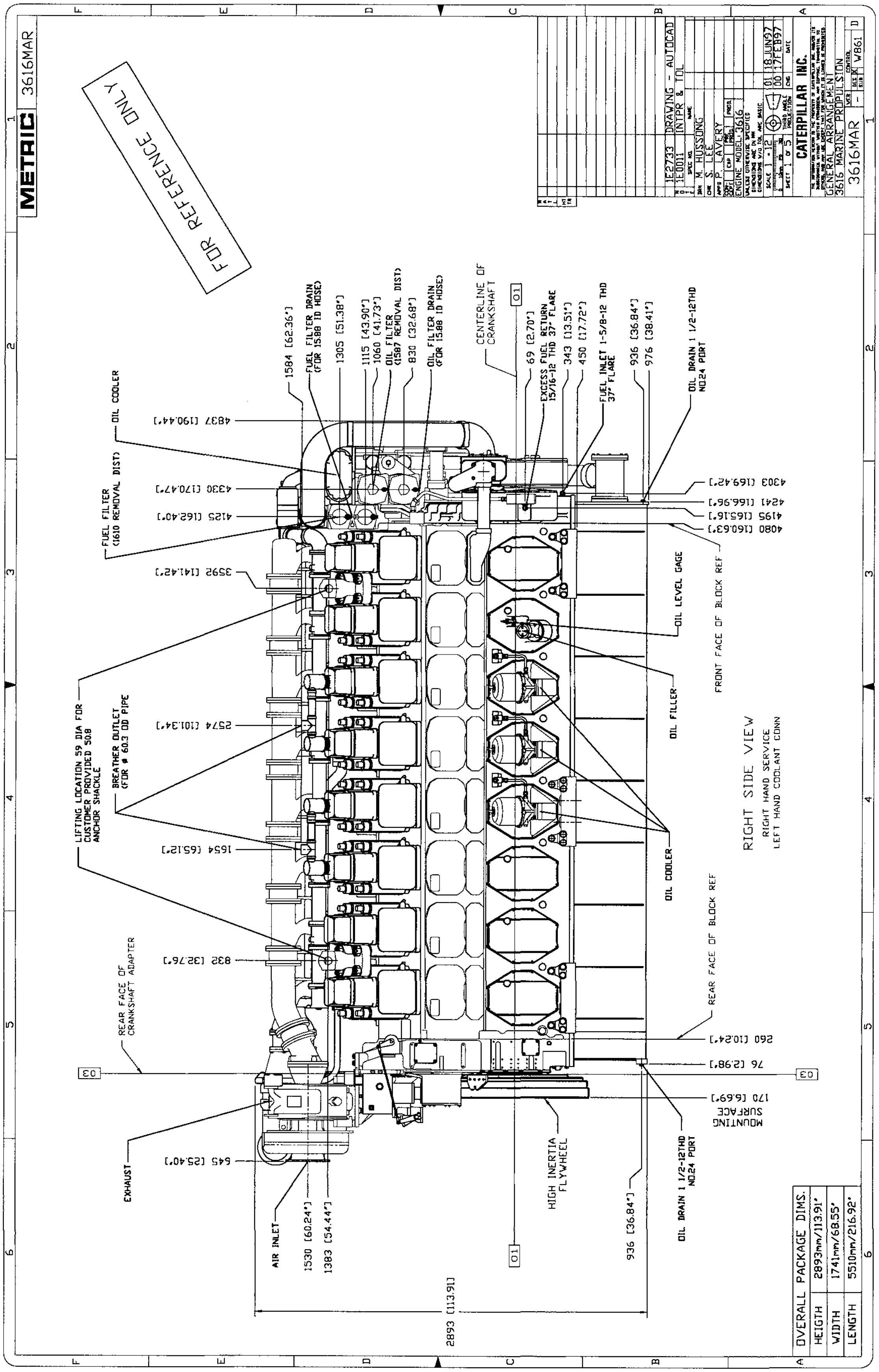


METRIC 3612 MAR
FOR REFERENCE ONLY
WATER OUTLET
OIL COOLER
OIL FILTER (1587 REMOVAL DIST)
WATER INLET
CENTERLINE OF ENGINE
FUEL FILTER DRAIN (FOR 15.88 ID HOSE)
OIL FILTER DRAIN (FOR 15.88 ID HOSE)
FUEL INLET 1 5/16-12THD 37° FLARE
OIL DRAIN - NO24 PORT 1 7/8-12THD
REAR VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
AIR OUTLET
BREATHER OUTLET FOR 60.3 OD PIPE
AIR INLET
SECONDARY OIL FILTER
CENTERLINE OF CRANKSHAFT
EXCESS FUEL RETURN 1 5/16-12THD 37° FLARE
EXPLOSION RELIEF VALVE
FRONT VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE □-□ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3612 MAR


METRIC 3612 MAR
FOR REFERENCE ONLY
REAR FACE OF CRANKSHAFT ADAPTER
AIR OUTLET
AIR INLET
1530 [60.24"]
1383 [54.44"]
645 [25.39"]
205 [8.08"]
CENTERLINE OF CRANKSHAFT
936 [36.84"]
976 [38.41"]
OIL DRAIN - NO.24 PORT 1 7/8-12 THD
76 [2.98"]
259 [10.21"]
748 [29.45"]
FUEL FILTER (1610 REMOVAL DIST)
LIFTING LOCATION (FOR 50.8 ANCHOR SHACKLE)
REAR FACE OF BLOCK REF
CRANKCASE EXPLOSION RELIEF VALVE
FRONT FACE OF BLOCK REF
2588 [101.89"]
3157 [124.27"]
3160 [124.41"]
3321 [130.74"]
3680 [144.89"]
WATER OUTLET
3917 [154.20"]
1688 [66.46"]
OIL COOLER
OIL FILTER (1587 REMOVAL DIST)
WATER INLET
240 [9.45"]
LEFT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE ▭—▭ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
1E2733 DRAWING - AUTOCAD
1E0011 INTPR & TOL
M. HUSSUNG
S. LEE
P. LAVERY
ENGINE MODEL 3612
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3612 MAR
17FEB97
W861


METRIC 3612 MAR
FOR REFERENCE ONLY
CENTERLINE OF ENGINE
517 [20.35]
801 [31.54]
855 [33.66]
3917 [154.21]
OIL COOLER
WATER OUTLET
3157 [124.27]
2588 [101.89]
2672 [105.20]
LIFTING LOCATION
2114 [83.23]
BREATHER OUTLET FOR 60.3 OD PIPE
4590 [180.71*]
LIFTING LOCATION FOR 50.8 ANCHOR SHACKLE
1194 [47.01]
FRONT FACE OF CRANKSHAFT ADAPTER
748 [29.45]
832 [32.76]
LIFTING LOCATION
205 [8.07]
645 [25.39]
673 [26.50]
AIR OUTLET
AIR INLET
520 [20.47]
440 [17.32]
1741 [68.55*]
TOP VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE ▭—▭ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
DRAWING - AUTOCAD
M. HUSSONG
S. LEE
P. LAVERY
ENGINE MODEL 3612
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3612 MAR


METRIC
3612 MAR
FOR REFERENCE ONLY
ENGINE MOUNTING HOLES (⌀33) 3 PLACES PER FOOT
CENTERLINE OF ENGINE
LEVELING SCREW LOCATION 1 1/2-12 THD 1 PLACE PER FOOT
FRONT FACE OF CRANKSHAFT ADAPTER
REAR FACE CRANKSHAFT ADAPTER
PROFILE BOTTOM OF OIL PAN
FLYWHEEL
NOTE A
PLAN VIEW
REAR VIEW
CUSTOMER MTG LOCATION ROTATED 90°
OIL DRAIN
NOTE A HOLE TO BE BORED OUT TO ⌀35mm FOR BODY BOLT
CUSTOMER TO SUPPLY MOUNTING BOLTS
TWO BOLTS REQUIRED PER FOOT FOR INSTALLATION
THE LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3612 MAR


METRIC
3616MAR
FOR REFERENCE ONLY
RIGHT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
OIL COOLER
FUEL FILTER (1610 REMOVAL DIST)
LIFTING LOCATION 59 DIA FOR CUSTOMER PROVIDED 50.8 ANCHOR SHACKLE
BREATHER OUTLET (FOR ø 60.3 OD PIPE
REAR FACE OF CRANKSHAFT ADAPTER
EXHAUST
AIR INLET
HIGH INERTIA FLYWHEEL
OIL DRAIN 1 1/2-12THD NO.24 PORT
MOUNTING SURFACE
REAR FACE OF BLOCK REF
FRONT FACE OF BLOCK REF
OIL LEVEL GAGE
OIL FILLER
CENTERLINE OF CRANKSHAFT
FUEL FILTER DRAIN (FOR 15.88 ID HOSE)
OIL FILTER (1587 REMOVAL DIST)
OIL FILTER DRAIN (FOR 15.88 ID HOSE)
EXCESS FUEL RETURN 15/16-12 THD 37° FLARE
FUEL INLET 1-5/8-12 THD 37° FLARE
4837 [190.44"]
4330 [170.47"]
4125 [162.40"]
3592 [141.42"]
2574 [101.34"]
1654 [65.12"]
832 [32.76"]
645 [25.40"]
1584 [62.36"]
1305 [51.38"]
1115 [43.90"]
1060 [41.73"]
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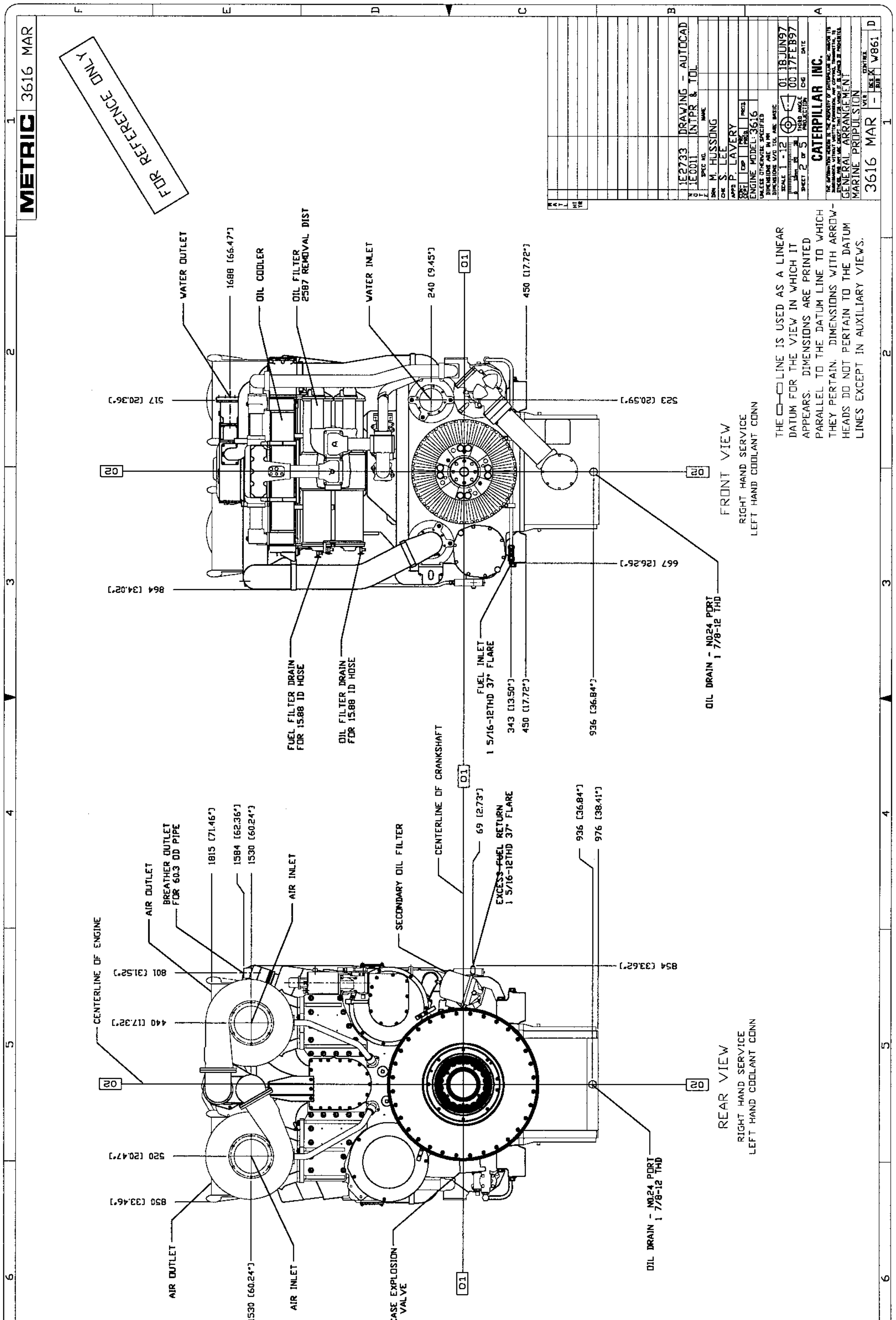
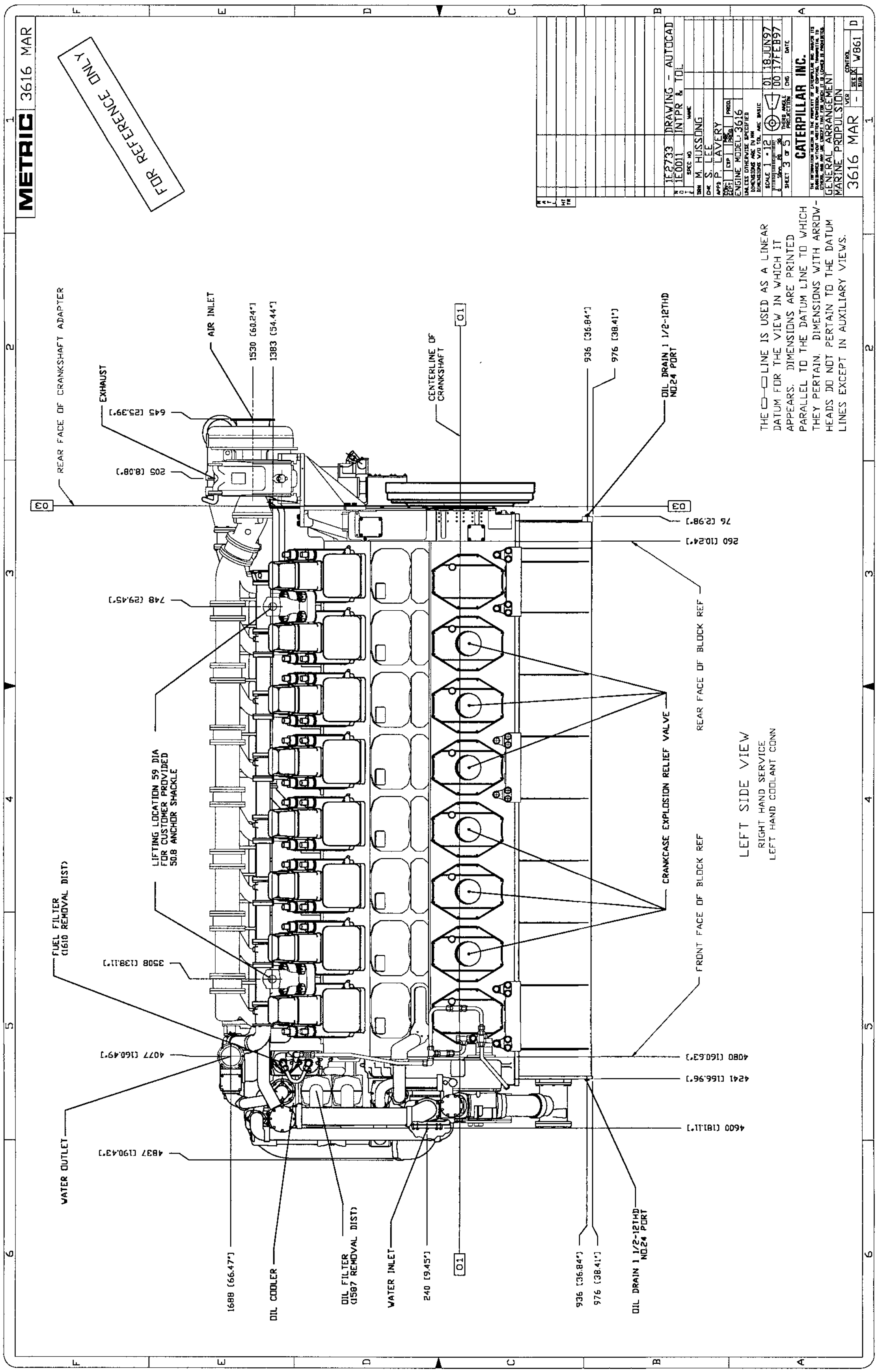
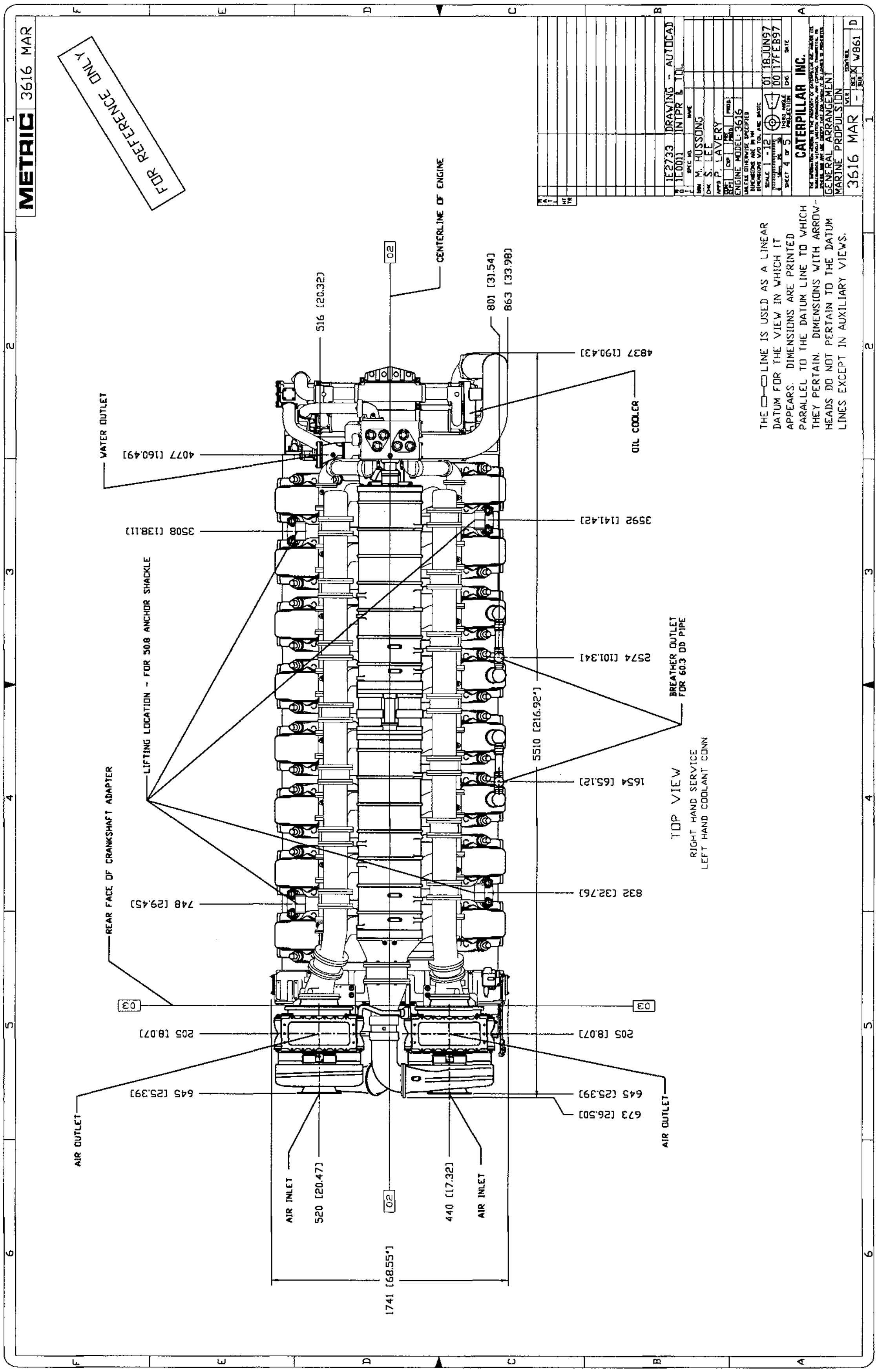
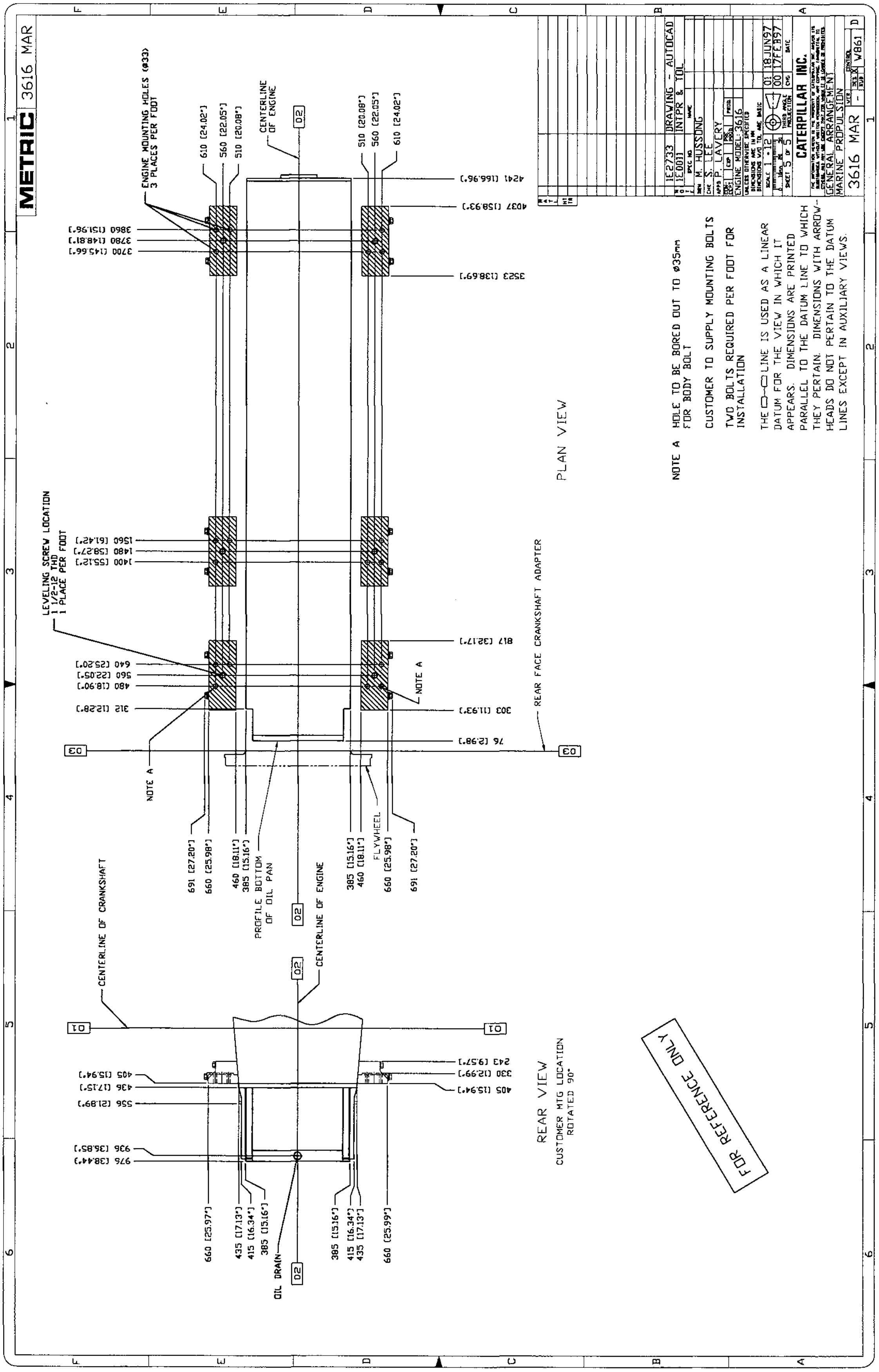
69 [2.70"]
343 [13.51"]
450 [17.72"]
936 [36.84"]
976 [38.41"]
4303 [169.42"]
4241 [166.96"]
4195 [165.16"]
4080 [160.63"]
260 [10.24"]
76 [2.98"]
170 [6.69"]
1530 [60.24"]
1383 [54.44"]
2893 [113.91]
OVERALL PACKAGE DIMS.
HEIGTH 2893mm/113.91"
WIDTH 1741mm/68.55"
LENGTH 5510mm/216.92"
CATERPILLAR INC.
GENERAL ARRANGEMENT
3616 MARINE PROPULSION
ENGINE MODEL 3616


METRIC
3616 MAR
FOR REFERENCE ONLY
WATER OUTLET
1688 [66.47"]
OIL COOLER
OIL FILTER
2587 REMOVAL DIST
WATER INLET
240 [9.45"]
450 [17.72"]
517 [20.36"]
523 [20.59"]
864 [34.02"]
667 [26.25"]
FUEL FILTER DRAIN
FOR 15.88 ID HOSE
OIL FILTER DRAIN
FOR 15.88 ID HOSE
FUEL INLET
1 5/16-12THD 37° FLARE
343 [13.50"]
450 [17.72"]
936 [36.84"]
OIL DRAIN - NO24 PORT
1 7/8-12 THD
FRONT VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
CENTERLINE OF CRANKSHAFT
69 [2.73"]
EXCESS FUEL RETURN
1 5/16-12THD 37° FLARE
936 [36.84"]
976 [38.41"]
SECONDARY OIL FILTER
AIR OUTLET
BREATHER OUTLET
FOR 60.3 OD PIPE
1815 [71.46"]
1584 [62.36"]
1530 [60.24"]
AIR INLET
CENTERLINE OF ENGINE
801 [31.52"]
440 [17.32"]
854 [33.62"]
520 [20.47"]
850 [33.46"]
AIR OUTLET
1530 [60.24"]
AIR INLET
CRANKCASE EXPLOSION
RELIEF VALVE
OIL DRAIN - NO24 PORT
1 7/8-12 THD
REAR VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE ▭—▭ LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
1E2733 DRAWING - AUTOCAD
1E0011 INTPR & TOL
M. HUSSONG
S. LEE
P. LAVERY
ENGINE MODEL 3616
01 18JUN97
00 17FEB97
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3616 MAR
W861



METRIC
3616 MAR
FOR REFERENCE ONLY
REAR FACE OF CRANKSHAFT ADAPTER
EXHAUST
AIR INLET
1530 [60.24"]
1383 [54.44"]
645 [25.39"]
205 [8.08"]
CENTERLINE OF CRANKSHAFT
936 [36.84"]
976 [38.41"]
OIL DRAIN 1 1/2-12THD NO.24 PORT
76 [2.98"]
260 [10.24"]
748 [29.45"]
REAR FACE OF BLOCK REF
LIFTING LOCATION 59 DIA FOR CUSTOMER PROVIDED 50.8 ANCHOR SHACKLE
CRANKCASE EXPLOSION RELIEF VALVE
LEFT SIDE VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
FUEL FILTER (1610 REMOVAL DIST)
3508 [138.11"]
FRONT FACE OF BLOCK REF
4077 [160.49"]
4080 [160.63"]
4241 [166.96"]
4600 [181.11"]
4837 [190.43"]
WATER OUTLET
1688 [66.47"]
OIL COOLER
OIL FILTER (1587 REMOVAL DIST)
WATER INLET
240 [9.45"]
THE LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROW-HEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3616 MAR


METRIC
3616 MAR
FOR REFERENCE ONLY
CENTERLINE OF ENGINE
WATER OUTLET
OIL COOLER
LIFTING LOCATION - FOR 50.8 ANCHOR SHACKLE
REAR FACE OF CRANKSHAFT ADAPTER
BREATHER OUTLET FOR 60.3 OD PIPE
AIR OUTLET
AIR INLET
516 [20.32]
801 [31.54]
863 [33.98]
4837 [190.43]
4077 [160.49]
3508 [138.11]
3592 [141.42]
2574 [101.34]
5510 [216.92"]
1654 [65.12]
832 [32.76]
748 [29.45]
205 [8.07]
645 [25.39]
673 [26.50]
520 [20.47]
440 [17.32]
1741 [68.55"]
TOP VIEW
RIGHT HAND SERVICE
LEFT HAND COOLANT CONN
THE LINE IS USED AS A LINEAR DATUM FOR THE VIEW IN WHICH IT APPEARS. DIMENSIONS ARE PRINTED PARALLEL TO THE DATUM LINE TO WHICH THEY PERTAIN. DIMENSIONS WITH ARROWHEADS DO NOT PERTAIN TO THE DATUM LINES EXCEPT IN AUXILIARY VIEWS.
CATERPILLAR INC.
GENERAL ARRANGEMENT
MARINE PROPULSION
3616 MAR


METRIC
3616 MAR
ENGINE MOUNTING HOLES (Ø33) 3 PLACES PER FOOT
LEVELING SCREW LOCATION 1 1/2-12 THD 1 PLACE PER FOOT
CENTERLINE OF ENGINE
CENTERLINE OF CRANKSHAFT
PROFILE BOTTOM OF OIL PAN
FLYWHEEL
REAR FACE CRANKSHAFT ADAPTER
OIL DRAIN
PLAN VIEW
REAR VIEW
CUSTOMER MTG LOCATION ROTATED 90°
NOTE A HOLE TO BE BORED OUT TO Ø35mm FOR BODY BOLT
CUSTOMER TO SUPPLY MOUNTING BOLTS
TWO BOLTS REQUIRED PER FOOT FOR INSTALLATION
CATERPILLAR INC.
GENERAL ARRANGEMENT MARINE PROPULSION
FOR REFERENCE ONLY

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

● Ancillary Equipment

LEKM8470 8-98

CATERPILLAR®

Ancillary Equipment

- Marine Gears
- Couplings
  - Torsional Limits
- Propellers
  - Fixed Pitch
  - Controllable Pitch

Marine Gears

Reversing marine gears are used:

- To match relatively small, economical medium speed engines to the low propeller rpm necessary for high efficiency.
- To reverse the propeller rotation for the non-reversing 3600 Family of Engines.

Marine gears are selected to transmit rated engine horsepower (plus overload if required) at rated rpm. Design the gear to meet appropriate classification society rules. Inspection and Certification may be required. Advise the gear manufacturer of expected adverse conditions, such as operation in ice.

Main engine marine gears are normally single or double reduction, with the ratio of input and output speeds selected to meet the propeller design rpm. The gears are either uni-directional or reverse reduction depending on the type of propeller selected (either fixed or controllable pitch).

Pinion and bull gear bearings are either sleeve or antifriction. The thrust bearing is normally built into the gear casing and sized to take the reactive thrust of the propeller.

Clutches are normally pneumatic or hydraulically actuated, straight engagement, or slip type. Ahead and astern clutches are required if a reversing gear is used.

The gear box lubrication and cooling oil system is normally self-contained and fitted on the gearbox assembly. It is also used for hydraulic clutch actuation.

The marine gear is mounted to a rugged fabricated steel foundation securely welded to the ship's structure; refer to the Mounting and Alignment section of this guide. The gearbox is bolted to its foundation using either steel or epoxy resin chocks to ensure alignment between the shafting, gearbox, and main engines. Collision chocks are normally fitted at the corners of the gearbox mounting flange to maintain alignment in the event of an accident.

Care should be taken in selecting the capacity of the low speed output bearing. It must be capable of carrying loads imposed by the line shaft or tail shaft directly connected to the low speed coupling. Advise the gear manufacturer if a propeller blade actuating box is to be mounted on the gearbox, or if auxiliary equipment is to be driven from power takeoffs on the gear housing.

Carefully review the final arrangement of the gearbox in the engine room for the best overall installation. Space must be available for service and maintenance. The following are examples of typical arrangements used with the 3600 Family of Engines:

- Single input/single output, horizontal offset, reversing. See Figure 1.
- Single input/single output, vertical offset, reversing. See Figure 2.
- Single input/single output, concentric, reversing. See Figure 3.
- Twin input/single output, horizontal-vertical offset, non-reversing. See Figure 4.
- Twin input/single output, horizontal offset, non-reversing. See Figure 5.

The Torsional and System Stability Analysis section within *General Information* in this guide describes the required torsional analysis. The marine gear manufacturer must provide data.

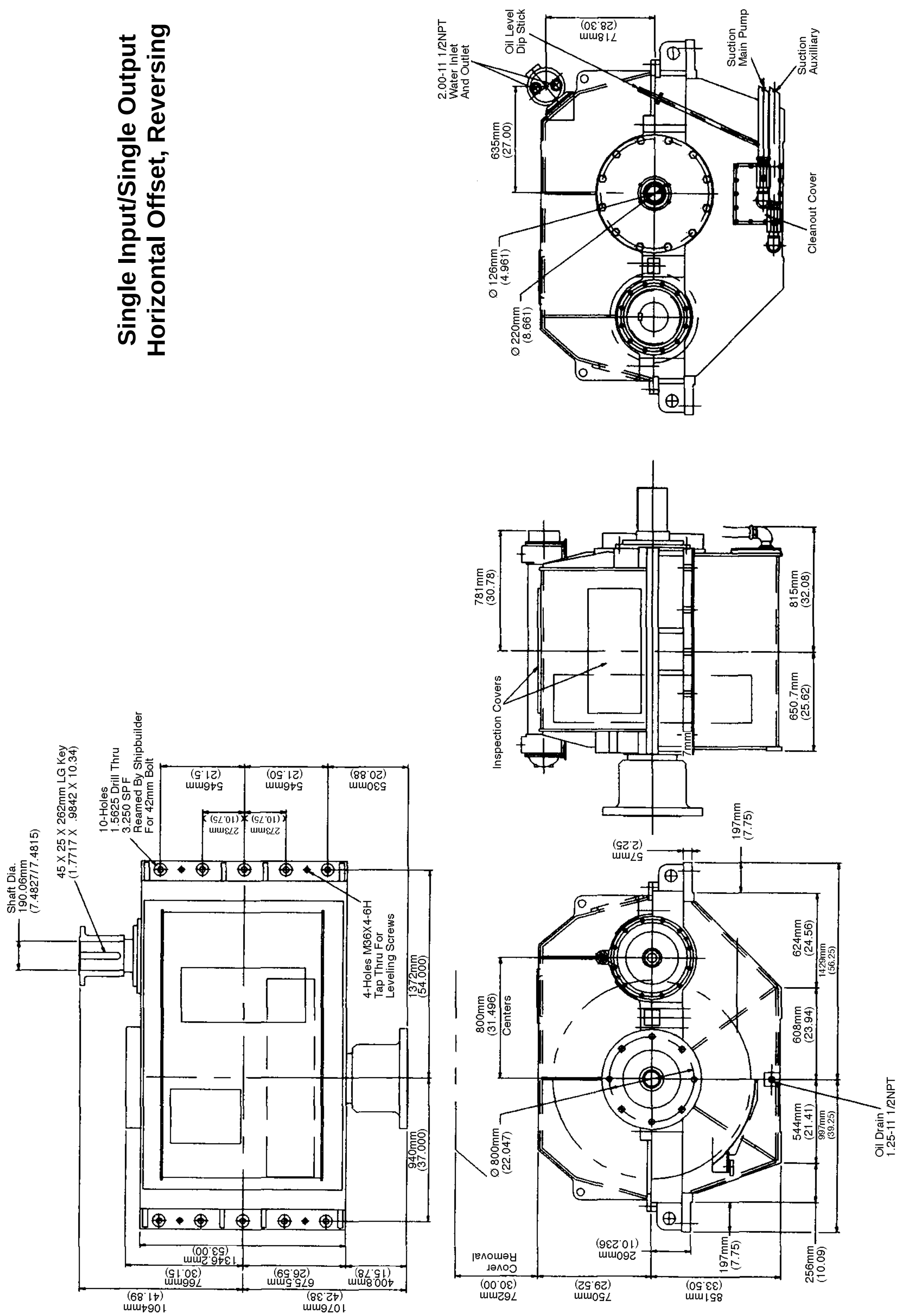
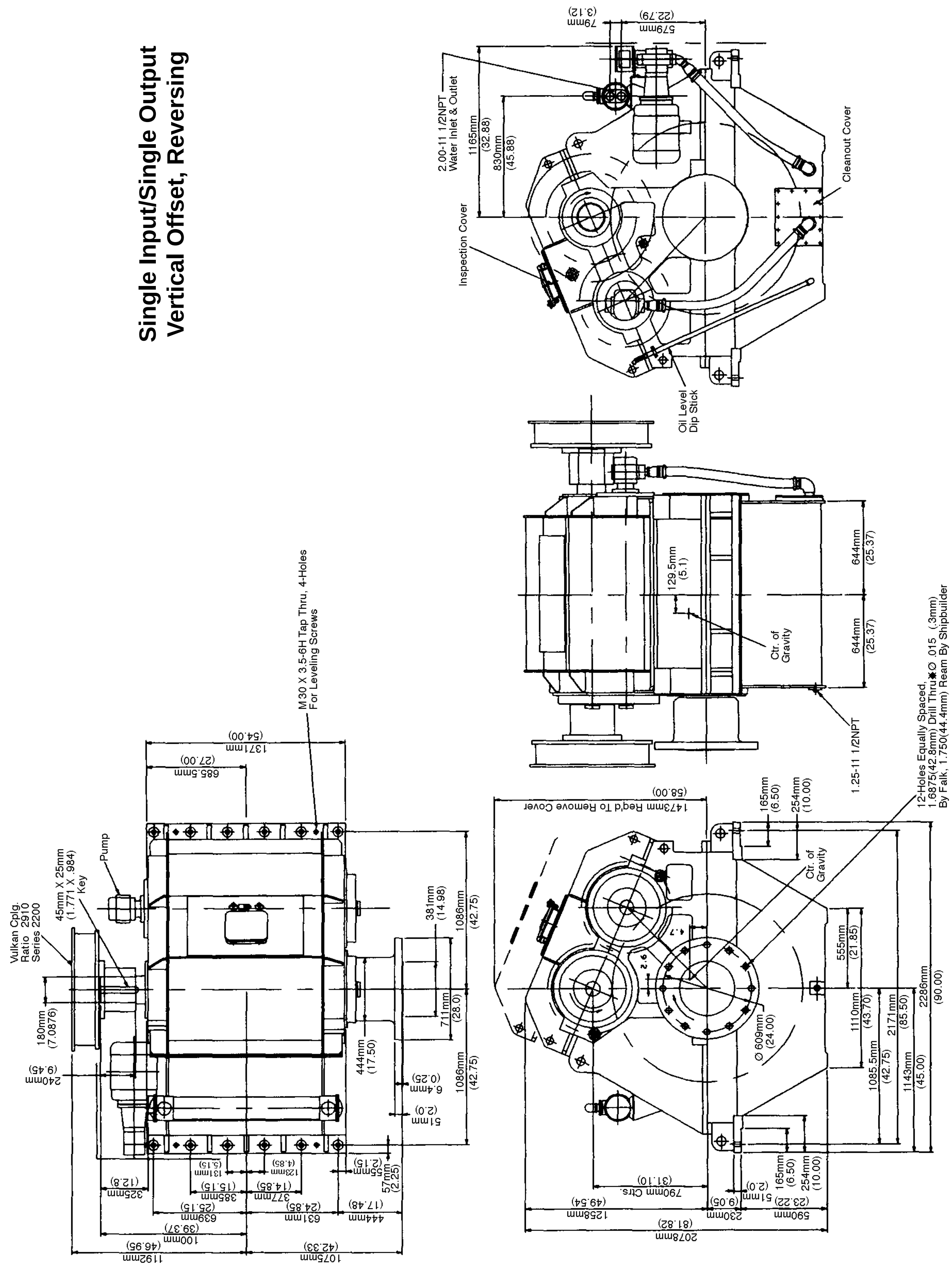
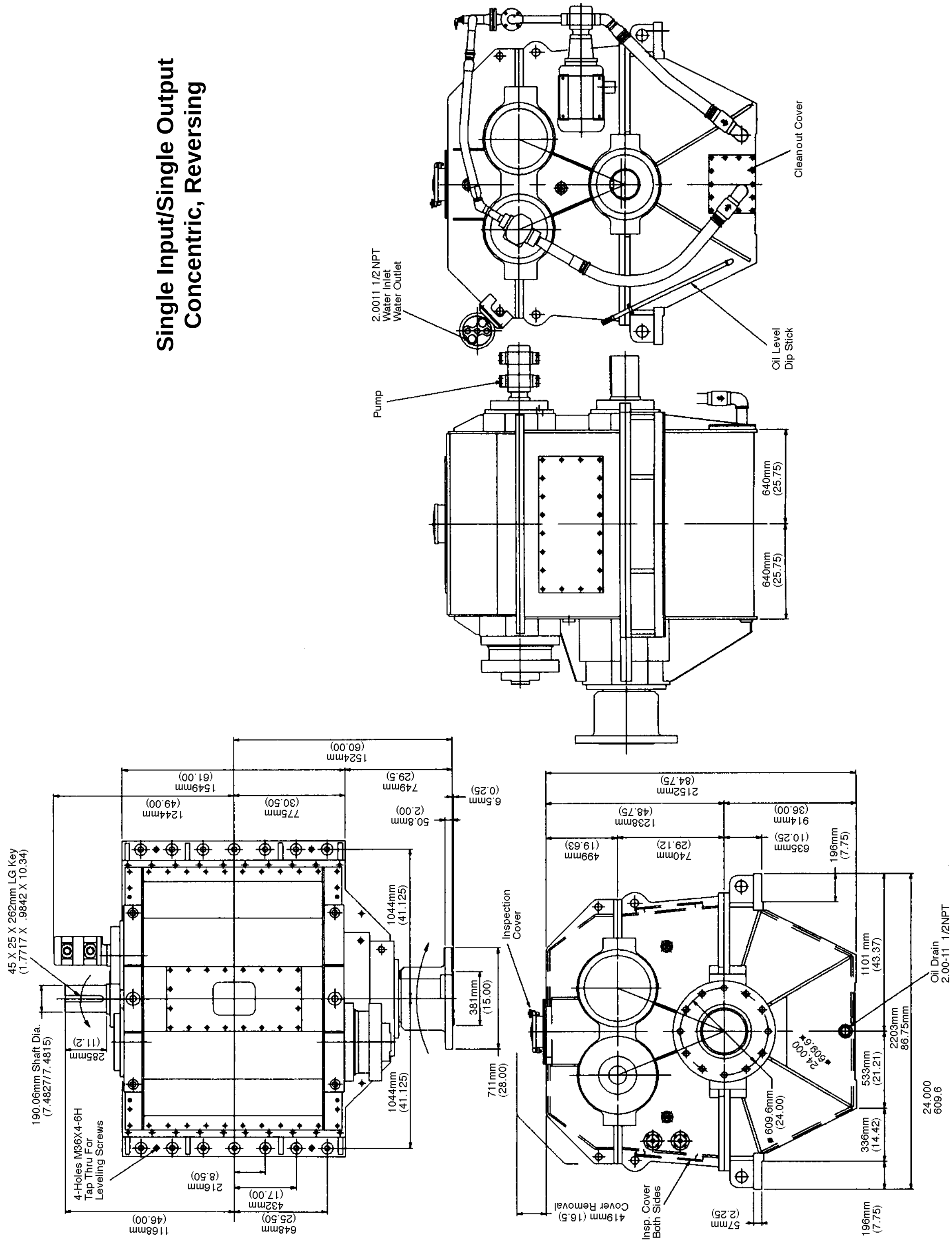

Single Input/Single Output
Horizontal Offset, Reversing
2.00-11 1/2NPT Water Inlet And Outlet
Oil Level Dip Stick
718mm (28.30)
635mm (27.00)
Ø 126mm (4.961)
Ø 220mm (8.661)
Suction Main Pump
Suction Auxilliary
Cleanout Cover
781mm (30.78)
Inspection Covers
815mm (32.08)
650.7mm (25.62)
197mm (7.75)
57mm (2.25)
800mm (31.496) Centers
Ø 800mm (22.047)
624mm (24.56)
608mm (23.94)
544mm (21.41)
1429mm (56.25)
997mm (39.25)
Oil Drain 1.25-11 1/2NPT
256mm (10.09)
197mm (7.75)
260mm (10.236)
Cover Removal
762mm (30.00)
750mm (29.52)
851mm (33.50)
Shaft Dia. 190.06mm (7.4827/7.4815)
45 X 25 X 262mm LG Key (1.7717 X .9842 X 10.34)
10-Holes 1.5625 Drill Thru 3.250 SP F Reamed By Shipbuilder For 42mm Bolt
546mm (21.5)
546mm (21.50)
530mm (20.88)
273mm (10.75)
273mm (10.75)
4-Holes M36X4-6H Tap Thru For Leveling Screws
1372mm (54.000)
940mm (37.000)
1346.2mm (53.00)
766mm (30.15)
675.5mm (26.59)
400.8mm (15.78)
1064mm (41.89)
1076mm (42.38)

Figure 1



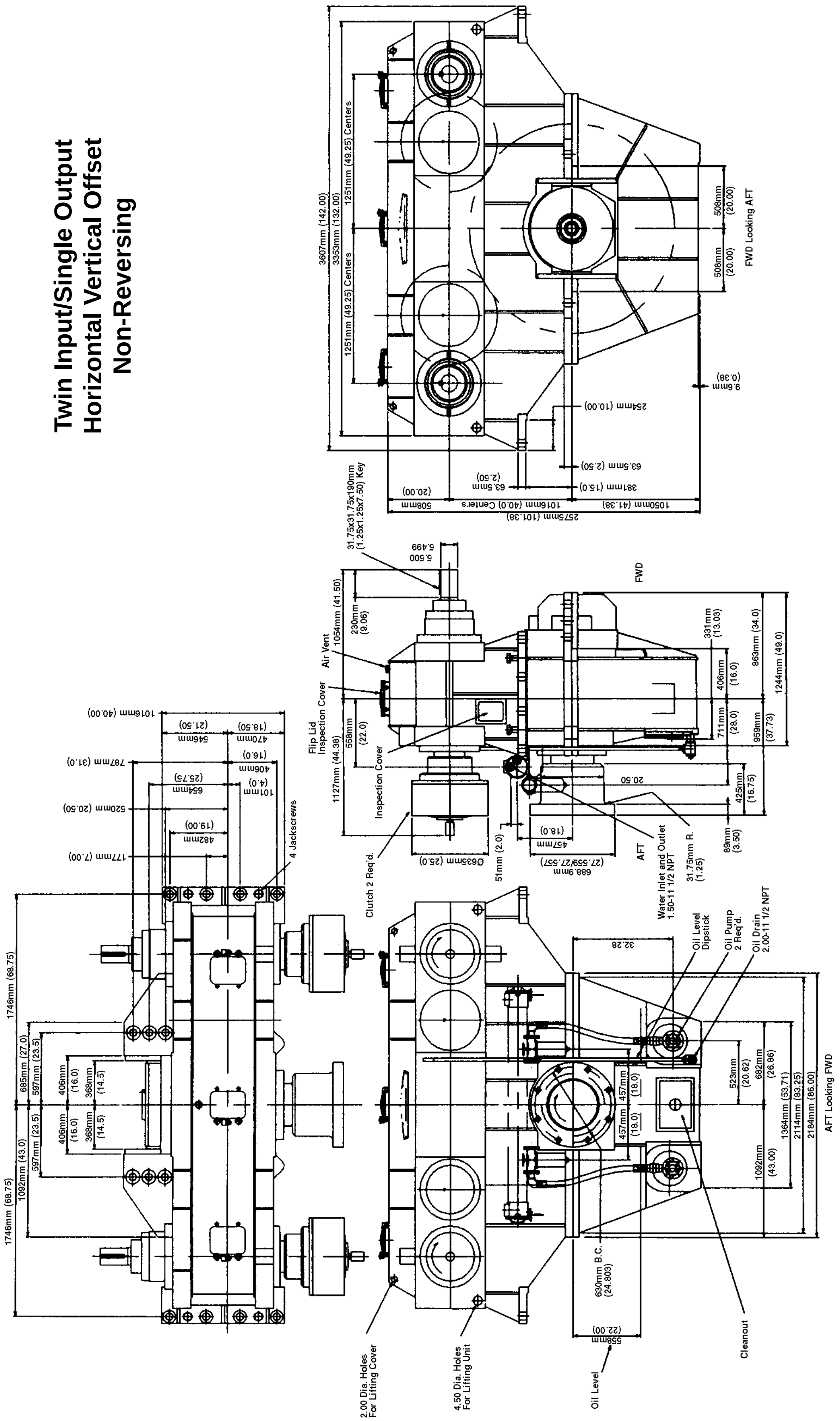
Single Input/Single Output
Vertical Offset, Reversing
Vulkan Cplg.
Ratio 2910
Series 2200
45mm X 25mm
(1.771 X .984)
Key
Pump
M30 X 3.5-6H Tap Thru, 4-Holes
For Leveling Screws
Inspection Cover
2.00-11 1/2NPT
Water Inlet & Outlet
Cleanout Cover
Oil Level
Dip Stick
Ctr. of
Gravity
1.25-11 1/2NPT
12-Holes Equally Spaced,
1.6875(42.8mm) Drill Thru
By Falk, 1.750(44.4mm) Ream By Shipbuilder
1473mm Req'd To Remove Cover
790mm Ctrs.

Figure 2



Single Input/Single Output
Concentric, Reversing
2.0011 1/2 NPT
Water Inlet
Water Outlet
Pump
Oil Level
Dip Stick
Cleanout Cover
640mm
(25.75)
Inspection
Cover
Insp. Cover
Both Sides
419mm (16.5)
Cover Removal
Oil Drain
2.00-11 1/2NPT
45 X 25 X 262mm LG Key
(1.7717 X .9842 X 10.34)
190.06mm Shaft Dia.
(7.4827/7.4815)
4-Holes M36X4-6H
Tap Thru For
Leveling Screws
1044mm
(41.125)
381mm
(15.00)
711mm
(28.00)
2152mm
(84.75)
1238mm
(48.75)
914mm
(36.00)
609.6mm
(24.00)

Figure 3



Twin Input/Single Output
Horizontal Vertical Offset
Non-Reversing

Figure 4

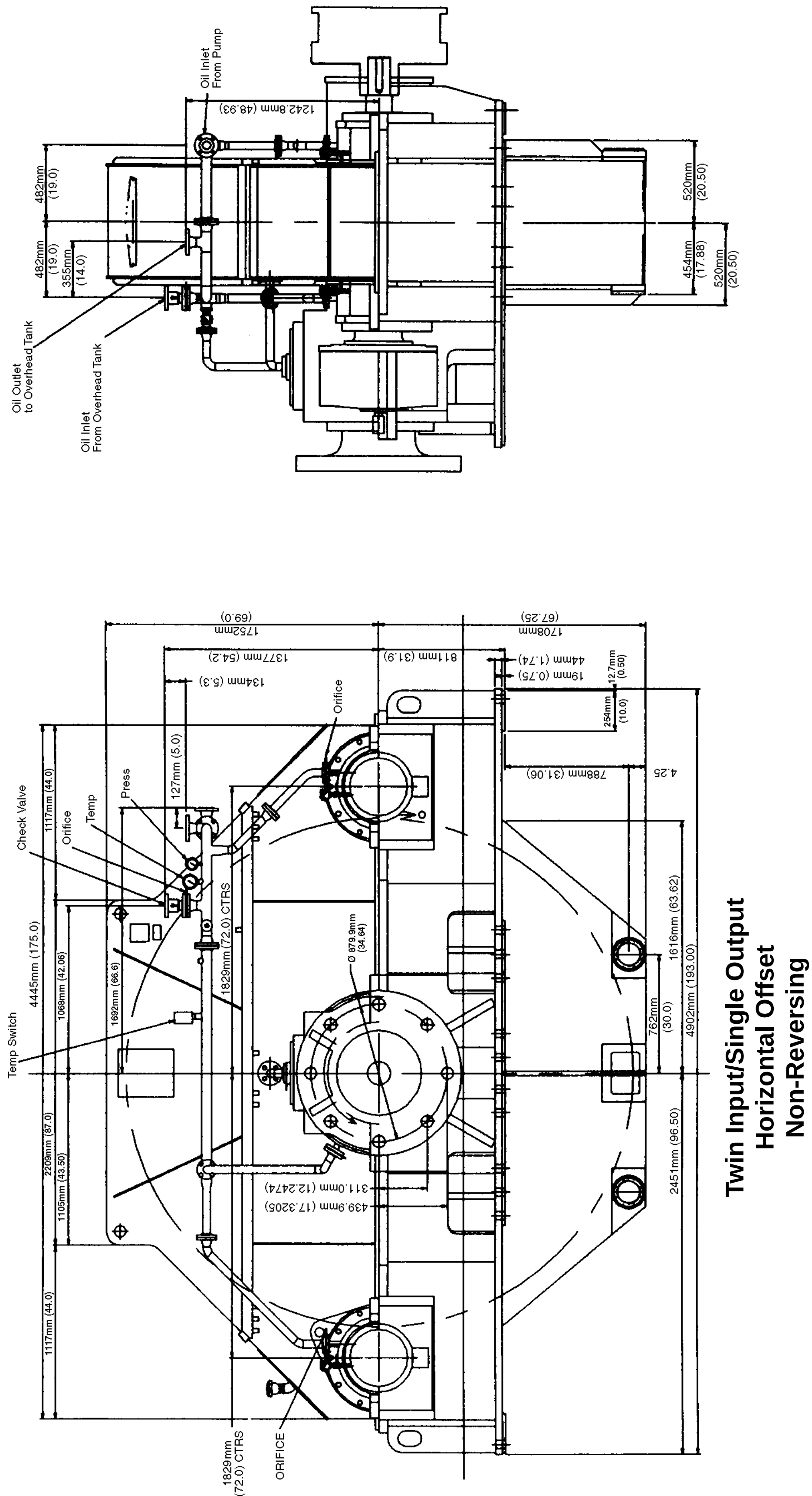
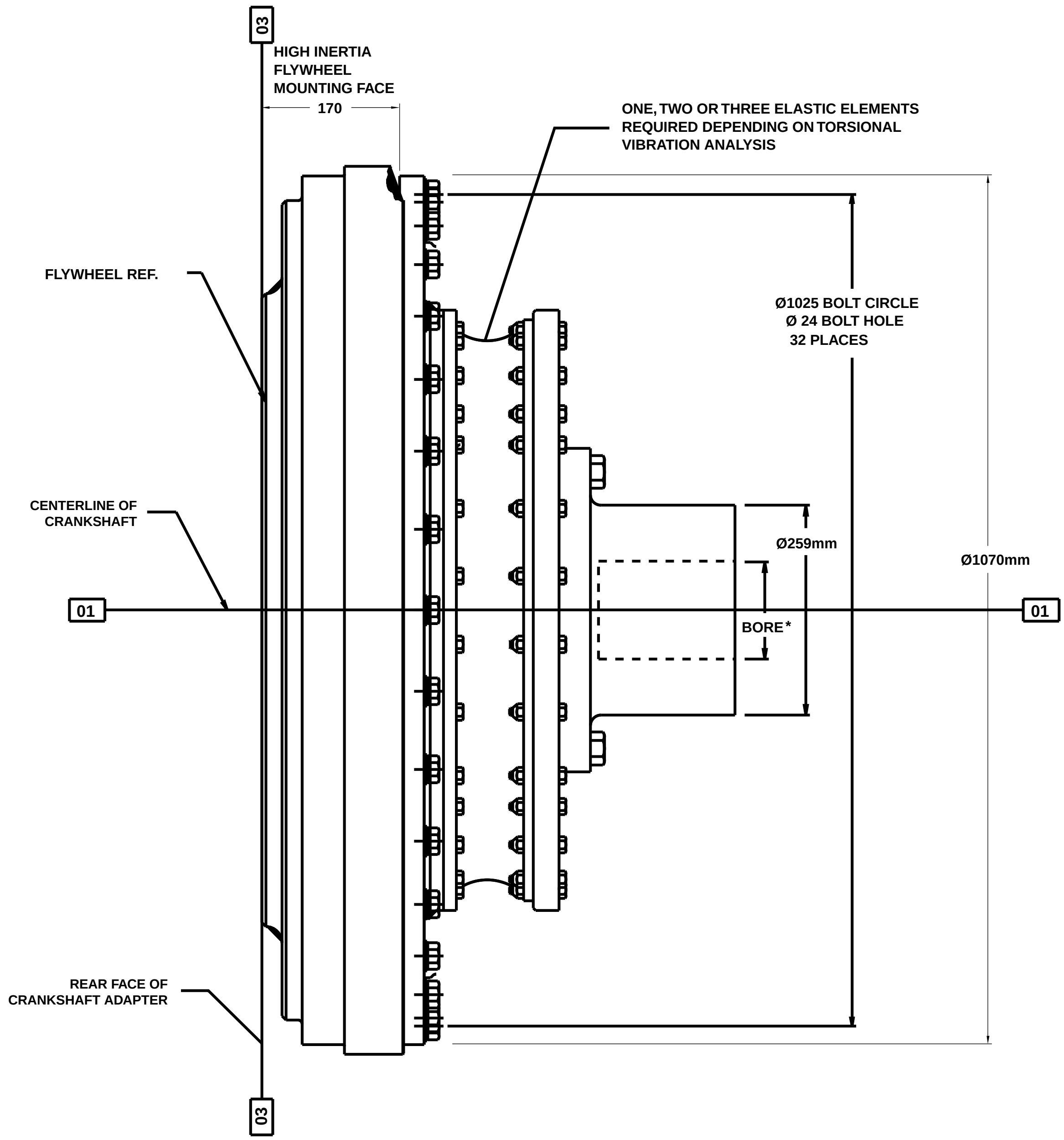

Oil Outlet to Overhead Tank
Oil Inlet From Overhead Tank
Oil Inlet From Pump
1242.8mm (48.93)
482mm (19.0)
482mm (19.0)
355mm (14.0)
520mm (20.50)
454mm (17.88)
520mm (20.50)
Temp Switch
Check Valve
Orifice
Temp
Press
4445mm (175.0)
1117mm (44.0)
1117mm (44.0)
127mm (5.0)
134mm (5.3)
1377mm (54.2)
1752mm (69.0)
811mm (31.9)
1708mm (67.25)
44mm (1.74)
19mm (0.75)
788mm (31.06)
1829mm (72.0) CTRS
311.0mm (12.2474)
439.9mm (17.3205)
762mm (30.0)
1616mm (63.62)
4902mm (193.00)
2451mm (96.50)
ORIFICE
Twin Input/Single Output
Horizontal Offset
Non-Reversing

Figure 5

Couplings

A propulsion engine's power transmission is through a flexible coupling, or a combined flexible coupling and clutch mounted on the flywheel. A heavy coupling can be mounted on the flywheel or shaft flange without intermediate bearings. The type of flexible coupling to be used for each installation must be determined on the basis of torsional vibration calculations. Two fundamental coupling types are used. The first uses elastomer elements to provide both torsional flexibility and damping. Figure 6 illustrates a *typical* example of this coupling design. The number of required elements depends on the torsional vibration calculation. In addition, engines with a resilient mounting system require a balanced coupling.

Note: *The application will determine the coupling size.*



DETAIL OF COUPLING

SCALE NONE

* HUB MACHINED TO CUSTOMER SPECIFICATION

Figure 6

A second type of coupling utilizes leaf or coil springs for torsional flexibility. Hydrodynamic damping is accomplished by oil displacement (dash pot). Figure 7 illustrates a *typical* example of this coupling type.

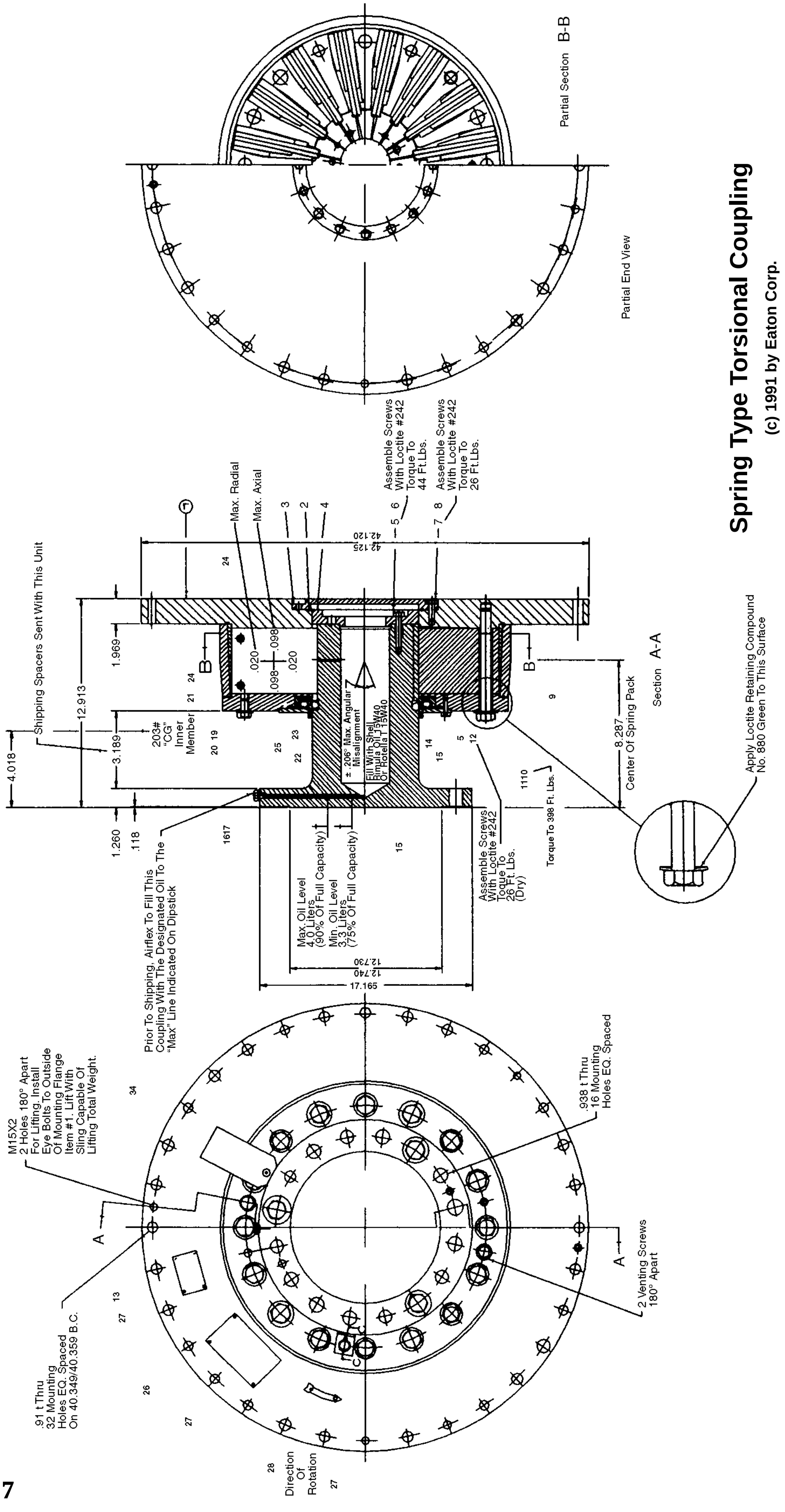


Figure 7

The selection of a coupling depends on the driveline configuration (gearbox, shafting, propeller, etc.). A complete set of driveline data is required to properly select a coupling. A Torsional Vibration Analysis (TVA) must be performed to confirm the coupling selection. The information required by Caterpillar to perform a TVA is shown in Figure 8. Also see *Torsional Vibration Analysis* under the *General Information* section of this guide.

Torsional Limits

The following guidelines should be used in the coupling selection process:

- Crankshaft Amplitude Limits: Misfire calculated using #1 engine cylinder misfiring. Individual order analysis with or without misfire.

  Amplitude limits at front of crank
  - Do not exceed ± 1.0° for 0.5 order
  - Do not exceed ± 1.0° for 1st order
  - Do not exceed ± 0.25° for 1.5 order
  - Do not exceed ± 0.15° for all orders above 1.5 at front of crank
  - Do not exceed ± 21 MPa (3000 psi) crankshaft stress for each engine order
  - Vibratory Torque: Limit of coupling with #1 cylinder misfire
  - Coupling Power Loss: Limit of coupling with #1 cylinder misfire

Coupling Selection

- Develop a coupling selection matrix based on:
  - Engine model
  - Power
  - Inertia - driveline data
  - Ambient temperature
    - 45°C
    - 60°C
  - Application
    - Main Propulsion or Ship Service Generator Set
- Select coupling that meets all the following criteria:
  - Coupling vibratory torque limits
  - Crankshaft vibration limits
- Analyze alternative couplings until all of the above conditions are met.

Use torsional limit stops (coupling locks if operated beyond limits) on couplings providing the sole source of transmitting propulsive power. A single screw vessel is an example. The vessels should have a take-home feature if the coupling fails.

Note: *Germanischer Lloyd and Bureau Veritas may not permit a torsional limit stop because of potentially severe torsional problems when the propulsion system is operated with a failed coupling.*

Propellers

Fixed Pitch

The dimensions of fixed pitch (FP) propellers must be carefully reviewed for each application. They control the level of engine power that can be used in a ship installation.

Factors influencing the design are:

- Propulsion resistance of the ship increases with time.
- Wake factor for the ship increases with time.
- Propeller blade frictional resistance in water increases with time.
- Bollard pull requires higher torque than free running.
- Propellers rotating in ice require higher torque.

Fixed pitch propellers are normally designed to absorb 85% of the Maximum Continuous Rating (MCR), or 90% of the Continuous Service Rating (CSR) at normal speed when the ship is on trial at specified speed and draft (see Figure 9).

Consider the accessory equipment power requirements for shaft generators or hydraulic pumps when sizing FP propellers.

3600 Torsional Vibration Analysis Request

Project Number ____

Project/Customer Name ____

Dealer Name ____

The information on this form is to be used for a specific request for a torsional vibration analysis on the above 3600 Diesel Engine application. Please provide a timely verbal response followed by a written report to the responsible project engineer. The following information describes the major components and performance data for this application:

Engine Model and Rating:

E29 ________ (36 ________); ________ kW (________ bhp)

Low Idle rpm ________ Rated Speed rpm ________

Engine Regulation: Isochronous (Y/N) ________, or Percent Droop ________ %

Application Specifics: ____

____

____

(quantity engines -- custom base -- front driven equipment, etc.)

Engine Room Maximum Ambient Temperature ________________________

Generator (____); and/or **Marine Gear** (____); plus **Other Driven Equipment** (____)

Supplier Name and Model Number ________________________________

Rotating Inertia/Drawing(s) ________________________________

Rotating Stiffness/Shaft Drawing(s) ________________________________

Gearbox Drawing ____________________ Propeller Inertia ____________________

Description (e.g. two bearing or single bearing) ________________________

____

(attached are supplier data sheets)

Part Numbers of Components:

Flywheel Group ___________

Drive Group ___________

Ring Gear Group ___________

3161 Governor Group ___________

EGB29P
Actuator Assembly ___________

Coupling Group ___________

Damper Group ___________

Other Groups ___________

Heinzmann Governor ___________

Electronic Control Group ___________

Engine Ship Date (RTS) ________________________________

Torsional Completion Date Required ________________________________

Caterpillar Project Engineer ________________________________

(Revised 4-25-97)

Figure 8

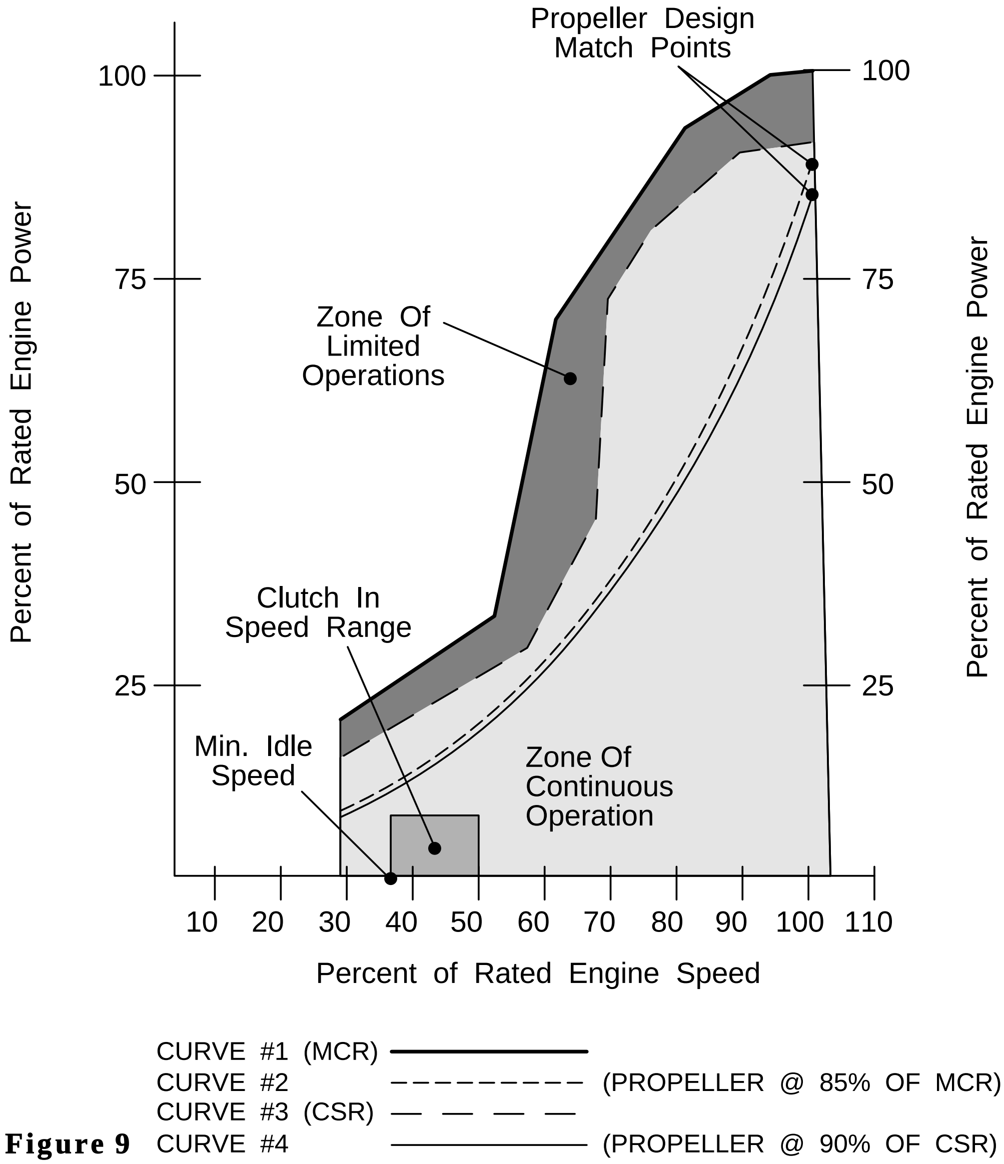


Figure 9

Fishing or towing ships should use a propeller designed for 85% MCR of the engine, the normal speed for fishing or bollard pull or at towing speed. The absorbed power at free running and normal speed is usually lower (about 65% to 85%) than the output at fishing or bollard pull.

Consult Caterpillar for special applications with additional torque requirements, such as dredges or ships operating in thick ice.

Figure 8 shows the permissible operating range for a FP propeller installation and the design point at 85% MCR at nominal speed. The minimum speed is decided separately for each application. The speed control system should give a boost signal to the speed actuator to prevent engine speed from decreasing when clutching in. Select the clutch to provide a slip time of 5-7 sec. Install a propeller shaft brake to facilitate fast maneuvering (ahead, astern, stop). See the *Engine Performance* section of this guide for a full explanation of the rating curve. Also see the section for *Controls*.

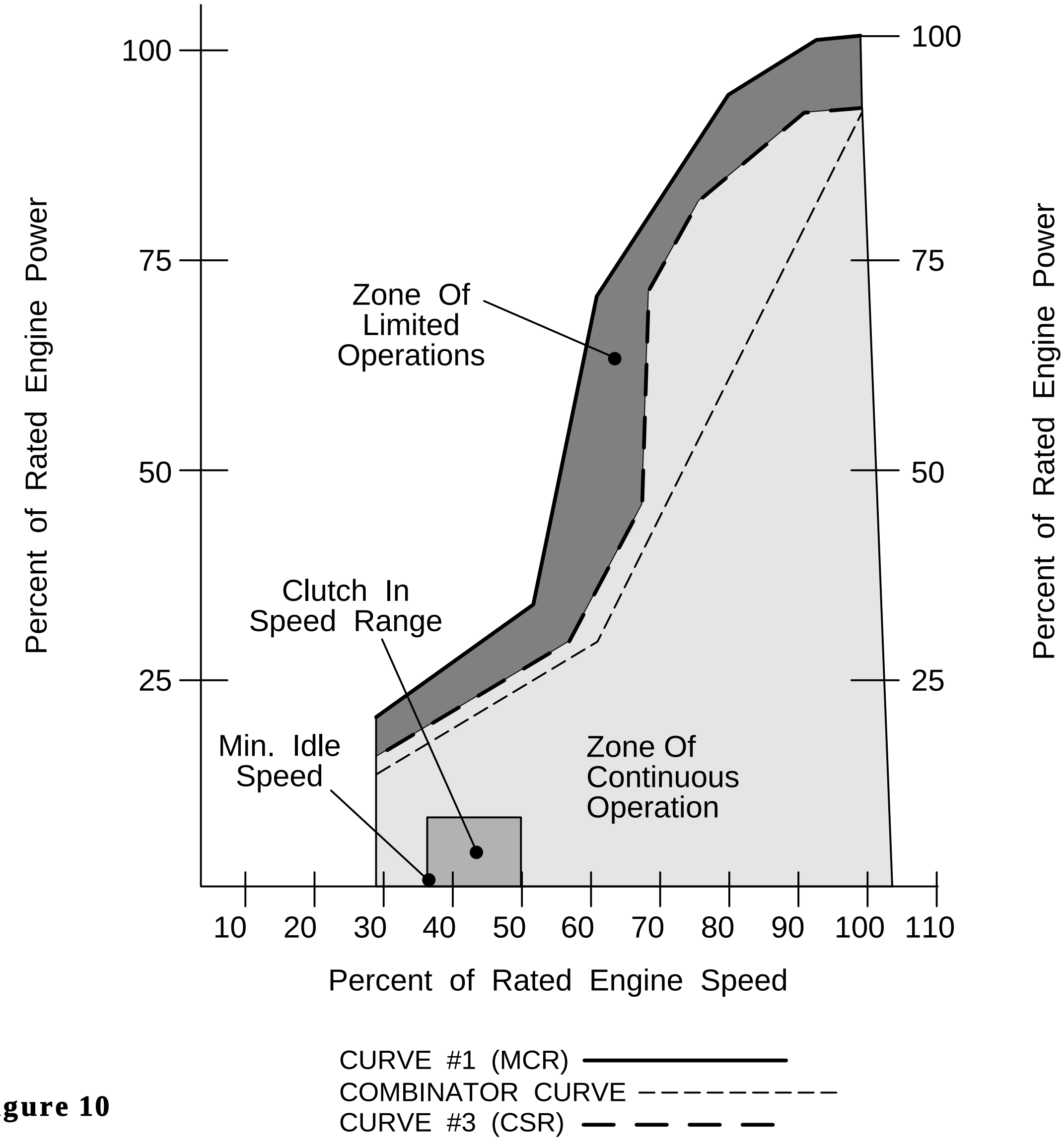


Figure 10

Controllable Pitch

Controllable pitch (CP) propellers are normally designed at 90 to 100% of the Continuous Service Rating (CSR) at rated rpm. See the Engine Performance section of this guide. This power level is used when the ship is on trial with a clean hull at specified speed and draft. Consider the shaft generators or generators connected to the free end of the engine when dimensioning CP propellers if continuous generator output is used at sea. Overload protection or load control is recommended in all installations.

Figure 10 shows the operating range for a typical CP propeller installation, see the Engine Performance section for a full explanation of the rating curve. The recommended combinator curve is valid for single engine installations. In installations where several engines are connected to the same propeller, overload protection or load control is necessary. Loads close to the combinator curve are also recommended when all engines are not operating. The idle (clutch-in) speed will be determined separately in each case.

CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- Repowering Applications
- Other Applications

LEKM8471 8-98

Repowering Applications

General
Foundations
Repower Survey Check List

Repower Applications

General

This section covers areas for a repower application review. Specific systems or equipment sizing and selection are described in greater detail in other guide sections.

Operation, maintenance, and overhaul accessibility is a prime concern in the arrangement of propulsion plants. This is especially true in repowers where space is often limited. For example, when locating the main engines in the aft end of the engine room, adequate space must be provided around the marine gear for periodic inspections, maintenance, and foundation girder locations. When arranging an engine room for repowering, the piping, ventilation ducts, wireways, and other equipment associated with the new propulsion plant must be carefully reviewed. New equipment functional requirements and its relationship with existing equipment is important regarding equipment supervision, inspection, overhaul, and maintenance.

Once the general location of the main engine or engines has been established and the reduction gear design decided on (vertical or horizontal, offset or inline) the vertical centerline of the engine and reduction gear can be determined. The engine and reduction gear foundation can then be designed. See the foundation description at the end of this section.

Trade-offs between auxiliary components selected and available installation space are sometimes required. The choice between horizontal or vertical pumps is an example. Horizontal pumps require more space to install, but are easier to overhaul and support. They tend to be less expensive to purchase. In heat transfer equipment, the choice between shell and tube or plate type is primarily a function of space and cost.

Existing auxiliary equipment such as ballast and bilge pumps, fire pumps, fuel oil transfer pumps, general service pumps, etc., are normally located in the lower engine room. This equipment will usually remain and must be considered when locating the new propulsion plant.

Depending on the extent of equipment located at the floorplate level, a new intermediate deck between the floorplate and the existing upper engine room deck may be required. The new deck can be used to locate the diesel generators, starting air compressors, switchboard, engine control room, etc.

The existing engine room ducting must be reviewed for installation, inspection, and maintenance of the engine exhaust pipes and exhaust services. Space must also be allowed for ventilation and intake air ducting.

Removal of large machinery components must be possible. In many repowers a hatch and lifting arrangement is provided. In others, components are removed through existing access rooms. Locate lifting gear and workshop equipment for the maintenance and overhaul of the main propulsion engines, diesel generators, and fuel treatment plants.

Adequate space must be provided for operating areas and access around the propulsion plant. The following are minimum requirements:

- The headroom in all working and walking areas should be at least 1.9 m (6 ft 3 in.).
- The width of main access passages in the engine room should be at least 915 mm (36 in.). Secondary, or infrequently used passageways, may be 610 mm (24 in.) wide.
- The width of main access ladders should be 685 mm (27 in.) and the angle of slope 60 degrees. The slope of infrequently used ladders may be greater if acceptable to the owner or the classification societies.

- The width of vertical ladders to infrequently used intermediate levels should be 380 mm (15 in.).

Develop several designs before selecting a final machinery arrangement offering the best combination of cost, performance, and accessibility for operation and service.

Consult the ship owner or operator to determine if the ship's operating profile or trade route will change after the repower is completed. If a change is contemplated, review the following points:

- *Operating environment* - An anticipated increase in ambient air and sea water temperatures can have an impact on the operation of existing machinery. It may require equipment replacement or size increases. Temperature increase also affects operating alignment.
- *Circulating water* - A ship designed for fresh water, but operated in sea water, will experience accelerated corrosion and increased maintenance of circulating pumps, heat exchangers, valves, fittings, and piping.
- *Ventilation and access openings* - If a ship originally designed to operate in coastal waters is modified and converted to operate in ocean waters, the ventilation, combustion air, and access openings may have to be relocated. This ensures no ingress of sea water from increased wave height.
- *Classification* - If the ship is classed by a classification society or governmental agency, the repowering may be considered to be a major conversion and many other areas of the ship may require upgraded machinery to meet regulations. The possible increased cost should be made known before proceeding.
- *Generating Plant* - The existing plant must have capacity to handle additional electrical loads resulting from the repower. An increase in the ship's electrical plant may be required.
- *Automation* - In many repowers, the engine room automation level is changed from manned to one man or to unmanned. Review classification society and/or governmental agency requirements for the engine room manning level.
- *Handling* - A ship's survey should include a review for removing the existing power plant and the requirements to transport the new engine into engine room position. This may include cutting the decks or side shell and temporarily removing other equipment, piping, and/or electrical items.
- *Stability* - The repowering of a large ship may not impact the ship's stability. In a small ship the new engine's weight and vertical and longitudinal centers of gravity may lead to marginal ship stability. It may become necessary to add permanent fixed ballast in the inner bottom to compensate for appreciable differences in the weights and centers of gravity.
- *Torsional analysis* - Perform a torsional analysis based on the new propulsion drive line arrangement and new operating parameters. This calculation could impact the decision to reuse or replace the shafting or propeller.
- *Drive shafting* - The shaft horsepower and/or the rpm may change with the repower. Check the existing shafting stresses. Shafting calculations may require a classification society and/or government agency's submittal.

A tabulation of information required during a survey of the ship to be repowered is included at the end of this section. The list will assist in engine room design, selection of necessary auxiliary machinery and piping, and electrical system arrangement.

Foundations

With some exceptions, the principles discussed in the *Mounting and Alignment* section are applicable for repowers.

When retaining the existing marine gear, the input shaft height and fore and aft positions are known. This determines the location for the torsional coupling and/or flywheel on the engine. It establishes the fore and aft location and height of the engine mounting feet (with chocking allowances) and the engine girder top flange.

When installing a new gear, the engine and gear box position must be determined. Once known, review the position of the gear box and engine mounting feet relative to the existing mounting flange. Not only changes to the existing foundation must be known, but also the effect of modifications to the double bottom structure. Existing foundation girders cannot arbitrarily be moved without providing suitable replacement double bottom structure aligned with foundation girders.

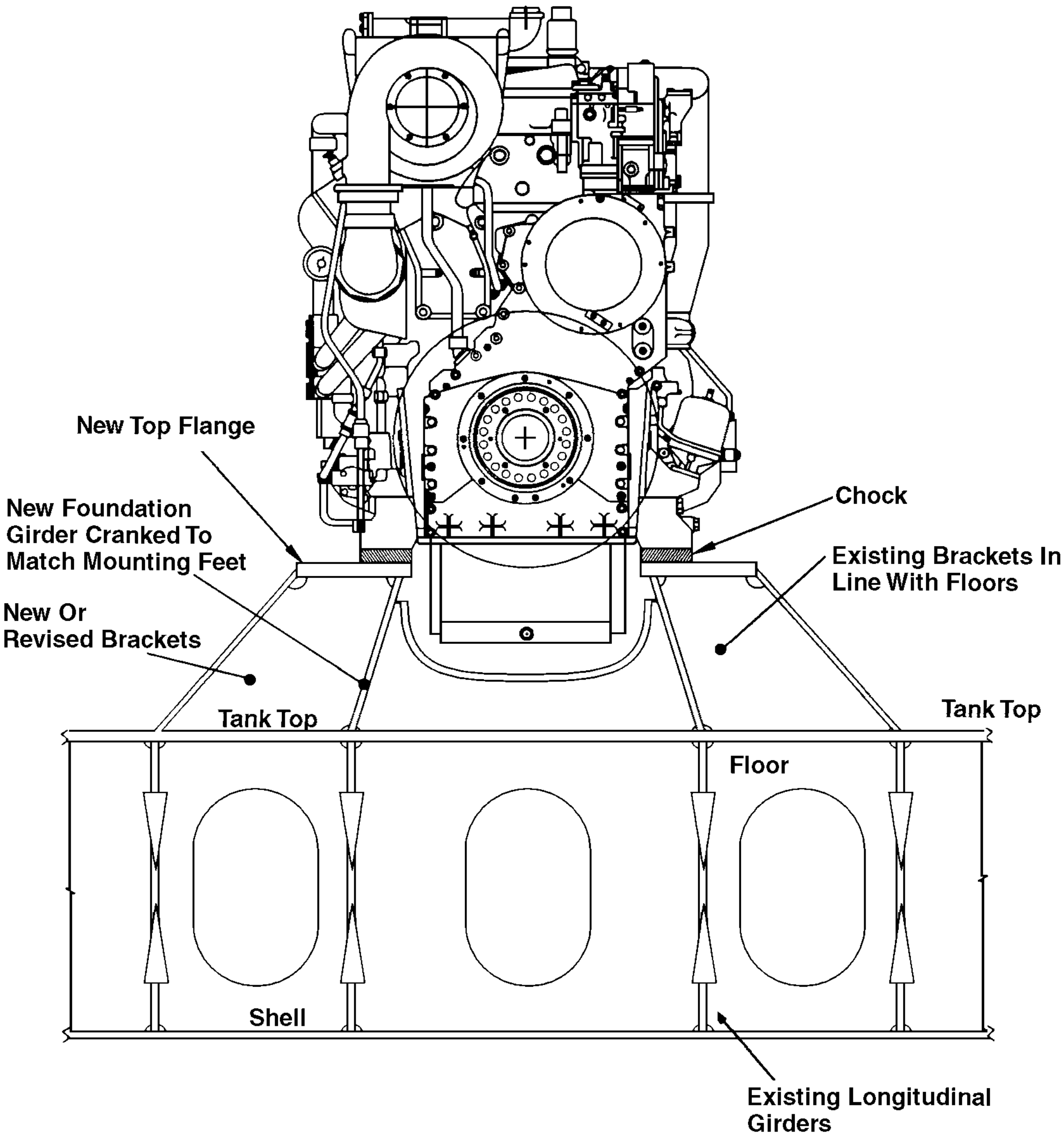
Minimize ship structure modifications and when possible, change only the structure above the tank top. Frequently it will be possible to alter the existing structure rather than construct a new foundation.

The ideal engine foundation design positions the foundation girders directly under and vertically in line with the engine mounting feet. This arrangement is generally not possible in a repower due to different spacing of engine mounting feet. The foundation girders may require cranking (sloping) to match engine mounting feet. Keep the engine girder base in line with the longitudinal structure in the double bottom as shown in Figure 1.

Cranking or sloping the foundation girders is a viable option if an integral engine/gear box foundation can be accommodated. When the engine foundation is cranked, the modified girders must eventually tie back into the longitudinal girders of the gear box foundation. When a new gear is installed, review the locations of both the engine and gear box mounting feet to keep modifications to the engine and gear box foundation structure minimal. Each repower will produce unique modifications due to differences in engines and foundations.

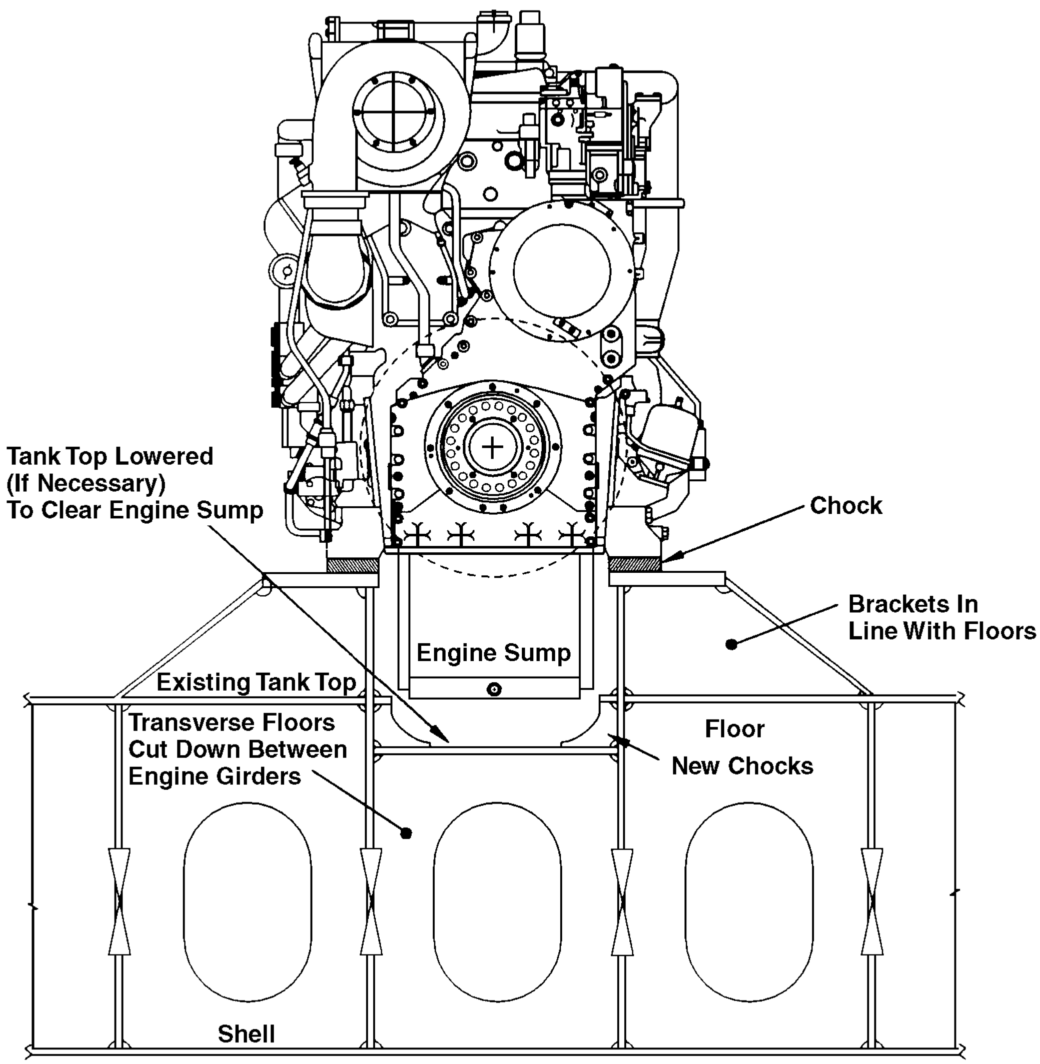
Clearance must be allowed between the engine sump and existing tank top elevation. Depending on the ship design, the engine sump and new gear box bottom may interfere with the existing tank top of the ship. This must be recognized early in the process to eliminate, or at least reduce, the interference. One option is to cut away the tank top and relocate it downward between the two foundation engine girders as shown in Figure 2. This involves cutting floors in the double bottom and perhaps the addition of ship's structure to retain continuity of the existing structure. Small chocks may be necessary between the two girders when the tank top offset becomes more than a few centimeters (inches).

A second option is to install new foundation girders sloped out from the engine centerline to match the engine mounting feet. Attach new girders to existing girders below the tank top level. They can generally be sloped far enough from the engine centerline to provide adequate clearance for the engine sump and still mate up to the engine mounting feet. Figure 3 is a typical engine foundation section with new girders.



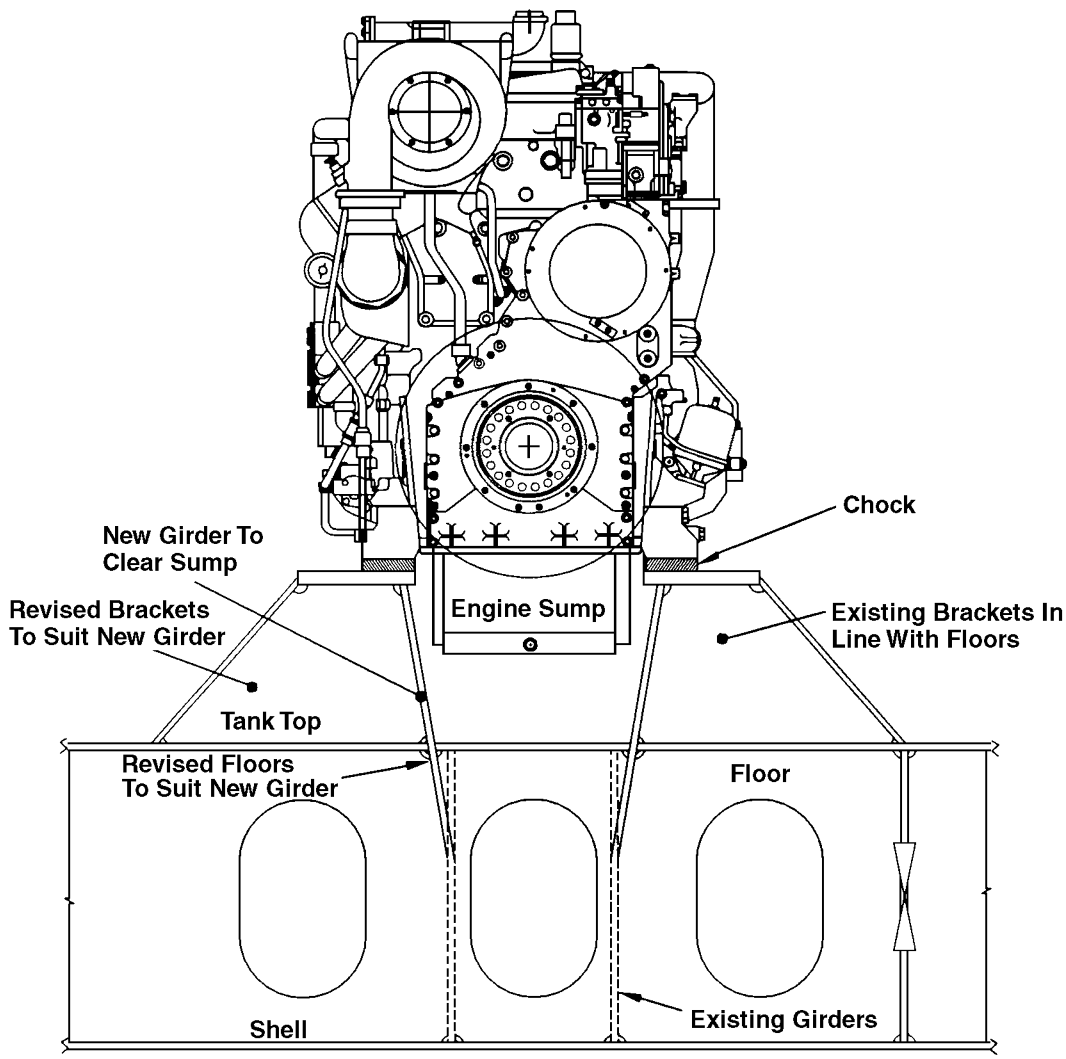
Typical Section
Sloped Girders

Figure 1



Typical Section
Lowered Tank Top

Figure 2



Typical Section
Foundation Modification To Clear Sump

Figure 3

REPOWERING SURVEY CHECK LIST

SHIP NAME: ____________________

OWNER: ____________________

____

____

____

____

TELEPHONE: ____________________

FAX: ____________________

DATE: ____________________

LOCATION: ____________________

TIME: ____________________

SHIP DATA

Existing Dimensions		Remarks:
Length, O.A.	m (ft.)	
Length, B.P.	m (ft.)	
Beam, Molded	m (ft.)	
Depth	m (ft.)	
Draft	m (ft.)	
Speed @ loaded draft	knots	

Where Built:		
Location		
Year		
Hull No.		

MAIN ENGINES

Manufacturer		Remarks:
Number installed		
Type		
No. of cylinders		
Bore x Stroke	mm (in.)	
Brake horsepower, MCR	kW (hp)	
BMEP	kPa (psi)	
Speed	rpm	
Fuel type		
Chocking type		

REDUCTION GEAR

Main Reduction Gear		Remarks:
Manufacturer		
Type		
Input speed	rpm	
Output speed	rpm	
Design horsepower	kW (hp)	
Chocking type		

Torsional Couplings		
Manufacturer		
Number installed		

Clutches:		
Manufacturer		
Number installed		
Type		
Operating pressure	kPa (psig)	

SHAFTING & PROPELLER

Line Shaft		**Remarks:**
Material		
Diameter (approx.)	mm (in.)	
Tail Shaft		
Number installed		
Material		
Diameter (approx.)	mm (in.)	
Thrust Bearing		
Manufacturer		
Number installed		
Type		
Bearing Pressure	kPa (psig)	
Line Shaft Bearing		
Manufacturer		
Number installed		
Type		
Stern Tube Bearing		
Manufacturer		
Number installed		
Type		
Propeller		
Manufacturer		
Number installed		
Type		
Material		
Diameter (approx.)	m (ft.)	
Number of blades		
Design horsepower	kW (hp)	
CPP Hydraulic Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Motor size	kW (hp)	
Stern Tube Lube Oil Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Motor size	kW (hp)	

SHAFTING & PROPELLER

CPP Hydraulic Tank		**Remarks:**
Number installed		
Head	kPa (psig)	
Capacity	liters (gal.)	

Stern Tube		
Number installed		
Type		

Seals		
Manufacturer		
Number installed		
Type		

Shaft Brake		
Manufacturer		
Number installed		
Type		

Provide sketch of existing lineshafting, tailshaft, bearings, etc.:
(include dimensions)

Provide sketch of propeller aperture:
(include dimensions)

FUEL OIL SYSTEM

Heavy Fuel Oil Purifier Heater		**Remarks:**
Manufacturer		
Number installed		
Type		
Capacity	kg/hr (#/hr)	
Oil inlet temperature	°C (F°)	
Oil outlet temperature	°C (F°)	
Steam pressure	kPa (psig)	
Pressure drop, oil	kPa (psig)	
Fouling factor		

Diesel Oil Transfer Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor Size	kW (hp)	

Heavy Fuel Oil Booster Pump		
Manufacturer		
Number installed		
Type		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor Size	kW (hp)	

Diesel Oil Booster Pump		
Manufacturer		
Number installed		
Type		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor Size	kW (hp)	

Fuel Tanks		
Heavy fuel oil tank	(Capacity)	# of tanks:
Diesel oil tank	(Capacity)	# of tanks:
Blend oil settling tank	(Capacity)	# of tanks:
Blend oil day tank	(Capacity)	# of tanks:
Diesel oil settling tank	(Capacity)	# of tanks:
Diesel oil day tank	(Capacity)	# of tanks:

FUEL OIL SYSTEM

Heavy Fuel Oil Purifier		**Remarks:**
Manufacturer		
Number installed		
Type		
Capacity (approx.)	L/hr (gph)	
Discharge pressure	kPa (psig)	
Oil viscosity (@ 50°C)	SSU	
Oil inlet temperature	°C (F°)	

Diesel Oil Purifier		
Manufacturer		
Number installed		
Type		
Capacity (approx.)	L/hr (gph)	
Discharge pressure	kPa (psig)	
Oil viscosity (@ 50°C)	SSU	
Oil inlet temperature	°C (F°)	

Booster Pump Heaters		
Manufacturer		
Number installed		
Type		
Capacity	L/hr (gph)	
Oil inlet temperature	°C (F°)	
Oil outlet temperature	°C (F°)	
Steam pressure	kPa (psig)	

Booster Pump Filters		
Manufacturer		
Number installed		
Type		
Capacity	L/min (gph)	
Filter ratings		

LUBRICATING OIL SYSTEM

Main Engine L. O. Purifier		**Remarks:**
Manufacturer		
Number installed		
Type		
Capacity (approx.)	L/hr (gph)	
Discharge pressure	kPa (psig)	
Oil viscosity (@ 50°C)	°C (F°)	
Oil inlet temperature	°C (F°)	

Main Engine L. O. Purifier Heater		
Manufacturer		
Number installed		
Type		
Capacity	L/hr (gph)	
Oil inlet temperature	°C (F°)	
Oil outlet temperature	SSU	
Steam Pressure	kPa (psig)	

Main Engine L. O. Suction Strainers		
Manufacturer		
Number installed		
Type		
Capacity	L/min (gpm)	
Screen Openings		

Main Engine L. O. Coolers		
Manufacturer		
Number installed		
Type		
Lube oil	L/min (gph)	
Oil inlet temperature	°C (F°)	
Oil outlet temperature	°C (F°)	
Tube diameter and thickness		
Tube and tube sheet material		
Shell and baffle material		
Fouling factor		

L.O. Temperature Control Valves		
Number installed		
Type		
Temperature setting	°C (F°)	

Main Engine L. O. Discharge Strainers		
Number installed		
Type		
Capacity	L/min (gpm)	

LUBRICATING OIL SYSTEM

Main Engine L. O. Filters		**Remarks:**
Number installed		
Type		
Capacity	L/min (gpm)	
Main Engine L. O. Sump Tank		
Number installed		
Type		
Capacity	liters (gal.)	
Main Engine L. O. Storage Tank		
Number installed		
Type		
Capacity	liters (gal.)	
Main Engine L. O. Settling Tank		
Number installed		
Type		
Capacity	liters (gal.)	
Main Reduction Gear L. O. Cooler		
Number installed		
Type		
Lube oil flow (approx.)	L/min (gpm)	
Lube oil inlet temperature	°C (°F)	
Lube oil outlet temperature	°C (°F)	
Sea water temperature	°C (°F)	
Material		
Lubricating oil cooler	liters (gal.)	
Main Reduction Gear L. O. Discharge Strainer		
Number installed		
Type		
Capacity	L/min (gpm)	
Screen Mesh		
Main Reduction Gear L. O. Sump Tank		
Number installed		
Type		
Capacity	liters (gal.)	
Main Reduction Gear L. O. Storage Tank		
Number installed		
Type		
Capacity	liters (gal.)	

LUBRICATING OIL SYSTEM

Main Reduction Gear L. O. Settling Tank		Remarks:
Number installed		
Type		
Capacity	liters (gal.)	

Auxiliary Engines L. O. Storage Tank		
Number installed		
Type		
Capacity	liters (gal.)	

Main Engine L. O. Service Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Reduction Gear L. O. Service Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Stern Tube L. O. Service Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

SEA WATER SYSTEMS

Oil/Water Separator		**Remarks:**
Manufacturer		
Number installed		
Capacity (approx.)	L/min (gpm)	

Bilge and Ballast Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Engine Room Bilge Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Ballast Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

General Service Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Sea Water Circulating Piping		
Type		
Material		
Size	mm (in.)	
Diameter of Sea main	mm (in.)	

SEA WATER SYSTEMS

Sea Water Circulating Pump — **Remarks:**

Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Sea Water Service Pump

Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Fire Pump

Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Emergency Fire Pump

Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Priming Pump

Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Suction	mm (in.)	
Motor size	kW (hp)	

Desalination Plant

Manufacturer		
Number installed		
Type		
Capacity	m^3/day (gpd)	
Evap. feed temp.	°C (°F)	
Steam supply pressure	kPa (psig)	

SEA WATER SYSTEMS

Sea Water Strainer		**Remarks:**
Manufacturer		
Number installed		
Type		
Size	mm (in.)	

Sea Chests		
Number installed		
High?		
Low?		

Sketch general locations of sea chests:

FRESH WATER SYSTEMS

Main Engine Jacket Water Coolers		Remarks:
Manufacturer		
Number installed		
Type		
Jacket water flow	L/min (gpm)	
Sea water flow	L/min (gpm)	
Jacket water inlet	°C (F°)	
Jacket water outlet	°C (F°)	
Sea water temp.	°C (F°)	
Tube diameter and thickness		
Shell and baffle material		
Head, tube sheet, and tube component material		
All wetted parts in contact with sea water		
Maximum sea water velocity	m/sec (ft/sec)	
Fouling factor		

Jacket Water Temperature Control Valve		
Number installed		
Type		
Temperature setting	°C (°F)	

Jacket Water Expansion Tank		
Number installed		
Type		
Capacity	liters (gal.)	

Auxiliary Water Coolers		
Manufacturer		
Number installed		
Type		
Fresh water flow	L/min (gpm)	
Sea water flow	L/min (gpm)	
Fresh water inlet	°C (F°)	
Fresh water outlet	°C (F°)	
Sea water temp.	°C (F°)	
Tube diameter and thickness		
Shell and baffle material		
Head, tube sheet, and tube component material		
All wetted parts in contact with sea water		
Maximum sea water velocity	m/sec (ft/sec)	
Fouling factor		

FRESH WATER SYSTEMS

Cooling Water Temperature Control Valve		**Remarks:**
Number installed		
Type		
Temperature setting	°C (°F)	

Jacket Water Cooling Pumps		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	m (ft)	
Motor size	kW (hp)	

Auxiliary Water Cooling Pumps		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	m (ft)	
Motor Size	kW (hp)	

Storage Type Hot Water Heater		
Manufacturer		
Number installed		
Type		
Storage capacity	liters (gal.)	
Capacity output	L/hr (gph)	
Water inlet	°C (°F)	
Water outlet	°C (°F)	
Steam pressure	kPa (psi)	

Fresh Water Hydropneumatic Tank		
Manufacturer		
Number installed		
Type		
Capacity	liters (gal.)	
Design pressure	kPa (psi)	

Fresh Water Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

Hot Water Circulating Pump		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	L/min (gpm)	
Head	kPa (psi)	
Motor size	kW (hp)	

FEED AND STEAM DRAIN SYSTEM

Drain and Inspection Tank		**Remarks:**
Number installed		
Type		
Capacity	liters (gal.)	

Boiler Feed Pumps		
Manufacturer		
Number installed		
Type		
Drive		
Capacity	liters (gal.)	
Head	m (ft)	
Motor size	kW (hp)	

STEAM GENERATING PLANT

Heat Recovery Silencer		**Remarks:**
Manufacturer		
Number installed		
Type		
Working pressure, steam	kPa (psig)	
Outlet capacity	kg/hr (#/hr)	

Main or Auxiliary Boiler		
Manufacturer		
Number installed		
Type		
Working pressure	kPa (psig)	
Total evaporation	kg/hr (#/hr)	

AIR CONDITIONING MACHINERY

Air Conditioning Compressor		**Remarks:**
Manufacturer		
Number installed		
Type		
Condensing temperature	°C (°F)	
Capacity	tons	
Motor size	kW (hp)	

Air Conditioning Condenser		
Manufacturer		
Number installed		
Type		
Condensing temperature	°C (°F)	
Sea water inlet temperature	°C (°F)	

Air Conditioning Receiver		
Number installed		
Type		
Pump-down capacity (approx.)	%	

SHIP'S SERVICE REFRIGERATION

Refrigerated Stores Compressors		**Remarks:**
Manufacturer		
Number installed		
Type		
Capacity (approx.)	tons	
Motor size	kW (hp)	
Refrigerated Stores Condenser		
Manufacturer		
Number installed		
Type		
Refrigerated Stores Receiver		
Manufacturer		
Number installed		
Type		
Pump-down capacity (approx.)	%	

COMPRESSED AIR SYSTEM

Air Starting Compressors		**Remarks:**
Manufacturer		
Number installed		
Type		
Free air		
Discharge pressure	m^3/hr (cfm)	
Motor size	kPa (psi)	
Start limit	kW (hp)	
Stop limit	kPa (psi)	
Control	kPa (psi)	
Air Start Receivers		
Manufacturer		
Number installed		
Type		
Capacity	m^3 (ft^3)	
Design pressure	kPa (psig)	
Ship's Service Air Receiver		
Number installed		
Type		
Capacity	m^3 (ft^3)	
Design pressure	kPa (psig)	
Control Air Receiver		
Number installed		
Type		
Capacity	m^3 (ft^3)	
Design pressure	kPa (psig)	
Control Air Dehydrator		
Manufacturer		
Number installed		
Type	m^3 (ft^3)	
Discharge air temp.	°C (°F)	
Capacity	m^3 hr (scfm)	

MACHINERY SPACE VENTILATION

Supply Fans		**Remarks:**
Manufacturer		
Number installed		
Type		
Capacity	m^3/hr (cfm)	
Static Head, H_2O	mm (inches)	
Motor size	kW (hp)	
Speed	rpm	

Exhaust Fans		
Manufacturer		
Number installed		
Type		
Capacity	m^3/hr (cfm)	
Static Head, H_2O	mm (inches)	
Motor size	kW (hp)	
Speed	rpm	

HULL MACHINERY

Steering Gear		**Remarks:**
Manufacturer		
Number installed		
Type		
Motor size	kW (hp)	

Mooring Winch and Windlass		
Manufacturer		
Number installed		
Type		
Motor size	kW (hp)	

Constant Tension Mooring Winches		
Manufacturer		
Number installed		
Type		
Motor size	kW (hp)	

Bow Thruster		
Manufacturer		
Number installed		
Type		
Output rating	kW (hp)	

Stern Thruster		
Manufacturer		
Number installed		
Type		
Output rating	kW (hp)	

ELECTRICAL SYSTEM

Main Engine Driven Generator		**Remarks:**
Manufacturer		
Number installed		
Type		
Volts at 0.8 pf		
Output rating	kW	
Speed	rpm	
Number of phases		
Hertz		

Diesel Generator		
Manufacturer, engine		
Manufacturer, generator		
Number installed		
Type		
Speed	rpm	
Output rating	kW	
Volts at 0.8 pf		
Number of phases		
Hertz		

Emergency Diesel Generator		
Manufacturer, engine		
Manufacturer, generator		
Number installed		
Type		
Speed	rpm	
Output rating	kW	
Volts at 0.8 pf		
Number of phases		
Hertz		

MISCELLANEOUS

Lifting Arrangements		Remarks:
Number installed		
Main engine		
Ship service generator (s)		
Emergency generator (s)		
Fuel oil centrifuge (s)		
Diesel oil centrifuge (s)		
Lube oil centrifuge (s)		
Others		

Listing of Alarms

Main Engine	Sensor Type	Voltage	Remarks:

MISCELLANEOUS

Listing of Alarms

Reduction Gear	Sensor Type	Voltage	Remarks:

Listing of Alarms

Others	Sensor Type	Voltage	Remarks:

MISCELLANEOUS

Listing of Gauges

Main Engine	Sensor Type	Voltage	Remarks:

Listing of Gauges

Others	Sensor Type	Voltage	Remarks:

MISCELLANEOUS

Control Locations		Remarks:
Number installed		
Type of controls		
Local	Yes/No	
Engine room	Yes/No	
Pilot house	Yes/No	
Bridge wings	Yes/No	
Others	Yes/No	

Miscellaneous

MISCELLANEOUS

Provide Sketch of existing Main Engine and Reduction gear foundation:
(include dimensions)

MISCELLANEOUS

Provide ideas/sketch for removal of Main Engines and other major equipment from machinery space:

MISCELLANEOUS

Provide any other technical information pertinent to the repower:

MISCELLANEOUS

Required Drawings		Remarks:
General Arrangement		
Machinery Arrangement		
Shafting Arrangement		
Ventilation Arrangement		
Exhaust Pipe Arrangement		
Fuel Oil System Diagram		
Diesel Oil System Diagram		
Lube Oil System Diagram		
Compressed Air Sys. Diagram		
Sea Water System Diagram		
Fresh Water System Diagram		
Exhaust System Diagram		
Control Air Diagram		
Steam System Diagram		
Condensate System Diagram		
Electrical One Line Diagram		
Electrical Load Analysis		

Note: If the above noted diagrams are not available, provide sketches of the various systems in way of the main engines: (Use additional pages as required.)

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Other Applications

Ship's Service Generators
Shaft Generators
Bow or Stern Thrusters
Dredge Pumps
Hydraulic Pump Drive

The 3600 Engine Family with its wide range of horsepower, speed and fuel burning capabilities can be used in a variety of applications.

The following paragraphs briefly describe other marine applications. Consult Caterpillar, Inc. or a Caterpillar dealer for further information on other applications.

Ship's Service Generators

Factory packaged generator set electrical output ratings on distillate fuel are shown on page 4 of LEKX6559, the Technical Data section of the *3600 EPG Application and Installation Guide,* Form LEKX1002. The engines can normally be applied at Prime Power ratings for ship's service generator applications. *See the Engine Data section of the EPG guide for heavy fuel ratings. Always consult TMI for the latest rating information.*

For ship's service diesel generator sets the rated load is restricted to 2 hours in 24 hours. *A Rating Request Form must be submitted if the usage is outside these limits.* A nominal 10% overload is available for transient loading.

The engine, generator, and equipment accessory rack can be furnished factory assembled and package tested on a rigid steel base. Auxiliary equipment such as accessory module, fresh water heat exchangers, expansion tank, instrument panels, piping, etc., can be factory mounted on the base and fully tested as a unit. This arrangement greatly reduces shipyard installation cost.

Approximate generator set dimensions are shown on pages 15 through 34 of LEKX6559, the Technical Data section of the *3600 EPG Application and Installation Guide,* Form LEKX1002.

Details of 3600 generator set applications can be found in the Caterpillar *3600 EPG Application and Installation Guide,* Form LEKX1002.

Auxiliary Marine Applications

The 3600 engine series can perform many other auxiliary marine applications including:
- Front power take-off to drive equipment such as a shaft generator or pump drive
- Large bow or stern thrusters
- Dredge pumps
- High speed ferry propulsion pump drive

Full engine torque can be transmitted through a front stub shaft from the free end of the engine as shown in Figure 1. In this application the accessory module normally located directly in front of the engine must be moved. Also, a front drive shaft can be provided to drive an air compressor or other small items of equipment up to 225 kW (300 hp). Consult Caterpillar or a Caterpillar Dealer for applications requiring complex free end driven machinery. Also see the *General Information* section of this guide for discussion of the required torsional vibration analysis for all applications.

The following figures are provided for guidance and indicate typical auxiliary drive arrangements.

Typical Front Stub Shaft

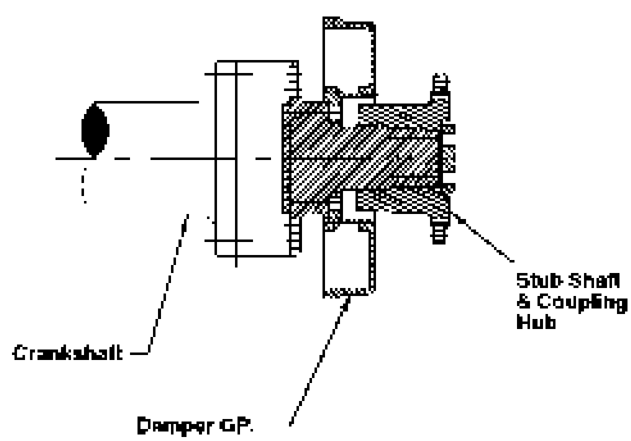


Figure 1

Shaft Generators

In Figure 2 a 3606 engine is driving an AC generator from the free end of the engine through a speed increaser and torsional coupling. This arrangement can be used on a self-unloading ship where large electrical power loads are required in port when unloading cargo. Figure 3 shows a 3612 engine connected to an AC generator via a torsional coupling. The generator is operating at the same rpm as the engine.

With controllable pitch propeller systems, the shaft generator can also be driven from the marine gear.

Bow or Stern Thruster

In Figure 4 a 3606 engine is driving a controllable pitch bow thruster. This arrangement could also be used for a stern thruster application.

Dredge Pumps

In dredging applications the engine is conected to the dredge pump via a marine gear and torsional coupling as shown in Figure 5.

Hydraulic Pump Drive

The engine can be used to drive hydraulic pumps through a speed increaser as shown in Figure 6. In this arrangement the engine is connected to a speed increaser with internal clutches.

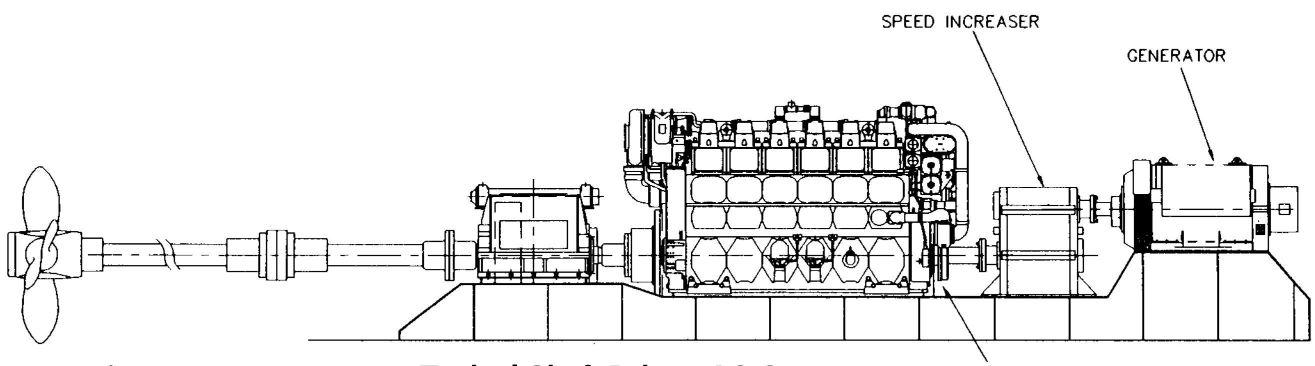


Figure 2 **Typical Shaft Driven AC Generator With Speed Increaser**

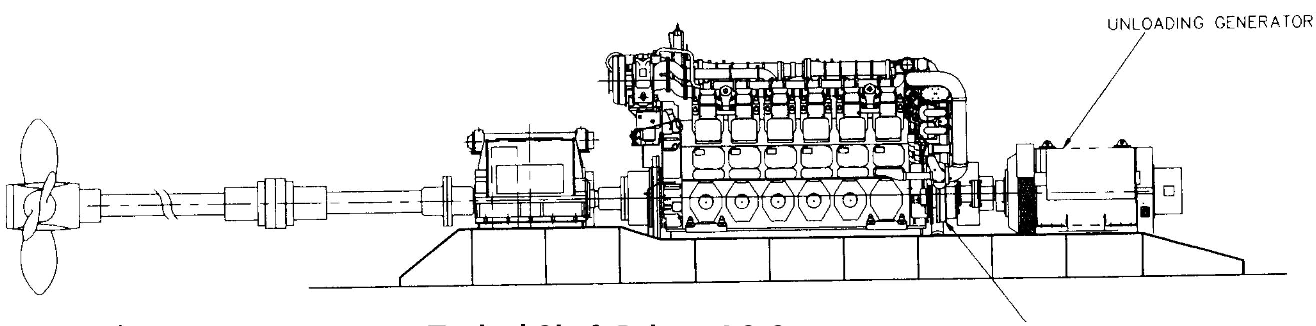
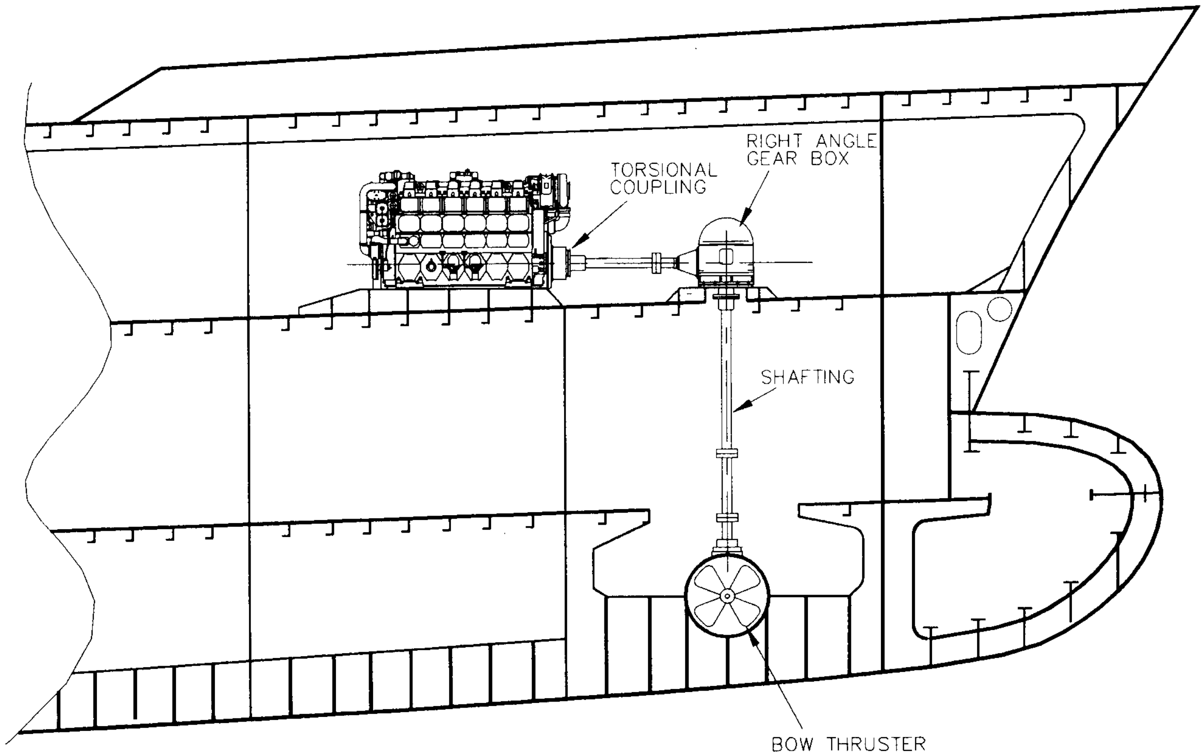
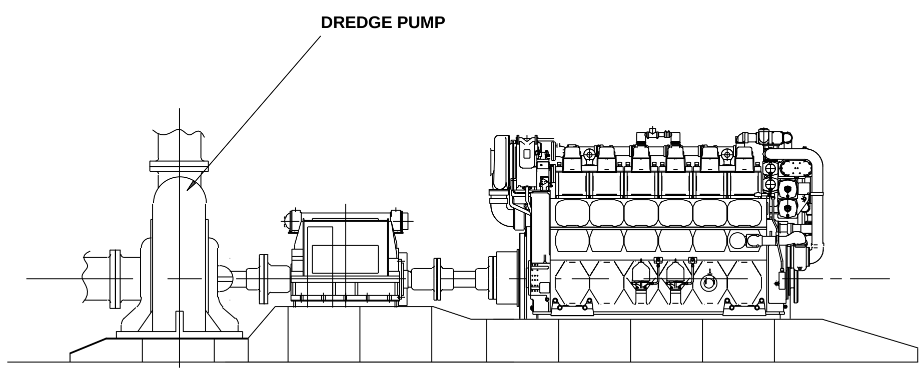


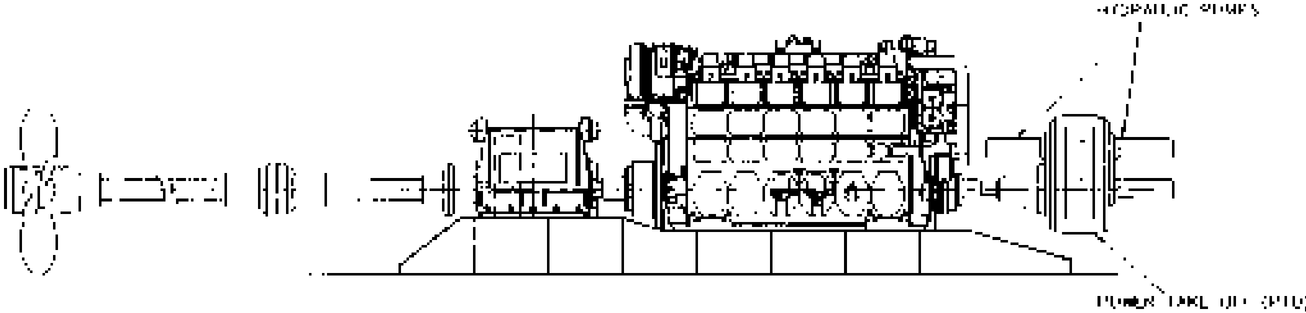
Figure 3 **Typical Shaft Driven AC Generator Without Speed Increaser**



Typical Bow Thruster Arrangement **Figure 4**



Typical Dredge Pump Arrangement **Figure 5**



Power Take-Off For Hydraulic Pump Drive **Figure 6**

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3600 Marine Engine Application and Installation Guide

● **Service and Maintenance**

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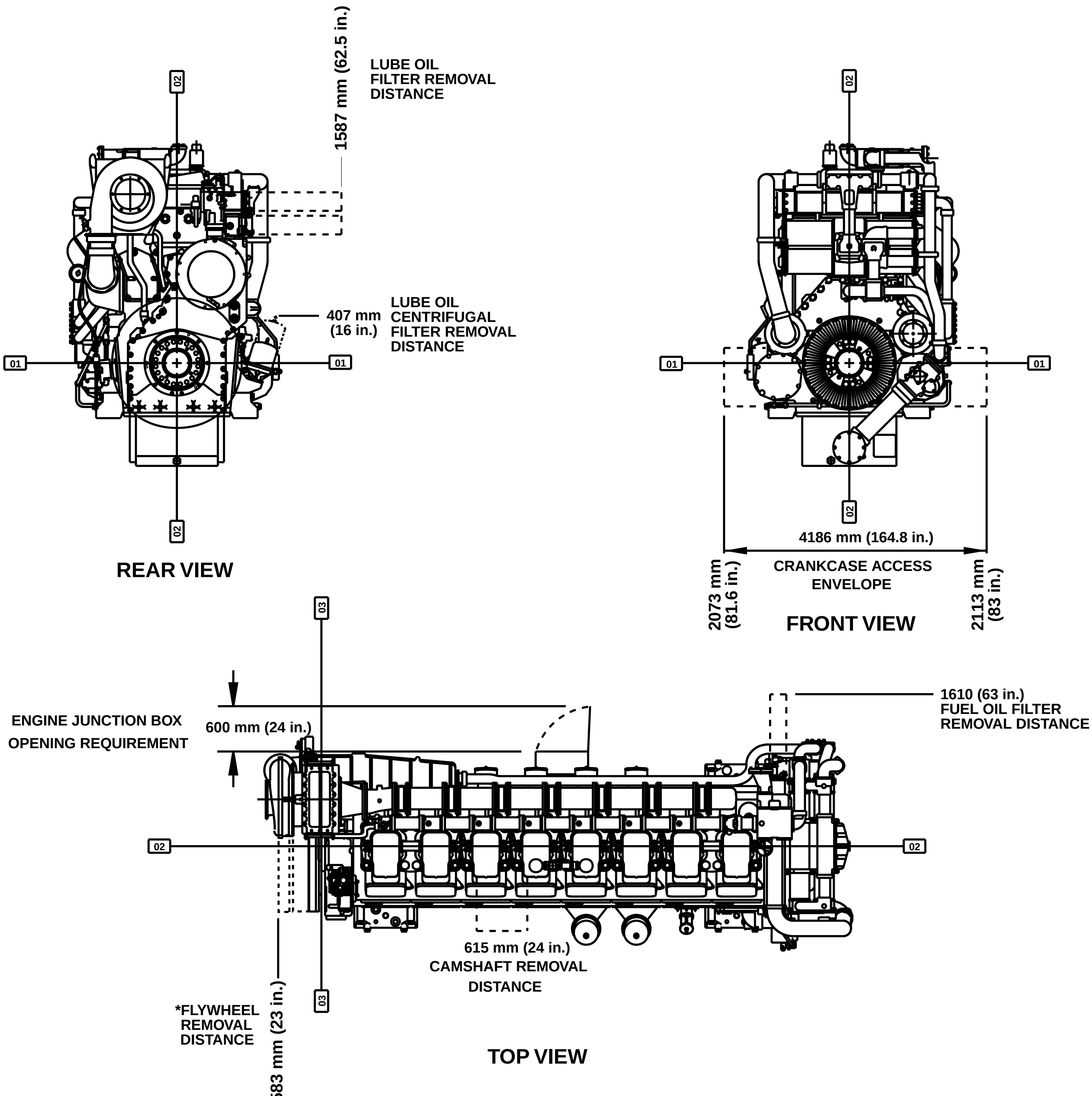
Service and Maintenance

- Service Envelopes/Component Weights
- Spare Parts Kits
- Expected Parts Life
- Service Tools
- Operation and Maintenance Documentation

Service Envelopes/ Component Weights

Figures 1 and 2 show component removal distances for the in-line engines. Figures 3 and 4 contain the same information for the vee engines.

Figures 5 and 6 illustrate the size and weights of major items to be stored as spares.



*** If Caterpillar service tool is used.**
355 mm is required if service tool is not used.

Figure 1

Service Removal Distances
In-line Engine

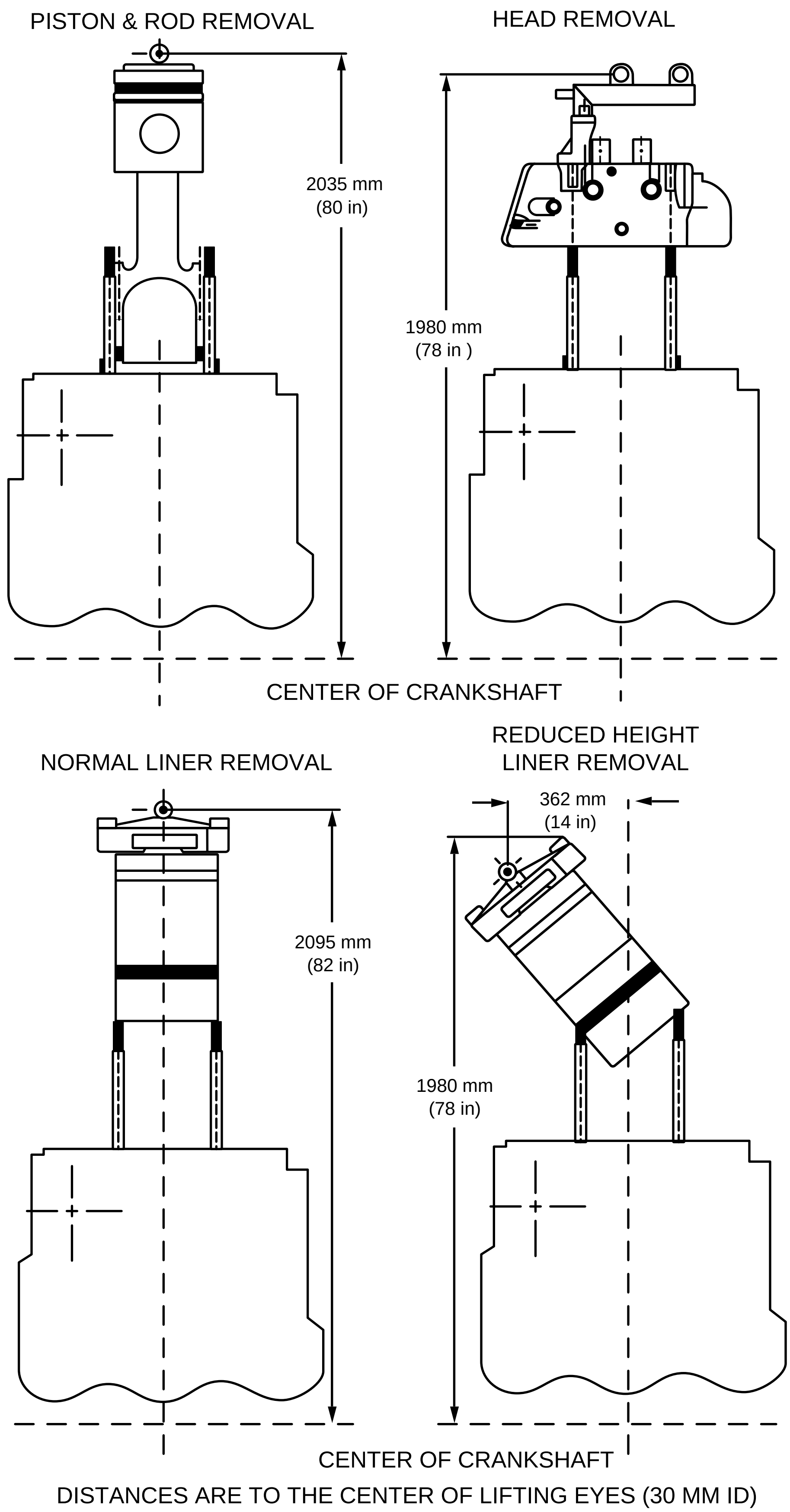
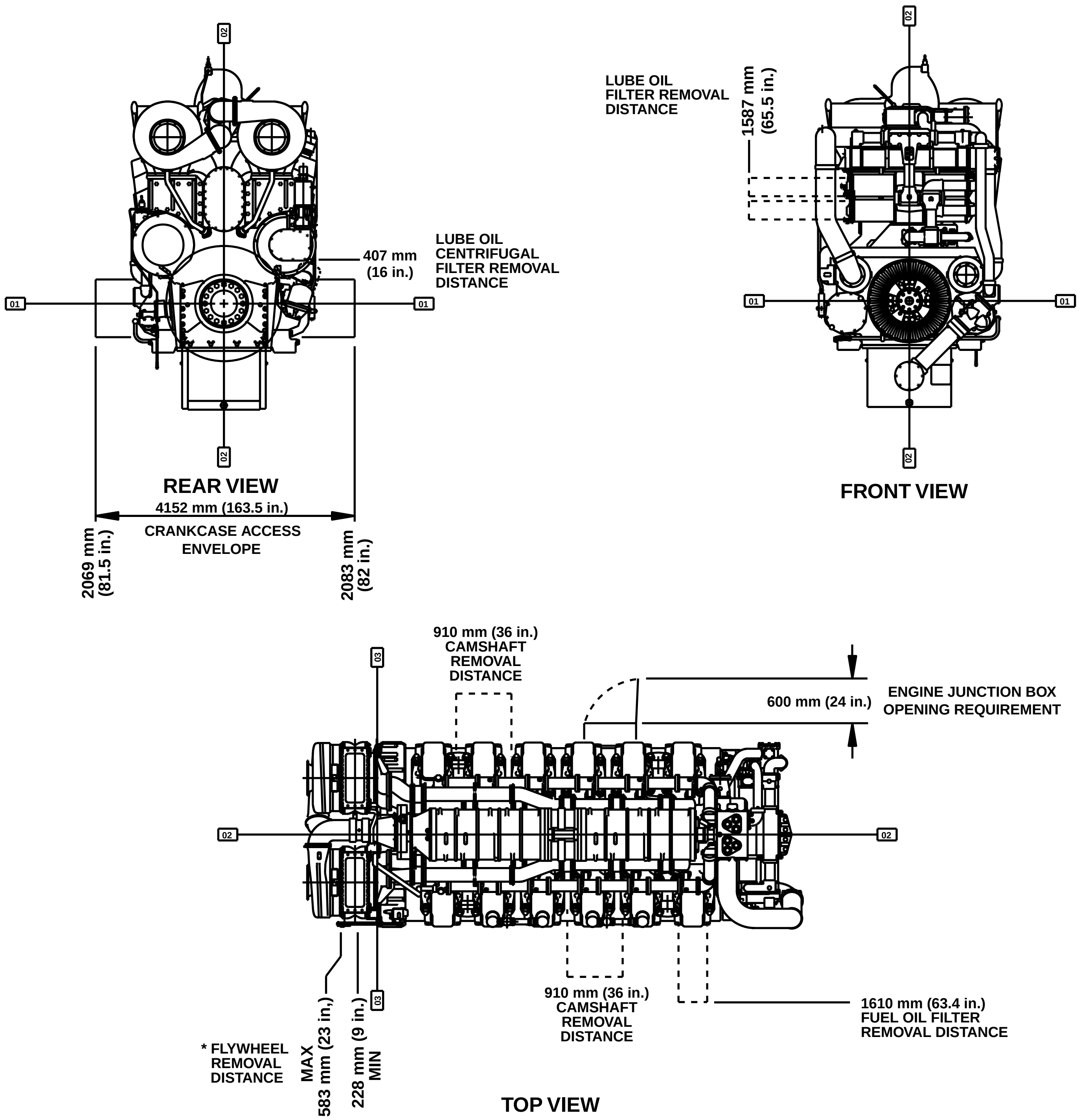


Figure 2



*** If Caterpillar service tool is used.**
355 mm is required if service tool is not used.

Figure 3

Service Removal Distances
Vee Engine

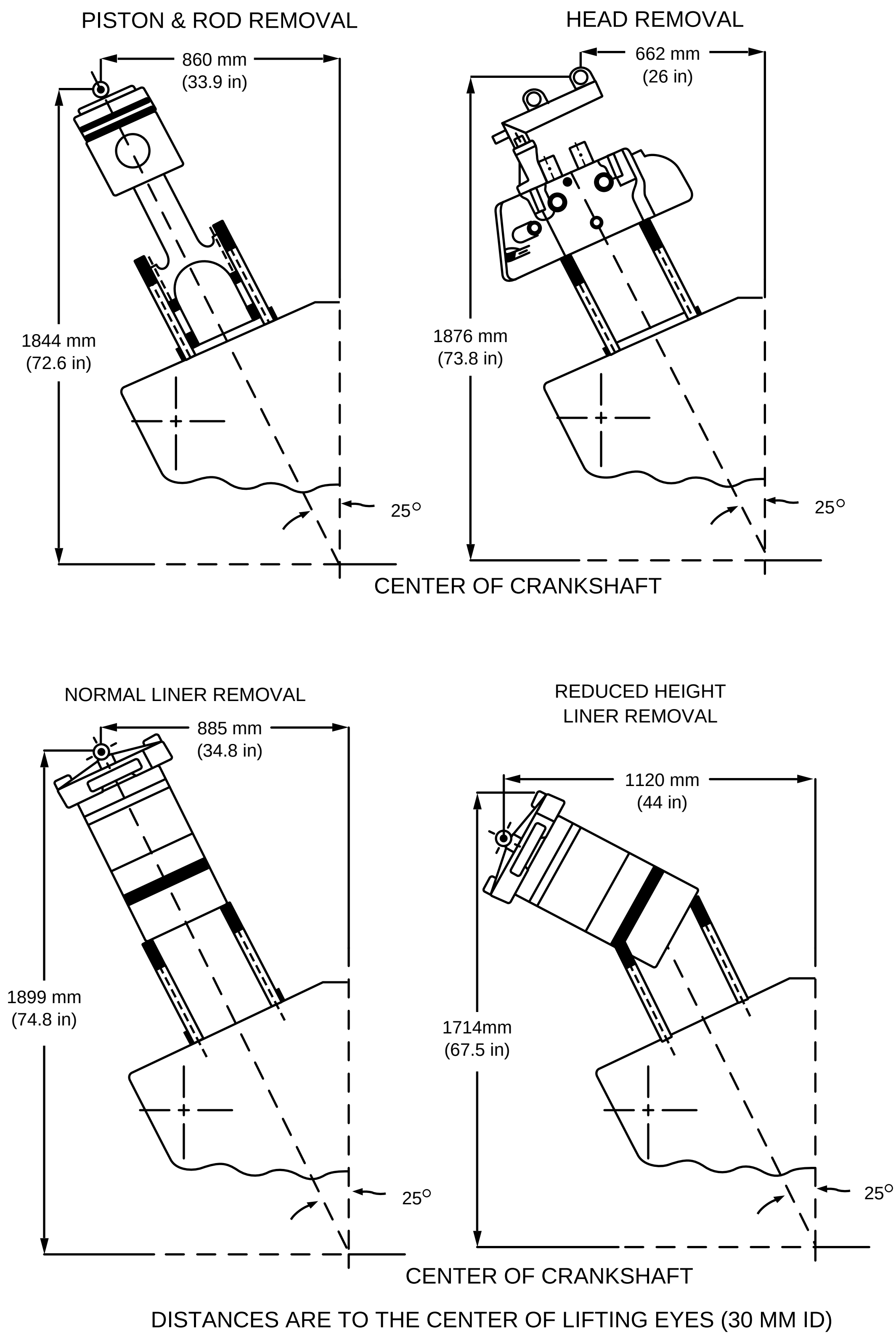
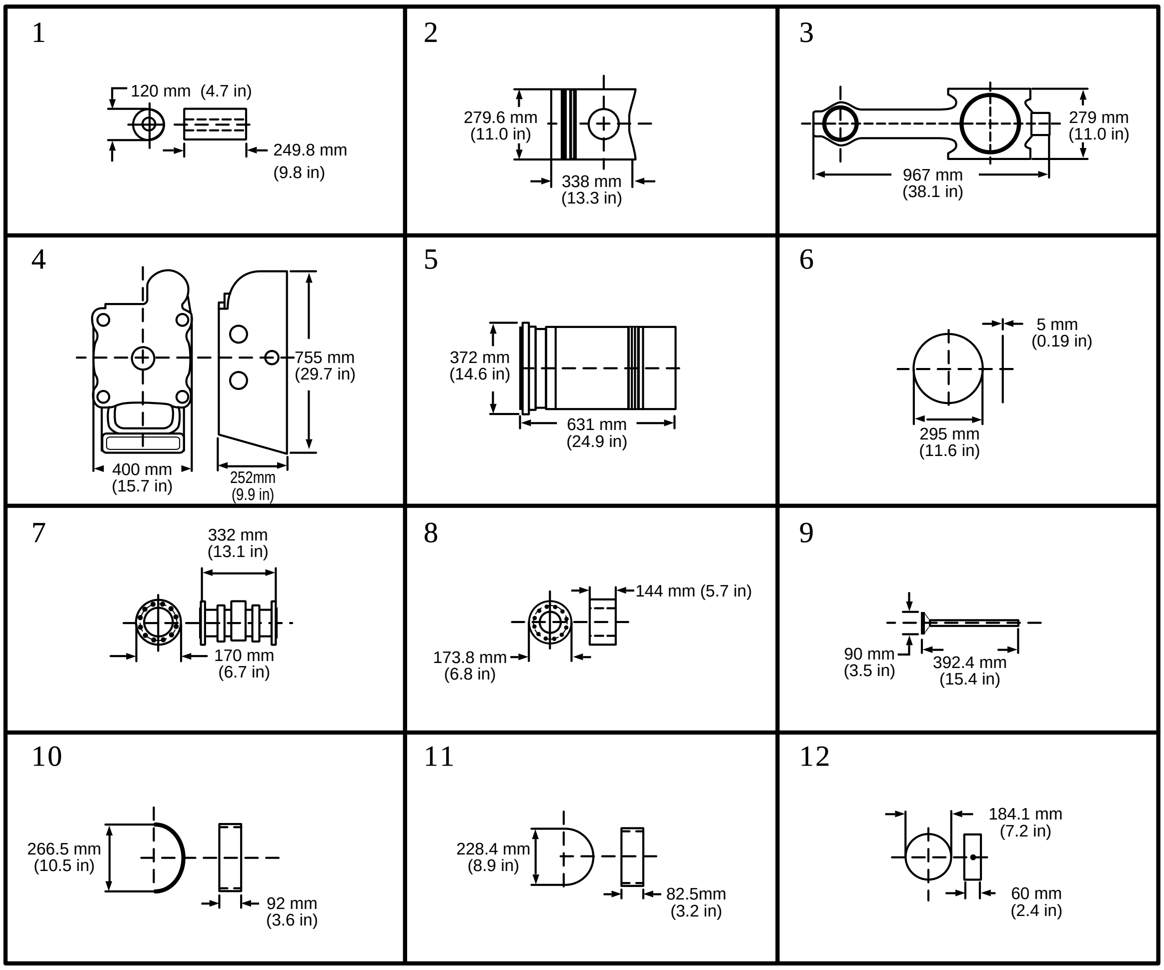
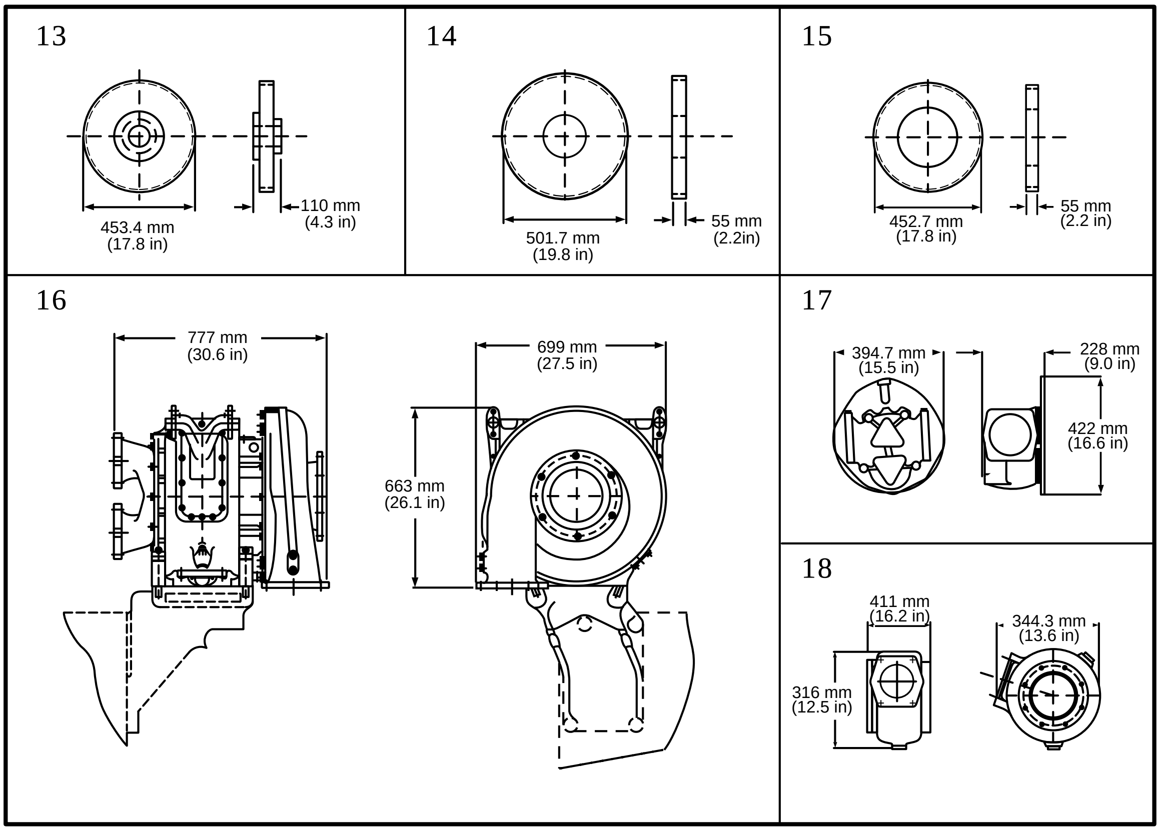


Figure 4



Shipping Weights							
Item	**Description**	**kg**	**(lb)**	**Item**	**Description**	**kg**	**(lb)**
1.	Piston Pin	19.1	(42)	7.	Camshaft Segment	30	(66)
2.	Piston	35.2	(77)	8.	Cam Journal	13.6	(30)
3.	Connecting Rod	56.2	(124)	9.	Valve	1.4	(3)
4.	Cylinder Head Assembly	235	(517)	10.	Main Crankshaft Bearing	4.5	(10)
5.	Cylinder Liner	127.9	(282)	11.	Connecting Rod Bearing	2.3	(5)
6.	Piston Ring	0.3	(0.7)	12.	Cam Bearing	1.4	(3.1)

Figure 5



Shipping Weights

Item	Description	kg	(lb)	Item	Description	kg	(lb)
13.	Camshaft Drive Gear	43.5	(96)	16.	Turbocharger (VTC 254)	500	(1100)
14.	Idler Gear	35.4	(78)	17.	Oil Pump	120	(264)
15.	Crankshaft Gear	37.6	(83)	18.	Water Pump	95	(210)

Figure 6

Spare Parts Kits

There are several spare parts kits available to ship from the factory with a 3600 engine order. The parts are boxed and preserved to insure protection for a minimum of two years in a marine environment. These spare parts kits are designed to allow the customer the flexibility to choose which items to keep in stock. In general, marine societies leave it to the discretion of the vessel owner to decide which spares to maintain on board.

The following is a list of the available Caterpillar spare parts kits and their contents:

Caterpillar P/N	Description	Contents
127-2441	Air/Exhaust Common	Gaskets
127-2442	Exhaust Bellows Kit 3606	Bellows and gaskets
127-2443	Exhaust Bellows Kit 3608	Bellows and gaskets
127-2444	Exhaust Bellows Kit 3612	Bellows and gaskets
127-2445	Exhaust Bellows Kit 3616	Bellows and gaskets
127-2446	Turbo Kit Common	Blanking plate, gaskets, etc.
127-2447	Turbo Kit 3612 and 3616	Extra blanking plate
127-2448	Head Kit Common	Pushrods, rocker arms, etc.
127-2449	Head Kit Distillate Constant Load	Cylinder head group
127-2450	Head Kit Distillate Cyclic Load	Cylinder head group
127-2451	Head Kit Heavy Fuel	Cylinder head group
127-2452	Gasket Kit Standard and Cuffed Liners	Liner gaskets
127-2453	Gasket Kit Flange Cooled Liners	Liner gaskets
127-2454	Basic Engine Kit	Studs, crank seal, etc..
127-2455	Flange Cooled Liner Kit	Cylinder liner
127-2457	Cuffed Liner Kit	Cylinder liner
127-2458	Rod Assembly Kit Vee Engine	Rod assembly
127-2459	Rod Assembly Kit In-line Engine	Rod assembly
127-2460	Fuel Kit Common	Seals, injector clamp, etc.
127-2461	Injector Kit Distillate	Two unit injectors
127-2462	Injector Kit Heavy Fuel	Two unit injectors
127-2463	Cooling System Kit Common	Gaskets, O-rings, etc.
127-2464	Instrumentation Kit	Standard thermocouples
127-2465	Instrumentation Kit	Marine society approved thermocouples
127-2466	Valve Kit Cyclic Load Distillate Fuel	Valves, inserts, rotocoils, etc.
127-2467	Valve Kit Constant Load Distillate Fuel	Valves, inserts, rotocoils, etc.
127-2468	Valve Kit Heavy Fuel	Valves, inserts, rotocoils, etc.
127-2469	Piston Assembly Kit	Piston assembly
127-2470	Bearing Kit	Bearings

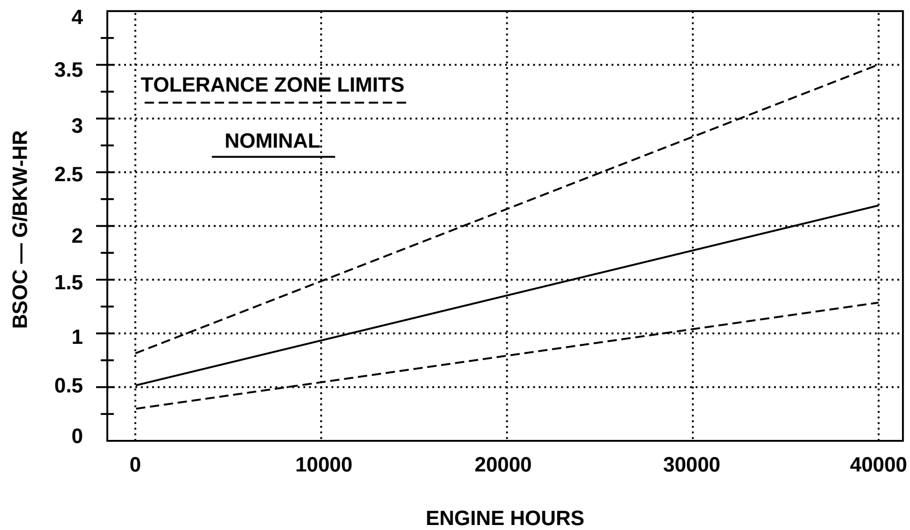
In addition to spare parts kits, a recommended spare parts list is available from Caterpillar to assist customers in selecting parts to support 3600 engines. For more information contact the 3600 Marine Product Support Group at (765) 448-5000.

Expected Parts Life

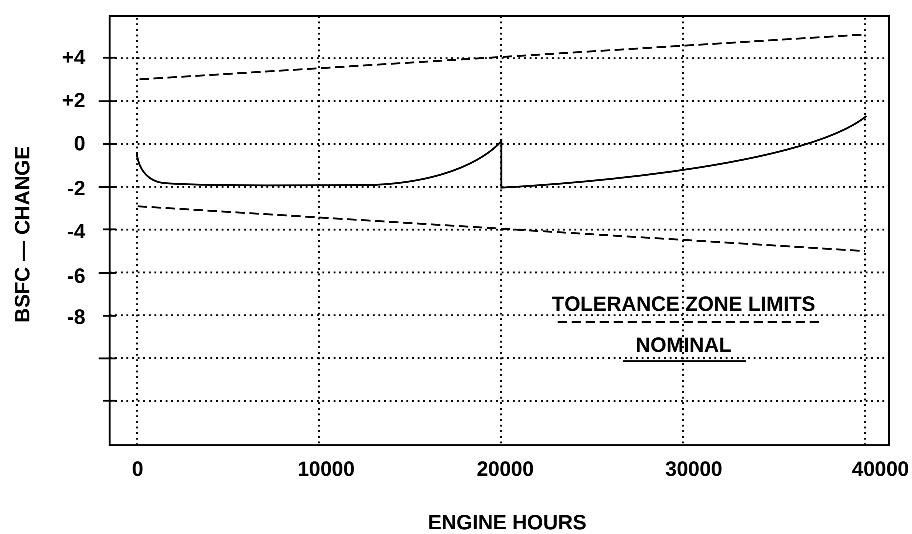
The life of major engine components such as cylinder liners, pistons, rings, bearings, etc. is dependent upon a number of factors including installation design, preventive maintenance practices, fuel type and quality, engine duty cycle and operating environment. Refer to the 3600 Operation & Maintenance Manual, Form SEBU6965, for maintenance intervals for major engine components.

Figure 7 shows the typical effects of engine operating hours on published oil and fuel consumption figures. The graphs assume that the guidelines in the Caterpillar Operation & Maintenance Manual are followed.

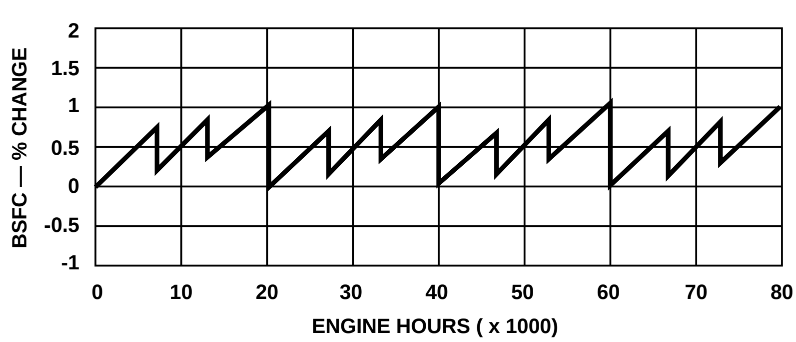
Oil Consumption vs Engine Hours



Diesel Fuel Consumption vs Engine Hours



Heavy Fuel Consumption vs Engine Hours



Note for heavy fuel:

The following conditions are necessary to maintain the specified fuel rate degradation:

1) Yearly injector replacement.
2) Regular service of aftercooler core and turbocharger.
3) Major overhaul every 20,000 hours.
4) Maintenance schedule adherence per all manufacturer's recommendations.

Figure 7

Service Tools

Caterpillar recommends the following special service tools. They are necessary for performing basic maintenance as well as to remove and install major engine components.

1U6428-Basic Service Tools Group (includes 8T2850 Basic Tool Group and a hydraulic hand pump)

1U6429-Basic Service Tool Group (includes 8T2850 Basic Tool Group and a 115V-50/50 Hertz hydraulic pump)

1U6430-Basic Service Tool Group (includes 8T2850 Basic Tool Group and a 230V-50/60 Hertz hydraulic pump)

The 8T2850 basic tool group contains tools to:

- Remove and install the cylinder liner, piston and connecting rod as an assembly.
- Remove and install the vibration damper
- Drain the oil and remove the filter element from the oil filter housing.
- Tension the cylinder head and main bearing cap studs.
- Drain the fuel filter housing and remove the filter elements.
- Protect the crankshaft journal and align the connecting rod onto the crankshaft during installation and removal of the piston and rod assembly.
- Remove and install the piston pin retainers (snap rings).
- Test, check and adjust the fuel timing and injector synchronization.
- Remove and install the cylinder liner.
- Disassemble the centrifugal oil filter.
- Remove and install the flywheel and rear gear assembly.
- Remove and install the crankshaft main bearings.
- Remove and install the camshaft bearing.
- Remove and install the cylinder head.
- Remove and install the piston and connecting rod assembly.
- Support the camshaft segments during removal and installation.
- Remove and install piston rings.
- Disassemble and assemble the water pumps.
- Remove the unit injector.
- Align the piston pin during assembly of the piston and connecting rod.
- Provide lifting eye bolts and link brackets necessary to service the engine.

Standard Service Tooling Recommendations

Quan.	Part No.	Description
1	8T0460	Standard Mechanic Service Tooling
1	9S1749	3/4 in. Drive Tool Group
1	FT1921	Guide Bolt
1	FT1922	Guide Bolt
1	6V2156	Lifting Bracket
1	1U8224	Nylon Lifting Sling 1 in. Wide
1	6V9093	Combination Wrench 13 mm
1	6V9097	Combination Wrench 17 mm
1	6V9099	Combination Wrench 19 mm
1	6V9103	Combination Wrench 24 mm
1	6V9104	Combination Wrench 30 mm
1	1U7827	Combination Wrench 32 mm
1	6V9109	Socket 3/8 in. Drive 13 mm
1	6V9112	Socket 1/2 in. Drive 17 mm
1	6V9114	Socket 1/2 in. Drive 19 mm
1	1U7883	Socket 1/2 in. Drive 24 mm
1	1U7902	Hex Socket 1/4 in. Drive 5 mm
1	1U7828	Hex Socket 3/8 in. Drive 8 mm
1	8T5096	Dial Indicator Group
1	6V2012	Depth Gauge Group
1	8H8581	Feeler Gauge Group
1	8T9293	Torque Wrench 1/2 in. Drive 4 to 339 N•m (3 to 250 lb ft)
1	8T9294	Torque Wrench 3/4 in. Drive 149 to 814 N•m (202 to 600 lb ft)
1	6V6080	Torque Multiplier

A complete set of Factory Diagnostic Tooling is also available for engine service. A recommended list for a specific application can be made available by contacting the Caterpillar Service Technology Group.

Operation and Maintenance Documentation

To order Caterpillar literature, consult your dealer or a Caterpillar 3600 Diesel Engine Application Engineer at
3701 State Rd. 26E, Lafayette, IN 47905
(317) 448-5000.

Caterpillar includes the following engine documentation:

3606 and 3608 Service Manual
Form SENR3595 includes:

1. Engine Specifications
2. Engine Systems Operation, Testing and Adjusting
3. Engine Disassembly and Assembly
4. Operation and Maintenance Manual Form SEBU6965

3606 and 3608 Operation and Maintenance Manual
Form SEBU6965 includes:

1. General Engine Information Including Emergency Service and Safety Information
2. Basic Engine Technical Data
3. Procedures for checking, starting, operating, stopping and storing the engine
4. Maintenance instructions
5. Maintenance Management Schedules
6. Preventative Maintenance Program
7. Warranty

3612 and 3616 Service Manual
Form SENR3590 includes:

1. Engine Specifications
2. Engine Systems Operation, Testing and Adjusting
3. Engine Disassembly and Assembly
4. Operation and Maintenance Manual Form SEBU6965

3612 and 3616 Operation and Maintenance Manual
Form SEBU6965 includes:

1. General Engine Information Including Emergency Service and Safety Information
2. Basic Engine Technical Data
3. Procedures for checking, starting, operating, stopping and storing the engine
4. Maintenance instructions
5. Maintenance Management Schedules
6. Preventence Maintenance Program
7. Warranty

3600 Parts Books
Form SEBP3600 and the Engine Serial Number

Two parts books are supplied with each engine. They are specific to each individual engine serial number.

3600 Technical Manual
Contains parts and service information on non-Caterpillar production parts based upon the Packaging Arrangement ordered by the customer.

See *Miscellaneous* section of this guide for a more detailed list of helpful publications for 3600 engines. Caterpillar literature can be ordered by using the LODE screen on the DTS order system. The following Caterpillar literature may be ordered to supplement the documents listed:

Form No.	**Title**
SEBF8100	Component List for 3600 engines
SEBF8101	Specifications for Cylinder Blocks
SEBF8102	Specifications for Crankshaft Measurement
SEBF8103	Specifications for Grinding Crankshafts
SEBF8104	Specifications for Camshaft Measurement
SEBF8105	Injector and Valve Lifter Groups
SEBF8106	Specifications for Cylinder Head Assemblies
SEBF8107	Specifications for Pistons and Rings
SEBF8108	Specifications for Connecting Rods and Bearings
SEBF8109	Cylinder Liners
SEBF8110	Specifications for Water Pumps
SEBF8129	Procedure to Salvage Cylinder Heads
SEBF8092	Specifications for Reusable Turbocharger Components
SEHS8841	Metal Stitching Procedures
SEBF8150	Piston Cleaning
SEBF8151	Cylinder Block Salvage
SEBF8152	Damper Rebuild
SEBF8160	Oil Pan Salvage
SEBF8171	Cleaning and Inspecting Engine Components
SEHS8704	Operation with Damaged Turbocharger

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3600 Marine Engine Application and Installation Guide

● Commissioning

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Commissioning Guide

Design Review

General

A well planned main propulsion installation aids reliability, performance, and serviceability. The designer must be aware of the application and installation requirements for 3600 engines. The designer should first be aware of pertinent reference publications, such as the *3600 Marine Application and Installation Guide*, as well as other information available from Caterpillar.

A poor installation can hinder serviceability and make routine maintenance and repairs difficult. The neglect of mounting, alignment, and support system requirements can lead to poor performance and increased operational cost.

After the ship designer has completed a review of the Caterpillar application and installation requirements, have a discussion with Caterpillar and/or Caterpillar dealer personnel to cover remaining concerns on specific areas of the installation. This will establish ground rules for further working relationships in the design phase. After the initial machinery arrangement, piping and structural drawings have been completed, follow-up discussions should take place with the designer to insure preliminary designs meet the *3600 Marine Application and Installation Guide* requirements. Utilize the *3600 Main Propulsion Design Review Report* as a review aid.

Explanation of Design Review Report

The report provides a checklist for the dealer and is available from Caterpillar. It will help determine if sufficient information has been provided to the installation designer for completion of initial layouts in compliance with requirements in the *3600 Marine Application and Installation Guide.*

Complete the form with general information about the owner, vessel, and builder/installer. Using the design criteria of the ship, record specific data concerning physical characteristics as well as the engine supporting systems.

There are provisions to record Caterpillar reference materials provided to the designer, as well as a checklist for results of the design and serviceability review. Note compliance with Caterpillar requirements by placing an “X” in the space next to the system reviewed, indicating satisfactory or unsatisfactory compliance. If the design of a system does not comply, space is provided to record required follow-up action.

After completing the design review form, and after reaching agreement on the required corrective action, all concerned parties should sign the form in the designated location.

Unsatisfactory System Design Review or Installation Audit

Engine systems which are declared unsatisfactory during the design review or installation audit require corrective action prior to vessel commissioning. The cost and effort to make design changes during the early stages of the design will be much less than the rework of the system once the vessel is placed in service. Appropriate measurements of all engine operating parameters will be taken during dock or sea trials to ensure that engine system temperatures and pressures are within prescribed limits. Engines not meeting the prescribed limits will be derated (if derating the engine to lower power or speed results in operating conditions below the limit) or the shipyard, installer, or customer must accept responsibility for shorter engine life or engine failures resulting from a design or installation deficiency. Notify all concerned parties (including the vessel owner or operator) of any system design deficiencies. Caterpillar warranty for defective material or workmanship remains in effect; however, failures resulting from non-compliance with published application requirements and operating limits are not warrantable.

CATERPILLAR 3600
Main Propulsion Design Review Report

Directions: Fill in the blanks below, or circle the appropriate choice listed.

GENERAL

Selling dealer:	District or Subsidiary:
Servicing dealer:	Customer:
Equipment suppliers:	Address:
	City, State, Zip:

CONSIST

Engine model #:		Engine arrangement #:	
OT specification #:		Serial #:	
Rating:	bkW (bhp)	Speed:	
Engine cooling circuit:	Separate /Combined	Coolant used:	Antifreeze/Corrosion inhibitor
Governor model and type:		Oil used in engine:	
High idle specified:		"OT" specification:	
Low idle specified:		% Droop specified:	
Fuel used:	Distillate/Blended/Residual	Fuel gravity:	kg/1(lb/gal)
Fuel treatment:	Filter/Centrifuge	Viscosity control:	Yes/No

SHIP DATA

Type of hull:		Expected ship usage:	service hours/year
Water line length:	meters/feet	Expected vessel speed:	knots
Displacement:	long tons	Fuel capacity:	liters/gallons
Midship coefficient:		Water capacity:	liters/gallons
Prismatic coefficient:		Beam:	meters/feet
Hull material:		Draft:	meters/feet

CATERPILLAR 3600
Main Propulsion Design Review Report

Directions: Fill in the blanks below, or circle the appropriate choice listed.

REDUCTION GEAR DATA

Reduction gear manufacturer:	Reduction gear type:
Reduction gear model #:	Ratio, forward:
Clutch type: Hydraulic/Pneumatic	Ratio, reverse:

PROPELLER DATA

Manufacturer:	Model #:
Propeller type: Fixed/Controllable	Kort nozzle: Yes/No
Number of blades:	Diameter:
Pitch:	Radius of aperture:
Developed blade area:	Radius of aperture:
Contact for propeller design information: Name: Address: Telephone:	

SHAFTING DATA

Intermediate shaft, diameter:	Tail shaft, diameter:
Intermediate shaft, material:	Tail shaft, material:
Intermediate shaft, length:	Tail shaft, length:
Maximum angle of operation: from horizontal	Add'l engine driven loads:
Shaft brake manufacturer:	Shaft brake model #:
Contact for drive line/shafting design information: Name: Address: Telephone:	

CATERPILLAR 3600
Main Propulsion Design Review Report

Directions: Fill in the blanks below, or circle the appropriate choice listed.

MISCELLANEOUS SYSTEMS

Type of cooler for engine jacket water:	Fuel day tank capacity:
Manufacturer of J.W. cooler:	Day tank temperature rise evaluated? Yes/No
Model # of J.W. cooler:	Fuel cooler type:
Manufacturer of propulsion control system:	Manufacturer of F.O. cooler:
Type of propulsion control system:	Model # of F.O. cooler:
Model # of propulsion control system:	

APPLICATION SUMMARY

Provide any comments/remarks regarding this installation:

CATERPILLAR 3600
Design Review Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Air Intake Satisfactory _____ Unsatisfactory_____	
Cooling Satisfactory_____ Unsatisfactory_____	
Starting Satisfactory_____ Unsatisfactory_____	
Exhaust Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Design Review Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Fuel Satisfactory _____ Unsatisfactory_____	
Lubrication Satisfactory_____ Unsatisfactory_____	
Engine Mounting Satisfactory_____ Unsatisfactory_____	
Driven Equipment Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Design Review Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Safety and Alarms Satisfactory _____ Unsatisfactory_____	
Engine Monitoring Satisfactory_____ Unsatisfactory_____	
Ventilation Satisfactory_____ Unsatisfactory_____	
Serviceability Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Design Review Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Equipment Safety Satisfactory _____ Unsatisfactory_____	
Propulsion Controls Satisfactory_____ Unsatisfactory_____	
Operation and Maintenance Satisfactory_____ Unsatisfactory_____	
Crankcase Ventilation Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Design Review Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Satisfactory _____ Unsatisfactory_____	
Satisfactory_____ Unsatisfactory_____	
Satisfactory_____ Unsatisfactory_____	
Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Design Review Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

The following parties have discussed and agreed to the results and required action during the design review process:

Field Engineer Signature:_______________________________________ Date__________

Builder/Installer Signature:_____________________________________ Date__________

Owner Signature:____ Date__________

Installation Audit

Introduction

Vessel construction follows the satisfactory completion of the design review. During this phase, visit the shipyard *at least* two times to perform an ongoing review of the installation progress.

The first visit should follow the engine installation. Additional visits may be necessary depending on the difficulty of the installation and the stage of completion. Make the final visit before the initial startup process begins.

Visit objectives are to determine if the previously agreed on design criteria are being followed. These visits not only continue to produce a better understanding of Caterpillar requirements, but also provide the basis for a more reliable installation. To avoid costly delays, experienced shipbuilders will make necessary changes as soon as possible.

Explanation of the Installation Audit Report

The *Caterpillar 3600 Main Propulsion Installation Audit Report* is intended to provide a checklist for dealer use only, and is available from Caterpillar. The report is a simple checklist used to determine if the previously agreed on design criteria have been successfully implemented during the construction process.

Fill out the report with general information about the owner, ship particulars and builder/installer information, including the engine room physical features. Provisions are made for recording the propulsion system component descriptions, including serial numbers and manufacturer where applicable.

When the construction and installation are in compliance with Caterpillar requirements, indicate by placing an “X” in the space next to the system reviewed for satisfactory and unsatisfactory compliance to requirements. If a system does not comply, there is space to record the necessary corrective action. The following system-by-system review provides general guidance for the audit.

Air Intake System Evaluation

The total system must be evaluated from the source of the air for the engine to the turbocharger. This may include engine room air, or the air cleaner may be mounted outside the engine room. Consider the following items:

A. Combustion Air

Air inlet temperature to the engine must not exceed 45°C (113°F) for distillate and heavy fuel engines.

The quantity of available air must be sufficient for combustion. The 3600 engine requires approximately 0.1 m^3/min/bkW (2.5 ft^3 of air/min/bhp) for engines using distillate fuel. Heavy fuel engines require more air for proper component temperatures.

The engine room or enclosure should not experience negative pressure if combustion air and ventilation air are from the same source.

In extremely cold climates, an alternate warm filtered air source must be available for starting the engine.

B. Remote Mounted Air Cleaners

Air cleaner elements must be accessible for periodic maintenance.

Mount the air cleaner elements in the housing to assure the engine does not ingest foreign material due to incorrect positioning.

The air cleaner housing air outlet must have a flexible transition attaching the air inlet ducting. Double band clamping at each end of the flex is required to assure nonfiltered air does not enter the ducting.

The epoxy paint provided on all Caterpillar supplied air cleaner housings must be maintained for good surface protection in harsh environments, such as salty atmosphere.

Air inlet restriction is recommended not to exceed 381 mm (15 in.) of water. New, clean systems should be near 127 mm (5 in.) of water restriction to allow appropriate service intervals for the filter elements.

The air cleaner housing must be mounted in a position that will not allow recirculating exhaust gases, crankcase fumes, rain, or sea spray to mix with the combustion air.

A typical method of conveying combustion air to the engine is with the air cleaner drawing outside air through the elements, and to use air ducting to the turbo inlet. The air cleaners may also be located within the engine room if the ambient conditions meet allowable air inlet temperatures.

In cold climates, the air cleaner can be subjected to filter icing when mounted outside the engine room. Consider the service of the ship and the potential variations in climate. The engine must receive filtered inlet air regardless of the geographic location of the ship.

C. Air Inlet Ducting

The intake air ducting must be clean and free of weld slag, debris, rust, or corrosion prior to operating the engine. Ducting must be inspected prior to initial startup.

The interior surface of the intake ducting must be protected from future rust and corrosion due to intake air quality.

If a single straight length from the air cleaner housing is not possible, the intake air piping must have long gentle radius bends (2 x Dia = bend radius) and generous straight lengths.

The diameter of the intake ducting must be the same or larger than the air cleaner housing outlet and the air inlet adapter for the turbocharger. Any abrupt transitions must be avoided. For further information and guidance, see the Engine Systems - Air Intake section of the *3600 Marine Application and Installation Guide* on air inlet ducting.

The air inlet restriction created by the ducting must be minimal to allow normal service intervals for the air cleaner elements.

Air inlet ducting must not be rigidly mounted to either the air cleaner housing or to the turbocharger inlet. Flexible nonmetallic connections must be used between the ducting of both the air cleaner housing and the turbocharger. The turbocharger must not support the weight of the ducting. Double band clamping must be used to insure nonfiltered air does not enter the engine.

Note the proximity of the exhaust piping and the air intake ducting. If heat transfer between the two sets of piping is evident, insist that either or both are insulated to protect both air inlet temperature and the non-metallic connections.

Air inlet ducting must be inspected for leaks during engine operation.

D. Filtered Engine Room Air

An ABB air intake silencer can be used at the turbocharger inlet if combustion air supplied to the engine room is properly filtered. The combustion air must also be free of insulation pericles, exhaust leakage, or other sources of contamination from the engine room

If an ABB intake silencer is remote-mounted, the same requirements apply for ducting to the turbocharger inlet as in the case of a remote-mounted air cleaner housing.

E. Air Cleaner Provided by Others

Engine air cleaners not provided by Caterpillar must meet air flow and contamination containment requirements to protect the engine from shortened component life. This requires prior factory approval.

Cooling System Evaluation

A cooling system evaluation must include engine operating parameters, external system piping, water quality and external cooling components. A properly controlled cooling system is essential for satisfactory engine life and performance. Defective cooling system and careless maintenance are a direct cause of many engine failures. Consider the following:

A. Engine Cooling Circuits

Water flow from the left side pump (viewed from the rear) is split between the aftercooler and oil cooler. Flow balance orifices are used on the outlet of both components. Insure the orifices are in place.

The right-hand pump (viewed from the rear) supplies water to the jacket water system. Insure the orifice is in place.

The two pump design can be used as either a combined or separate circuit cooling system. The temperature of the water is always inlet controlled.

During performance testing of the engine, be sure the appropriate inlet water temperature is being supplied to both circuits and the temperature rise of the water is within specified limits.

B. System Coolers

3600 propulsion engines have the coolant water cooled by various methods, including shell and tube heat exchangers, plate and frame heat exchangers, keel coolers, and box coolers.

It is the user/installer's responsibility to provide proper venting and isolation of the cooler for required maintenance or repair.

C. Cooling System Pressure Drop

The external system resistance must be site adjusted to specifications based on the rated speed of the engine and full flow to the external system. Circuits with thermostats must be replaced with blocked open stats (for adjustment only) to allow full flow.

The inlet and outlet pressure of the coolant must be measured as close to the engine as possible to obtain a correct external system resistance. Customer piping must have monitoring ports for this measurement.

Insure that the flow control orifice is positioned in the outlet lines from the engine to the cooler. A lockable plug valve is preferred but a plate-type orifice or other type adjustable valves are permitted. The external system resistance *must* be maintained at the specified value. See the Engine Systems - Cooling section of the *3600 Marine Application and Installation Guide.*

The method used to set external resistance depends on cooling system geometry.

Method 1: Used with Caterpillar expansion tank and regulators mounted on the front module. External pressure drop is measured from the engine outlet to the cold flow entrance at the regulator housing (see Figure 1).

rpm	(Δ) P (P_1 - P_2) kPa (psi)
1000	**90 (13)**
900	**73 (11)**
750	**51 (7.5)**
720	**47 (7)**
Tolerance:	**± 10%**

Method 2: Used when the circuit includes a remote-mounted expansion tank and remote regulators. External pressure drop is measured from the engine outlet to the pump inlet (see Figure 2).

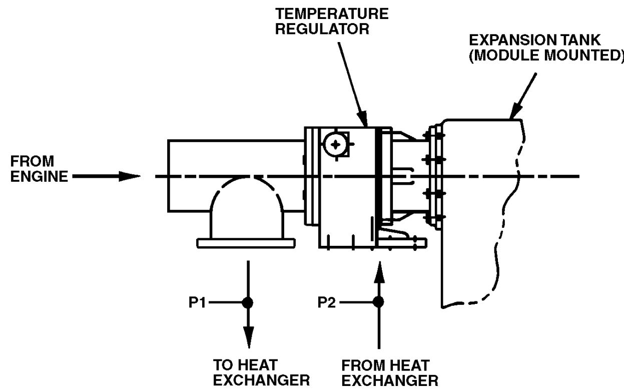
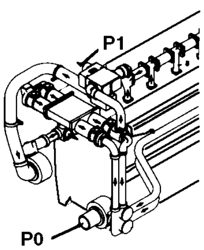


Figure 1

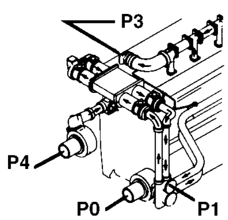
3606 and 3608 Combined Circuit

External Circuit Resistance, kPa (psi)



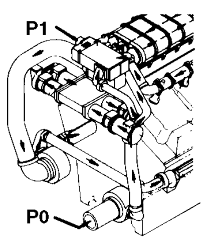
Engine Speed rpm	Low Temperature Circuit (Δ) P (P1-P2)	High Temperature Circuit (Δ) P (P3-P4)
1000	91 (13)	—
900	71 (10)	—
750	45 (6.5)	—
720	40 (5.8)	—
Tolerance:	± 10%	—

3606 and 3608 Separate Circuit



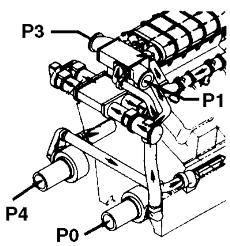
1000	104 (15)	99 (14)
900	84(12)	77 (11)
750	58 (8)	50 (7)
720	52 (7.5)	44 (6)
Tolerance:	± 10%	± 10%

3612 and 3616 Combined Circuit



1000	85 (12)	—
900	66 (9.6)	—
750	42 (6)	—
720	38 (5.5)	—
Tolerance:	± 10%	—

3612 and 3616 Separate Circuit



1000	85 (12)	103 (15)
900	66 (9.6)	81 (12)
750	42 (6)	52 (7.5)
720	38 (5.5)	47 (7)
Tolerance:	± 10%	± 10%

Figure 2

D. Expansion Tanks

The water level in the expansion tank should be at the highest point in the cooling system to allow proper venting during initial filling of the system. This will also provide a single fill point for the cooling system.

If the expansion tank is not the highest point in the system, it is the user/installer's responsibility to provide an auxiliary expansion tank at the highest point in the system. The auxiliary tank must be interconnected with the expansion tank to provide complete venting of the system.

Run vent lines from other cooling system components to the auxiliary tank, or vent them independently.

Initial filling of the system must be done at a rate to allow complete venting of the system. Always be ready to add supplemental volume of water to system at initial start-up in case air has been trapped in the system. The Caterpillar expansion tank is provided with a 48 kPa (7 psi) pressure cap. Remove the pressure cap during the testing and adjusting the external system resistance. Reinstall the pressure cap prior to the engine performance testing under load.

If an expansion tank pressure cap is not used, adjust the water temperature alarm and shutdown contactors according to atmospheric conditions to insure adequate engine protection.

If a non-Caterpillar expansion tank or a shunt style cooling system is used, a complete test must be done complying with requirements listed in Caterpillar EDS 50.5, *Cooling System Field Test,* Form No. LEKQ7235.

Automatic air release valves are recommended when it is not practical to route vent lines to a common venting point. The heavy duty (cast iron body) style is recommended. The valves usually have a *fast-vent* port which can be replaced by a ball valve to allow venting during the system initial fill. An internal diaphragm collects entrained air and automatically releases it to atmosphere.

E. Cooling System Protection

Protecting the engine from cooling system problems is imperative. Insure the engine is equipped with the following, and the protection system functions according to specification.

- High jacket water temperature alarm and shutdown
- High oil temperature alarm and shutdown
- Low water detector alarm and shutdown
- High air inlet manifold temperature alarm

The protection system functions listed above may require modification due to the involvement of marine classification societies and other regulatory bodies.

It is the user/installer's responsibility to provide additional pressure and temperature gauges and alarms in the external system for the operators to monitor daily. Detection of a developing cooling system problem can prevent an unscheduled shutdown of the engine or an operation alarm condition.

F. Central Cooling Systems

Cooling multiple engines from one system is becoming common on large ocean going vessels.

If a central cooling system is used, the system performance must be evaluated with the maximum heat rejection possible from all engines being cooled. Since every system, application and installation will be unique, they must be approved by Caterpillar.

G. External System Piping

The external system piping must be clean and free of weld slag and other debris. Insure the piping is thoroughly cleaned before filling the system.

Install temporary strainers at the engine in the coolant inlet lines prior to initial engine operation. Operate the engine at no-load and rated speed for at least 15 minutes. Remove the strainers and check for debris. If debris is found, reinstall the strainers and repeat the operation. Continue this procedure until no debris is found in the screen. *Do not* adjust external system resistance with the strainers installed. The temporary strainers are available from Caterpillar for 101 mm (4 in.) [4C9045], 127mm (5 in.) [4C9046], and 152 mm (6 in.) [4C9047] pipe.

If a permanent strainer in the coolant inlet lines is provided by the user/installer, the pressure drop across the strainer must be monitored as well as alarmed. Excessive pressure drop can cause improper coolant flow to the engine. The same procedure should be followed for permanent strainers as was described above for temporary strainers during initial engine operation. At maximum flow condition clean strainers should have no more than a 10-14 kPa (1.5-2 psi) pressure drop.

H. Corrosion Protection

Ensure that Caterpillar guidelines established for water quality are followed precisely. They are published by Caterpillar and available in the standard publication system. *Engine Installation and Service Handbook*, Form No. LEBV0915, and *Coolant and Your Engine*, Form No. SEBD0970, are two publications containing information.

Ensure the system is filled with the proper quality fresh water. It should also be treated with corrosion inhibitor. Caterpillar Coolant additive is 8C3680 and 5P2907 in 18.95 L (5 gal) and 208 L (55 gal) containers. Caterpillar does not approve other additives.

If ambient conditions require antifreeze, only low silicate antifreeze is allowed. Caterpillar Antifreeze is available in 3.8 L (1 gal) and 208 L (55 gal) containers, part No's. 8C3684 and 8C3686 respectively. Use the Cooling System Test Kit (8T5296) to evaluate the concentration of corrosion inhibitor in the system. Excessive concentrations are as detrimental to the engine as insufficient concentrations.

I. Heat Recovery

Recovering heat from the engine coolant can improve the efficiency of the operation but can also be detrimental to the engine if not designed and installed properly. A common example of heat recovery is using engine jacket water heat to operate fresh water distilling plants.

External temperature regulators must not, in any way, inhibit the operation and temperature control of the engine temperature regulators.

The external heat recovery components must not cause excessive coolant flow resistance.

Inlet temperature control at the engine is often misunderstood during the design of the system. The water temperature returning to the engine must be cooled sufficiently to achieve the required coolant mix temperature at the engine pump inlets.

J. Cooling System Performance

The complexity of the external cooling system, which may include heat recovery and/or some other cooler, is best understood by reviewing the installed system and producing a schematic of that system. The schematic should indicate all of the system flow paths, test and monitoring points, and external system components. It should be included as an attachment to the Installation Audit Report.

Assign 900 series description numbers to each of the test and monitoring points and record their readings on the Installation Audit Report test sheet.

Starting System Evaluation

Air starting is typical for 3600 engines. The system components can have a significant effect on the life of the starters.

A. Air Compressor

Must be sized to match the air receiver tank(s) make-up rate due to starting.

An air dryer is suggested on the compressor outlet to prevent water vapor in the air from freezing if expanded below 0°C (32°F).

B. Air Receiver Tanks

Tanks should be sized to provide the required consecutive engine starts without depleting the air pressure below minimum required starting pressure.

Manual or automatic drains should allow oil and water deposits to be drained daily. Operators must be informed of this requirement.

Receiver tanks must meet specific characteristics, such as the specifications of the American Society of Mechanical Engineers (ASME). If the ship is classed, the Classification Societies may have specific requirements for air receivers (unfired pressure vessels). Each receiver tank should have been pretested at 1 $^1/_2$ times the normal working pressure unless the cognizant Classification Society requires some greater value. Make sure the tank pressure relief valve is set at a level below test pressure.

Receiver tanks must be equipped with a maximum pressure relief valve and a pressure gauge. Provide monitoring to assure proper operation.

C. Air Supply Piping

Size piping to provide a minimal pressure drop of supply air from the receiver tank to the engine starters. Piping must not be smaller than the connection at the engine.

Route piping to trap water vapor and oil deposits at the lowest point in the piping. Drain the trap daily if a manual trap is used, or install an automatic trap for this purpose. Operators must be informed of this requirement. If possible, the supply piping can be routed upward from the reservoir to the engine allowing condensation to drain to the reservoir.

Piping systems should withstand 1$^1/_2$ times the normal working pressure unless the cognizant Classification Society requires some greater value. See note in Air Receiver Tanks above.

Prior to the initial startup of the engine, disconnect the air piping from the engine and allow controlled air to blow water vapor, oil deposits or debris out of the pipe. Starter damage can result otherwise.

D. Engine Starters and Accessories

Note: *Maximum air pressure to the starter inlet ports is 1550 kPag (225 psig). An air regulator must be used if supply pressure exceeds this level.*

Adjust the starter lubricator to limit excessive leakage of starter lubricant at the starter air outlet. This should be done during initial engine startup. The starter silencer discharge must not endanger personal safety. Provide shielding if the discharge is directed toward potentially occupied areas.

E. Start-up and Shutdown Procedure

The following procedure is a guide for:

- 3600 engine start-up procedures
- Design consideration of the engine control systems.

Before Starting the Engine

- Check the coolant level in the expansion tank site glass.
- Check the crankcase oil level using the engine dip stick. Be sure to use the side marked “Engine Stopped Cold Oil”. Mark the dipstick for operating and non-operating conditions.
- Be sure all protective guards are in place and the barring device is disengaged.
- Open and close the drain valve on the bottom of the starting air tank and fuel day tank to drain condensation and sediment.
- Open the starting air shutoff valve at the side of the engine.
- Check the starting air pressure. There must be a maximum of 1551 kPa (225 psi) or a minimum of 861 kPa (125 psi) air pressure available for starting.
- Check the air starter lubricator oil level. Check the prelube motor lubricator oil level (if air prelube equipped).
- Be sure the engine control system allows engine shutdown from the engine starting panel.
- Remember that other engine support systems or control systems must be prepared before engine startup. This includes reduction gear prelube and external piping system valve position.
- Open the combustion chamber snifter valves (Keine valves) and with the fuel control switch in the *OFF* position, rotate the engine with the air starters while watching for fluids expelled from Keine valves. After this step is completed, close the Keine valves hand tight. If the valves are over tightened, the seat may be damaged when the engine reaches operating temperatures.

Starting the Engine

- Put the engine fuel on/off switch to the *ON* position.
- Put the engine start/prelube switch in the prelube position. The green indicator will light when prelube oil pressure reaches 7 kPa (1 psi). The engine can now be started. Verify oil gauge pressure if time is not a critical factor.
- Move engine start/prelube switch to the *START* position while viewing the engine tachometer. At 130 to 150 rpm, the start/prelube switch can be released from the start position. If not the starters will automatically disengage when the engine reaches 170 rpm.
- The engine should stabilize at low idle speed, typically 350 rpm. Check the gauge panel oil and fuel pressure readings to see they reach normal levels.

- Inspect the engine for leaks and listen for abnormal noises.
- After proper engine operation is assured, adjust the engine and other control systems to increase engine speed/load to normal operation.

After starting the engine

- Close the starting air shutoff valve.
- Monitor engine operating parameters every hour and record the readings on an appropriate log sheet.
- Compare the operating parameters recorded to the factory specifications on a daily basis. Monitor operating trends and take action when discrepancies are found.

Stopping the engine

- Reduce load on engine to zero.
- Allow the engine to operate for the period of time necessary to reduce jacket water temperature to 85°C (185°F) and the average cylinder exhaust temperature (of all cylinders when exhaust pyrometer equipped) is reduced to below 150°C (302°F). Fifteen minutes of operating time will normally achieve the cooler temperatures.
- Request the wheelhouse to release propulsion system control to the engine room.
- Turn the engine fuel on/off switch to the *OFF* position. The engine will coast to a stop by energizing the fuel shutoff solenoid.
- Check (and put into shutdown mode) all other non-engine driven system components that have been operating to support engine operation.

Exhaust System Evaluation

The exhaust system for 3600 engines must be evaluated from the exit of exhaust gases from the turbocharger to the atmospheric conditions at the muffler outlet. Fuel consumption and component life of the engine are affected by a faulty exhaust system.
Consider the following items:

A. Exhaust System Warnings

The engine installer must protect engine room equipment and personnel from the heat of exhaust system piping.

The engine installer must provide appropriate drains and/or rain caps to protect the engine from rain water and sea spray entering the engine through the exhaust piping. The configuration of the last few feet of exhaust outlet should prohibit rain water or sea spray entry without excessive exhaust backpressure.

Common exhaust systems between engines are to be strictly avoided.

The turbocharger must be protected from debris entering the exhaust outlet during construction of the exhaust piping. A properly tagged blanking plate is recommended. It must be removed prior to initial engine operation. The debris collected on the plate must not enter the turbocharger.

B. Exhaust System Piping

The exhaust system piping material must withstand the effects of exhaust gas temperature, velocity, and thermal expansion. Insulation added to the exhaust piping must not deteriorate the piping. Insulated pipe temperatures are higher than non-insulated.

Exhaust backpressure of the total piping system must be minimal to allow for muffler restriction, outlet piping from the muffler, and piping degradation during the life of the engine. Fuel consumption and component life will be affected if the backpressure is beyond the recommended value of 254 mm (10 in. H_2O). *Heavy fuel engines are limited to 254 mm (10 in. H_2O). Consult Caterpillar if higher backpressures are anticipated.*

Exhaust backpressure on each bank of the twin turbocharged 3612 and 3616 (vee) engines must be balanced, even when the dual pipes exiting the turbos are transitioned into one larger pipe going to the muffler. Do not allow gas flow to turn at a right angle during a transition. If possible, do not allow the exhaust system piping for a vee engine to be routed vertically from each turbocharger and then be blended horizontally. This will cause excessive backpressure on one bank. Blend the exhaust gasses into a common pipe before making the directional change. If this is not possible, the blending area must be designed to maintain equal bank-to-bank restriction.

Measure backpressure in a straight length of the exhaust pipe at least 3 to 5 pipe diameters away from the last size transition change from the turbocharger outlet. System backpressure measurement is part of the engine performance testing and must be recorded. A 1/4 in. NPT or 1/8 in. NPT fitting is required in the exhaust piping for backpressure measurements. Extensions may be required to protect instrumentation from heat damage and reach through exhaust lagging into the gas stream. Backpressure gauges are available to continuously monitor pressure levels.

Do not support exhaust piping from the engine package and do not allow it to interfere with the service of the engine.

Expansion joints and vertical supports in appropriate positions must allow for free movement of the exhaust piping during thermal expansion.

The exhaust piping must be rigidly supported (with off- engine supports) near the engine to minimize compression and offset of the engine exhaust bellows. Exhaust pipe expansion must be directed away from the engine. Rollers are strongly recommended when vertical supports are required between expansion joints and rigid supports.

Fuel System Evaluation

Clean fuel meeting Caterpillar's fuel recommendations provides the maximum engine service life and performance; anything less is a compromise and the risk is the user's responsibility. The fuel system must be evaluated from the storage tank to the engine, including the engine fuel controls. A fuel sample must be analyzed to verify engine performance. The data is used in the Caterpillar CAMPAR evaluation. The governor control system should be described along with information concerning the governor's interaction with the engine.

A. Fuel Tanks

Fuel tanks vented to atmosphere must have some form of flame arrester in the vent opening to prevent flames entering or exiting the tank. As a minimum precaution, install a fine mesh screen at the outlet opening in the tank vents to act as a flame arrester. Other forms of flame arresters can be used and the vent opening must never be left totally open to atmosphere.

The fuel supply piping should draw fuel from approximately 100 mm (4 in.) above the bottom of the day tank. The fuel return to the day tank must enter at the top (above the fuel level) and opposite the supply end.

A tank valve must be provided to drain water and sediment. Typically classification societies or other regulatory bodies require the valve to be a fast acting spring closure type.

B. Fuel Lines

Galvanized fittings or piping must not be used in any portion of the lines. Zinc can leak from piping or fittings and react with sulphur in the fuel during the combustion process to form zinc sulphate with a detrimental effect on exhaust valves. Fuel line size and length must conform to the fuel transfer pump inlet and return restriction limits. The inlet restriction must not exceed 39 kPa (5.7 psi) and the fuel return line restriction must not exceed 350 kPa (51 psi). Measure and record the values.

Note: The limits are independent of each other and should not be combined in the evaluation.

Fuel lines must be treated (pickled) and coated on the inside with lube oil prior to final assembly.

Fuel lines must never be smaller than the engine connections of 32 mm (1.25 in.) pipe for the supply and 25 mm (1 in.) pipe on the return.

C. Fuel Filters

Monitor initial fuel filter differential pressure to eliminate premature plugging of engine filters.

The user and/or installer is responsible for providing primary filtering of the fuel supplied to the engine. Water separation is of prime concern. Install water separators or coalescing filters. If the fuel does not meet the required recommendations, use a fuel centrifuge/purifier. Recirculate the fuel in the day tank through the centrifuge for 24 hours prior to operating the engine. A stock of engine fuel filters should be on-board prior to initially starting the engine.

D. Fuel Coolers

A fuel cooler may be required if the day tank is not large enough to handle heat transfer from the injection pumps. Size the fuel cooler to cool fuel returning to the day tank to below 40°C (100°F) with distillate fuel. Return heavy fuel oil (HFO) to the booster module without cooling to allow viscosity control back to the engine. Parallel HFO and distillate systems must have control valves to send fuel to the cooler when switching to distillate. HFO systems are operated at higher temperatures to ° maintain proper viscosity.

Note: *See the section on Engine Systems - Fuel in this guide for additional information.*

A *water-to-fuel* cooler is typical but a cooler failure can result in water entering the fuel supply leading to subsequent fuel injector failures. If sea water is used for a cooling medium, the operator must inspect the sacrificial anodes at least once a week until a consumption rate has been established.

Governors/Actuators

The governor type and its operating characteristics must be described in the Installation Audit Report.

If a hydra-mechanical governor is used, the smoke limiter and droop must be properly adjusted to assure optimum response to load changes.

If a Heinzmann or Woodward electronic governor is used, evaluate proper governor operation prior to initial startup. Consult the governor operator's manual for procedures.

Lubrication System Evaluation

The lubrication system supplies a constant flow of oil to engine components. The oil is filtered, cooled, and pressure regulated throughout the engine operating range. Bearing failure, piston ring sticking, and excessive oil consumption are classic symptoms of oil related engine problems. Maintaining the lubrication system, using scheduled oil sampling and quality oil can make the difference between repeated oil related failures and satisfactory engine life.

A. Engine Oil

The oil must be evaluated for 3600 oil requirements prior to filling the sump, including scheduled oil sampling (S•O•S). Record oil brand and type. Note: Refer to the *Engine Systems - Lubricating Oil* section of this guide for additional information. An S•O•S sample must also be evaluated after sea trails completion.

A system must be in place to properly handle waste oil from engine oil changes.

B. Engine Sump

The oil sump may be filled through the oil filler tube or via the sump valves through the lube oil transfer system. All lube oil transfer piping must be pickled and flushed prior to being placed in service. Inspect the proposed oil storage tank prior to filling.

The user may connect one of the oil sump drain valves to external piping for draining oil during an oil change. Use a flexible connector between external piping and the drain valve.

Insure that the cold engine oil level is correct and check the oil level several times during initial engine operation. Allow the engine oil temperature to reach normal operating temperature, which is 82°-85°C (180°-185°F). The dipstick must be marked for the proper operating level at rated speed and installed engine tilt angle.

C. Engine Prelube

If equipped, insure that the air prelube motor is properly lubricated prior to operation.

Check the air receiver tank sizing for the required starting requirements. Consider air prelubing requirements.

Prelube time must be within the required engine starting time. If not, a larger pump or continuous prelube may be required.

Electric prelube systems must have motor starters sized for the proper current draw to maintain pump operation until prelubing is complete.

Continuous prelube systems must have the Caterpillar spill tube system installed to prevent oil collecting in the cylinders, resulting in hydraulic lock and damage to cylinder components on startup.

D. Oil Pressure and Temperature

Provide safety shutdowns and alarms for these engine operating parameters.

Mounting and Alignment Evaluation

See guide section on *Mounting and Alignment* for detailed instructions and guidelines. The commissioning engineer should record final alignment measurements and include them as an attachment to the Installation Audit Report. It is also necessary to check crankshaft end play and crankshaft deflection. Record the readings in the Installation Audit Report. Consult Caterpillar publication *3600 Generator Set Commissioning Guide*, Form No. LEKX6560, when a generator set is involved.

Driven Equipment Evaluation

Driven equipment can be in many configurations, but each must be evaluated according to the external distribution system requirements. When more than one engine is involved, each must be described in the commissioning report. Ensure engine mounting, alignment, and connections are correct per the *Mounting and Alignment* section of this guide. Consider the following items:

A. Torsional Coupling

Record all manufacturer's data (serial number, model number, etc.) and other information relating to features such as torsional stops or emergency take home devices. Route cooling air into the vicinity of the coupling.

B. Marine Reduction Gear

- Record all manufacturer's data (serial number, model number, reduction ratio, etc.) and the manufacturer and type of clutches utilized.
- Record marine gear oil pressure and temperature during initial operation.

C. Fixed Pitch Propeller Installation

Record all propeller data (number of blades, type of material, diameter, pitch, etc.). If the propeller uses a Kort nozzle, record nozzle data and note if fixed or steerable. Develop a sketch of the shafting. Indicate the placement and type of line shaft bearings, shafting material and dimensions. Describe the type, manufacturer, and external equipment associated with the stern tube and the stern tube bearings.

Use the Caterpillar CAMPAR program to evaluate the propeller match.

D. Controllable Pitch Propeller Installation

Record all propeller data (number of blades, type of material, diameter, pitch, etc.). Indicate the manufacturer and system model number. Describe the CPP control system and identify the engine governor and CPP system interfaces. If a Kort nozzle is used, record nozzle data and note if fixed or steerable. Develop a sketch of the shafting. Indicate the placement and type of line shaft bearings, shafting material, and dimensions. Describe the type, manufacturer, and external equipment associated with the stern tube and stern tube bearing.

Use the Caterpillar CAMPAR program to evaluate the propeller operation and match.

E. Auxiliary Equipment Vibration

Measure vibration of engine mounted auxiliary equipment. Mounting resonances should not be present.

F. Auxiliary Power Takeoffs (PTOs)

Record the serial number of the auxiliary PTOs and other appropriate data relating to horsepower, rotational speed, etc. (typical nameplate data).

Safety System Evaluation

The safety systems on the engine must give early notice to the operator of pending problems and shut the engine down to protect it from imminent danger, or to limit contingent damage due to failure. Proper maintenance of the system is imperative for constant protection. Consider the following when evaluating the engine safety system:

A. Engine Contactors

Ensure the minimum Caterpillar required shutdowns and alarms are on the engine. The *minimum* requirements for propulsion engines are generally determined by the classification society and/or regulatory body involved in the project. The commissioning engineer must be prepared to demonstrate how shutdown and alarm contactors activate and de-activate according to Caterpillar specifications. Record demonstrated values. If the vessel is classed, notify a society surveyor at the time of demonstration.

The user must provide both audible and visual annunciation of faults in both the engine room and the control room. This should include horns, rotating beacons, or other forms of audible or visual alert.

B. External Engine Support Systems

The user must provide alarms and/or shutdowns on external system components that can adversely affect engine operation in a fault condition. These components may include fuel day tanks, primary fuel filters and/or centrifuges, sea water cooling pumps, etc.

C. Emergency Stops

The user must provide both local (at the engine) and remote emergency stop buttons, allowing an operator to safely shutdown the system without endangering personnel. The stop buttons must be guarded from accidental personnel contact, but still be operational by trained personnel in case of an emergency. Locate them in the engine room, the control room, and the bridge control console.

Monitoring System Evaluation

Monitoring the propulsion system requires periodic readings of gauges and readouts during a 24 hour period to insure all systems are not changing more than normal.

A. Engine Operating Parameters

Gauges and instrumentation on the engine gauge panel or mounted by user/shipbuilder on the external systems should give accurate readings of operational parameters for the oil, water, fuel, air and exhaust systems for the engine.

Periodic maintenance of oil, fuel and air filters is based on differential pressure as well as hours. Ensure gauges are provided to monitor filter conditions. An hour meter is required to properly monitor operating time.

B. External Engine Support Systems

The user is responsible for providing instrumentation to monitor operation of the external engine support systems. These should include, but not be limited to, the following:

- Fuel day tank site glass
- Oil storage tank site glass
- Water temperature to and from external cooler. This will include both treated cooling water and raw water to and from the heat exchangers.
- When strainers are permanently installed before the pump inlets, monitor pump inlet pressure to check strainer condition.

C. Daily Log Sheet

The user is responsible to provide a log sheet to record gauge and instrumentation readings taken periodically by the operators and/or the automatic monitoring system. Regulatory bodies usually require an engine room log book.

Ventilation Evaluation

Radiated heat from the engine and driven equipment can cause engine room temperature rise to adversely affect personnel and the propulsion system performance. Supply clean, cool air to the control rooms and engine rooms. It flows across and around equipment to carry radiated heat to the outside.

A. Engine Room Ventilation

Direct ventilating air toward the floor of the engine room and then upward around the engine before exiting above the engine. Design the machinery space ventilation to bring the coolest air to the turbocharger intake ducting/air cleaner. For personnel comfort, maintain the air velocity at 1.5 m/sec (5 ft/sec) in areas of heat sources or areas exceeding 38°C (100°F).

Check the temperature rise in potentially dead air spaces during engine operation. Check all electrical and mechanical equipment in the dead air space. If necessary, require corrections to be made.

Engine room pressure should not become negative. This indicates a shortage of ventilating air or excessive exhaust fan flow.

Serviceability Evaluation

Well designed engine rooms include serviceability features for the engines and support equipment. They include overhead lifting, space for component storage and cleaning, and required service tools. Consider the following when evaluating serviceability:

A. Engine Component Removal

Overhead and side clearance must be provided around the engine for major component removal and serviceability. Unfortunately, at the time of commissioning it may be too late to change the configuration.

Overhead lifting equipment must be provided. Most engine components are heavier than one man can safely lift. Review the overhead features for multidirection motion. Most engine component removal involves at least two direction motion for removal. Arrange for multiple engine installations to use the same overhead lifting equipment without major disassembly of piping or ducting. Equipment should be available for engine component movement to and from the engine room.

B. Engine Maintenance

The shipbuilder is responsible for locating the deck plating adjacent to the engine. It should not hinder periodic maintenance functions, daily inspections, or engine overhauls.

C. Reserved Work Area

Provide a work area in the engine room for disassembly and cleaning engine components and support equipment. Overhead lifting capacity must be sized for the largest component expected to be placed in this area.

D. Spare Parts Storage

Reserve an area for storage of spare parts and tools for all equipment in the engine room. They should be inventoried to ensure ready access during a repair. Lock the area. Missing parts or tools can impair scheduled maintenance or repair.

Equipment Safety Evaluation

The commissioning engineer must be able to recognize a safe operating environment. The entire system operation must be reviewed to provide operator safety in all situations. Consider the following when evaluating the safety of the operating systems:

A. Engine Room

- Shield or guard hot engine water pipes to prevent operator contact.
- Generator drive components and damper guards must be in place prior to operating the engine.
- Floor openings in the engine room must be covered with plating or grating.
- Chains and hooks on overhead lifting equipment must not endanger operating personnel.
- Floors must be cleaned of debris or liquid spills.
- Engine heat shields must be in place prior to operating the engine.

- Remote emergency system stops must be guarded but operable during a safety simulation.
- Test fire suppression systems prior to allowing normal operation.
- Independently test all engine emergency stops while operating at no load.
- Check engine room noise levels in normal operating areas. Include the data in the Installation Audit Report.

B. Control Room

- Ensure control room emergency stops are guarded to prevent accidental contact.
- Check control room noise levels and include this data in the Installation Audit Report.

Propulsion System Control Evaluation

Propulsion control system consists of the equipment for safe and precise operation of the main engine and the other components in the propulsion system.

There are two fundamental types of control systems — electric and pneumatic. A number of variations can be developed from these two basic schemes.

A. Pneumatic Controls

Thoroughly blow-down the air supply to purge debris and moisture prior to placing the control system in service. It is important to perform a point-to-point tubing connection inspection to assure individual control lines have been properly installed. Typically, the control system calibration is a joint effort between the Caterpillar commissioning engineers and the pneumatic control manufacturer. Exercise extreme caution while operating the main engine alongside a dock to prevent accidental clutch engagements. When the air supply is contamination free, the engine governor pneumatic speed adjustments can be evaluated. Ensure throttle boost is part of the system to facilitate crash reversals.

B. Electronic Controls

Delays must be part of the system to allow the engine speed to increase slightly as the clutch is engaging.

Prior to energizing the control system evaluate the power supply to determine if AC ripple and DC voltage levels are within control supplier tolerances. This may be accomplished by using a portable battery powered oscilloscope. Another method using standard test instrumentation is:

Before turning on the power of the governor control unit, disconnect the power supply input leads and connect a multimeter in the DC volts mode across the conductors. Turn on power to the governor control unit. The voltage must be 20 to 35 VDC (preferably 24 VDC). With the multimeter still connected, put the multimeter in AC volts mode. If it reads more than approximately 1 VAC, the voltage supply must be inspected to find the source of the excessive AC voltage. *Do not connect* the power supply leads to the controller if any excessive AC voltage is present. The governor system will not function properly and can be damaged.

After the power supply has been satisfactorily inspected, the electrical interconnections must be reviewed. This will prevent damage to sensitive components when the control system is placed in service. Locate the control components in a vibration free air conditioned space.

Operation and Maintenance Evaluation

Operating and maintenance training for the ship's crew involved in the operation and/or maintenance of 3600 engines and support equipment is an important factor in achieving dependable engine operation. The Commissioning Engineer should be prepared to give this training at the time of commissioning.

A. Engine Operation and Maintenance

Introduce each engineer to the engine maintenance guide and explain each topic. This may require a presentation be given several times to match the rotation of the watch-standing engineers. Coordinate the effort with the ship's chief engineer.

Ensure instruction is given for starting and stopping the engine. Include a demonstration at the engine and allow each operator to observe and follow the directions given. Follow the procedure outlined in the *Starting System Evaluation* section.

B. Engine Support Equipment

Review the list of equipment suppliers that will be on-site during commissioning. If representatives are on-site, ensure they are prepared to train the engineers.

C. Mechanical Training

Train shipboard engineers and shore-side maintenance personnel to make major repairs as well as be familiar with routine maintenance.

Crankcase Ventilation System Evaluation

Crankcase fumes must be piped away from the engine to atmosphere.

A. Crankcase Breathers

Crankcase breathers can be arranged in several positions to match the best piping routing away from the engine. Breather connections must be easily disconnected for scheduled maintenance. Piping of the same size as the breather outlet is suitable unless the length and/or bends cause excessive restriction. This can cause a false crankcase pressure measurement. See the *Engine Systems* section of this guide for additional information on pipe sizing requirements. Consideration must be given to the blow-by requirements of a worn engine when initially sizing the pipe.

A separate ventilation piping system must be installed for each engine. Slope piping away from the engine at a minimum of 13 mm per 300 mm, (.5 in. per ft). Configure the outlet to collect oil droplets prior to fumes exiting the piping. If piping rises from the engine, a trap with an appropriate drain valve must be installed to collect condensation or oil droplets before they reenter the breathers. Crankcase fumes must never be discharged directly to the engine room.

After the installation audit and the installation audit forms are completed and corrective action agreed to, it is recommended that all parties concerned sign the installation audit form at the designated locations on the report.

CATERPILLAR 3600
Main Propulsion Installation Audit Report

Directions: Fill in the blanks below, or circle the appropriate choice listed.

GENERAL

Selling dealer:		District or Subsidiary:	
Servicing dealer:		Customer:	
Equipment suppliers:		Address:	
		City, State, Zip:	

CONSIST

Engine model #:		Engine arrangement #:	
OT specification #:		Serial #:	
Rating:	bkW (bhp)	Speed:	
Engine cooling circuit:	Separate /Combined	Coolant used:	Antifreeze/Corrosion inhibitor
Governor model and type:		Oil used in engine:	
High idle specified:		“OT” specification:	
Low idle specified:		% Droop specified:	
Fuel used:	Distillate/Blended/Residual	Fuel gravity:	kg/1(lb/gal)
Fuel treatment:	Filter/Centrifuge	Viscosity control:	Yes/No

SHIP DATA

Type of hull:		Expected ship usage:	service hours/year
Water line length:	meters/feet	Expected vessel speed:	knots
Displacement:	long tons	Fuel capacity:	liters/gallons
Midship coefficient:		Water capacity:	liters/gallons
Prismatic coefficient:		Beam:	meters/feet
Hull material:		Draft:	meters/feet

CATERPILLAR 3600
Main Propulsion Installation Audit Report

Directions: Fill in the blanks below, or circle the appropriate choice listed.

REDUCTION GEAR DATA

Reduction gear manufacturer:	Reduction gear type:
Reduction gear model #:	Ratio, forward:
Clutch type: Hydraulic/Pneumatic	Ratio, reverse:

PROPELLER DATA

Manufacturer:	Model #:
Propeller type: Fixed/Controllable	Kort nozzle: Yes/No
Number of blades:	Diameter:
Pitch:	Radius of aperture:
Developed blade area:	Radius of aperture:

Contact for propeller design information:

Name:
Address:
Telephone:

SHAFTING DATA

Intermediate shaft, diameter:	Tail shaft, diameter:
Intermediate shaft, material:	Tail shaft, material:
Intermediate shaft, length:	Tail shaft, length:
Maximum angle of operation: from horizontal	Add'l engine driven loads:
Shaft brake manufacturer:	Shaft brake model #:

Contact for drive line/shafting design information:
Name:
Address:
Telephone:

CATERPILLAR 3600
Main Propulsion Installation Audit Report

Directions: Fill in the blanks below, or circle the appropriate choice listed.

MISCELLANEOUS SYSTEMS

Type of cooler for engine jacket water:	Fuel day tank capacity:
Manufacturer of J.W. cooler:	Day tank temperature rise evaluated? Yes/No
Model # of J.W. cooler:	Fuel cooler type:
Manufacturer of propulsion control system:	Manufacturer of F.O. cooler:
Type of propulsion control system:	Model # of F.O. cooler:
Model # of propulsion control system:	

APPLICATION SUMMARY

Provide any comments/remarks regarding this installation:

CATERPILLAR 3600
Installation Audit Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Air Intake	
Satisfactory _____	
Unsatisfactory_____	
Cooling	
Satisfactory_____	
Unsatisfactory_____	
Starting	
Satisfactory_____	
Unsatisfactory_____	
Exhaust	
Satisfactory_____	
Unsatisfactory_____	

CATERPILLAR 3600
Installation Audit Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Fuel Satisfactory _____ Unsatisfactory_____	
Lubrication Satisfactory_____ Unsatisfactory_____	
Engine Mounting Satisfactory_____ Unsatisfactory_____	
Driven Equipment Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Installation Audit Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Safety and Alarms Satisfactory _____ Unsatisfactory_____	
Engine Monitoring Satisfactory_____ Unsatisfactory_____	
Ventilation Satisfactory_____ Unsatisfactory_____	
Serviceability Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Installation Audit Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Equipment Safety Satisfactory _____ Unsatisfactory_____	
Propulsion Controls Satisfactory_____ Unsatisfactory_____	
Operation and Maintenance Satisfactory_____ Unsatisfactory_____	
Crankcase Ventilation Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Installation Audit Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

SYSTEM	DESIGN COMPLIANCE WITH 3600 ENGINE REQUIREMENTS
Satisfactory _____ Unsatisfactory_____	
Satisfactory_____ Unsatisfactory_____	
Satisfactory_____ Unsatisfactory_____	
Satisfactory_____ Unsatisfactory_____	

CATERPILLAR 3600
Installation Audit Report Results

Directions: Fill in the blanks below, or circle the appropriate choice listed.

The following parties have discussed and agreed to the results and required action during the design review process:

Field Engineer Signature:____ Date__________

Builder/Installer Signature:______________________________________ Date__________

Owner Signature:____ Date__________

Dock Trials

A thorough *Dock Trial* of the main propulsion system has extreme value to both the builder and the propulsion machinery commissioning engineers. It allows system design validation at the shipyard.

A typical dock trial consists of making a vessel fast to a suitable structure capable of withstanding the vessel's developed forward thrust (Bollard pull). The fundamental purpose of the dock trial is:

- To evaluate the main engine's ancillary systems with the systems operating under simulated at sea conditions.
- With vessels such as tug boats, trawlers or push boats, the propeller's developed thrust can be measured to validate the propeller design criteria.

The commissioning engineer's primary responsibility is to operate the propulsion machinery in a safe manner. The following are key items crucial to a successful trial:

- Work closely with the owner and builder in the development of a thorough trial agenda. The value of the dock trial is only as good as the data recorded and the tests performed.
- Determine the points to be monitored. Usually these will be the same as those for sea trials. This will allow sufficient time to install additional necessary instrumentation. See Figure 3 and Figure 4 for guidance on engine monitoring point locations. For guidance on sensor self sealing plug types available from Caterpillar, see Figure 5.
- Assemble all available performance data (OT, sea trial data, and test cell report) prior to the dock trial date.

Self Sealing Probe	
Plug Size	**Cat P/N**
1/8 in. NPT	5P2720
1/4 in. NPT	5P2725
1/2 in. O-Ring	4C4547
9/16 in. O-Ring	5P3591
3/4 in. O-Ring	4C4545
Pressure Probe Adapter	5P2718

Figure 5

3600 COMMISSIONING SENSOR POINTS

Function & Use Index	G - Gauge	H - HMSO A - Alarm	M - Manufacturing P - Pressure	T - Temperature POS - Position	L - LEVEL S - SPEED

Cooling System:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Elbow - H_2O Pump Out	#6 O-Ring	S	#6 O-Ring	S							T	P			
Elbow - Engine Out	#6 O-Ring	S	1/2" NPT	G	1/2" NPT	H	1/2" NPT	A	#6 O-Ring	S	T	T	T	T	P
Tube - AS Turbo Inlet	#6 O-Ring	S	#6 O-Ring	S							T	P			
Elbow Turbo H_2O Out	#6 O-Ring	S	#6 O-Ring	S							T	P			
Adapter - A/C In	#6 O-Ring	S	#6 O-Ring	S							T	P			
Water Terminal - A/C Out	1/2" NPT	G									T				
Elbow Seawater -Pump Out	#6 O-Ring	A									P				

Lube System:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Priority Valve Body	#6 O-Ring	S	#6 O-Rin	G&P							P	P			
Elbow - Temp. Reg. Out	#6 O-Ring	S&M	1/2" NPT	G	1/2" NPT	H	1/2" NPT	A			T	T	T	T	
Elbow - Scav. Pump Out	#6 O-Ring	G									G				
Tee - Pump Discharge	#6 O-Ring	S									P				
Oil Manifold (External)	#6 O-Ring	S&M	#6 O-Ring	G	#6 O-Ring	H	#6 O-Rin	A			P	P	P	P	
Oil Pan (Level)	#6 O-Ring	S	4 bolt hole	A							T	I	L		

Fuel System:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Fitting - Pump In	#6 O-Ring	S									P				
Housing End of Fuel Filter	#6 O-Ring (In)	S	#6 O-Ring (In)	G	#6 O-Ring (Out)	S&M					P	P	P		
backpressure Regulator Body	#6 O-Ring	S	#6 O-Ring	G							T	P			
Tee - Lines Out of filter	37° Fitting (Out)	G&A									P				
Tee - Lines Into Filter	#7 O-Ring (In)	S&M									T				

Speed System:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Camshaft Cover	5/8"-18-2B	S	5/8"-18-2B	S	5/8"-18-2B	S					S	S	S		
Housing - HMSO	5/8"-18-2B	A	5/8"-18-2B	A	5/8"-18-2B	A									

Figure 3 (continued on page 43)

3600 COMMISSIONING SENSOR POINTS

Function & Use Index	G - Gauge	H - HMSO A - Alarm	M - Manufacturing P - Pressure	T - Temperature POS - Position	L - LEVEL S - SPEED

Intake System:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Silence GP	#6 O-Ring	S	#6 O-Ring	G							P	P			
Aftercooler Hsg	#6 O-Ring	S	#6 O-Ring	G	#6 O-Ring	S					P	P	T		
Block	#8 O-Ring	S&M	#8 O-Ring	S&M	#8 O-Ring	G					T	P	T		
Engine Room	Ambient Air Temperature										T				
Elbow Assy - Air Inlet	#6 O-Ring	S	#6 O-Ring	G	#6 O-Ring	S					T	P	P		

Exhaust System:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Exhaust Stack	1/2" NPT	G	1/2" NPTF	A							T	T			
Exhaust Manifold Ports	1/4" NPSF	G									T				

Air Start System:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Distributor - Air Rcvr.	#6 O-Ring	G&A									P				

Crankcase:

Name	Point 1		Point 2		Point 3		Point 4		Point 5		Function				
	Type	Use	Type	Use	Type	Use	Type	Use	Type	Use	1	2	3	4	5
Front Housing	#6 O-Ring	S	#6 O-Ring	A							P	P			

Figure 3

3600 COMMISSIONING INSTRUMENTS SENSING LOCATION BY FUNCTION

Cooling System

Function	Location	Plug Type
Jacket water temp. rise	Elbow - JW pump out	#6 O-ring
	Elbow - engine out	#6 O-ring
Jacket water temperature	Elbow - engine out	12mm(1/2") NPT (3)
Temperature rise across turbo	Tube ass'y - turbo inlet	#6 O-ring
	Elbow - turbo water out	#6 O-ring
Turbo water flow restriction	Tube ass'y - turbo water in	#6 O-ring
(pressure drop)	Elbow - turbo water out	#6 O-ring
Jacket water flow restriction	Elbow - JW pump out	#6 O-ring
(pressure drop)	Elbow - engine out	#6 O-rin
Temp. rise across aftercooler	Adapter - A/C in	#6 O-ring
	Adapter - A/C out	#6 O-ring
A/C water flow restriction	Adapter - A/C in	#6 O-ring
(diff. pressure)	Adapter - A/C out	#6 O-ring
A/C & O/C coolant temperature	Water terminal	12mm(1/2") NPT
Seawater pump pressure	Elbow - pump out	#6 O-ring
Jacket water temperature	Manifold water	12mm(1/2") NPT

Lube System

Function	Location	Plug Type
Main oil manifold pressure	Elbow	
Piston cooling jet manifold press.	Priority valve body	#6 O-ring
		#6 O-ring
Engine oil temperature	Elbow - temp. reg. out	#6 O-ring
		12mm(1/2") NPT(3)
Scavange pump pressure	Elbow - pump discharge	#6 O-ring
Pressure drop across oil filter	Elbow - oil filter in	#6 O-ring
	Elbow - oil filter out	#6 O-ring
Main oil pump pressure	Tee - pump discharge	#6 O-ring
Main manifold pressure	Manifold ext. to turbo	#6 O-ring (3)
Temp. drop from manifold to pan	Oil pan	#6 O-ring
Pan oil level	Oil pan	4 bolt hole
Priority valve position	Priority valve body	

Speed System

Function	Location	Plug Type
Engine speed "rpm"	from camshaft cover, or	5/8"-18-2B(3)
	Hydro/mechanical shut off housing	5/8"18-2B(3)

Figure 4 (continued on page 45)

3600 COMMISSIONING INSTRUMENTS SENSING LOCATION BY FUNCTION

Fuel System

Function	Location	Plug Type
Press. rise across transfer pump	Fitting - pump in	#6 O-ring
	Housing-end fuel filter in	#6 O-ring (2)
Pressure drop across filter	Housing-end fuel filter out	#6 O-ring
	Tee - filter out37° fitting (2)	
Temp. rise across injector	Fitting-fuel filter in	#6 O-ring
	Regulator body	#6 O-ring
Regulator setting	Regulator body	#6 O-ring
Fuel temp. into eng. (hi-low alarm)	Tee - transfer pump out	37° fitting

Intake System

Function	Location	Plug Type
Engine room temperature, or temperature rise across turbo	Elbow ass'y - air inlet	#6 O-ring
	Aftercooler housing	#6 O-ring
Pressure rise across turbo	Silencer GP	#6 O-ring (2)
	Elbow ass'y - air inlet	#6 O-ring (2)
	Aftercooler housing	#6 O-ring (2)
Air plenum temperature	Block - adapter	#6 O-ring
	Block - adapter	12mm(1/2") NPT
Air plenum pressure	Block - adapter	#6 O-ring

Exhaust System

Function	Location	Plug Type
Exhaust stack temperature	Exhaust stack	12mm(1/2") NPTF
Exhaust port temperature	Manifold	7mm(1/4") NPSF

Air Start System

Function	Location	Plug Type
Main manifold pressure	Distributor - air	#6 O-ring

Crankcase

Function	Location	Plug Type
Crankcase pressure	Front housing#6 O-ring (2)	

Figure 4

Sea Trials

Sea trials are the final test of the installed machinery. The duration and complexity of a sea trial is related to the vessel type, the propulsion system configuration, and the class of service.

The commissioning engineer *must* play an active role in planning the Sea Trial Agenda relating to the propulsion system. All points highlighted under the previous dock trial section are applicable to preparing for the sea trial. In addition to the standard gauge panel instrumentation, Figure 6 can be used to customize sensor points needed to validate performance of unique marine installations.

Ensure test data and fuel rate are entered in the CAMPAR program for evaluation. Figure 7 can be used to draw a performance curve based on actual fuel rate at operating conditions.

ENGINE PERFORMANCE DATA

Record the following data using field equipment while the engine is at rated conditions and speed:

SHIP NAME: ______________
DATE: ______________
TIME: ______________
ENGINE S/N #: ______________ **Speed:** ______________

900 SERIES POINTS	DESCRIPTION	FACTORY SPEC.	ACTUAL MEASUREMENT TAKEN
910	Engine speed - Low idle		
910	Engine speed - High idle		
910	Engine speed - Free running		
910	Engine speed - Bollard pull		
910	Engine speed - Towing/trawling		
910	Engine speed - Emergency reversal		
	Engine room air temperature		
930	Air temperature at air cleaner		
907	Air inlet restriction		
906	Intake manifold temperature		
911	Intake manifold pressure		
931	Turbocharger compressor outlet temperature		
960	Turbocharger compressor outlet pressure		
908	Exhaust backpressure		
912	Exhaust stack temperature		
932	Crankcase pressure		
913	Engine oil to bearings temperature		
914	Engine oil to bearings pressure		
934	Engine oil to cooling jet pressure		
927	Oil filter inlet pressure		
928	Oil filter outlet pressure		
909	Crankshaft deflection		
	Fuel temperature - Injector inlet		
917	Fuel pressure - Injector inlet		
	Fuel temperature - Injector outlet		
	Fuel pressure - Injector outlet		
936	Fuel return line restriction		
961	Fuel pump - Inlet restriction		
901	Jacket water cyl. block outlet temperature		
942	Jacket water cyl. block outlet pressure		
943	Water temp. to combined circuit heat exch.		
944	Water press. to combined circuit heat exch.		
945	Water temp. to reg. from comb. circ. H/E		
946	Water press. to reg. from comb. circ. H/E		
954	R. W. temp. to combined circuit heat exch.		
	Auxiliary pump inlet temperature		
904	Auxiliary pump inlet pressure		
	Auxiliary pump outlet temperature		

Comments:

Figure 6 (continued on page 48)

ENGINE PERFORMANCE DATA

Record the following data using field equipment while the engine is at rated conditions and speed:

SHIP NAME: ______________
DATE: ______________
TIME: ______________
ENGINE S/N #: ______________ **Speed:** ______________

900 SERIES POINTS	DESCRIPTION	FACTORY SPEC.	ACTUAL MEASUREMENT TAKEN
905	Auxiliary pump outlet pressure		
951	AC/OC water pump inlet temperature		
952	AC/OC water pump inlet pressure		
953	AC/OC water pump outlet pressure		
903	AC/OC water inlet temperature		
923	AC/OC water inlet pressure		
937	AC water temp. between front & rear housing		
903A	AC/OC outlet water temperature		
924	AC/OC outlet water pressure		
940	AC/OC outlet mixing box temperature		
941	AC/OC outlet mixing box pressure		
938	Oil cooler water outlet temperature		
939	Oil cooler water outlet pressure		
920	Jacket water pump inlet pressure		
902	Jacket water pump outlet temperature		
919	Jacket water pump outlet temperature		
922	Jacket water temp. from cooling system		
947	Water temperature at engine outlet to		
	separate circuit heat exchanger		
948	Water pressure at engine outlet to		
	separate circuit heat exchanger		
949	Water temperature to regulator from		
	separate circuit heat exchanger		
950	Water pressure to regulator from		
	separate circuit heat exchanger		
956	R. W. temperature to separate circuit		
	jacket water heat exchanger		
957	R. W. temperature from separate circuit		
	jacket water heat exchanger		
958	R. W. temperature to separate circuit		
	AC/OC water heat exchanger		
959	R. W. temperature from separate circuit		
	AC/OC water heat exchanger		
915	Reduction gear lube oil temperature		
916	Reduction gear lube oil pressure		
925	Reduction gear oil cooler inlet water temperature		
926	Reduction gear oil cooler outlet water temperature		

Comments:

Figure 6

Caterpillar Marine Engine Performance Analysis Report

Vessel Name________ Engine Model________ Test Number________ Customer________ Engine S/N________ HOURS________

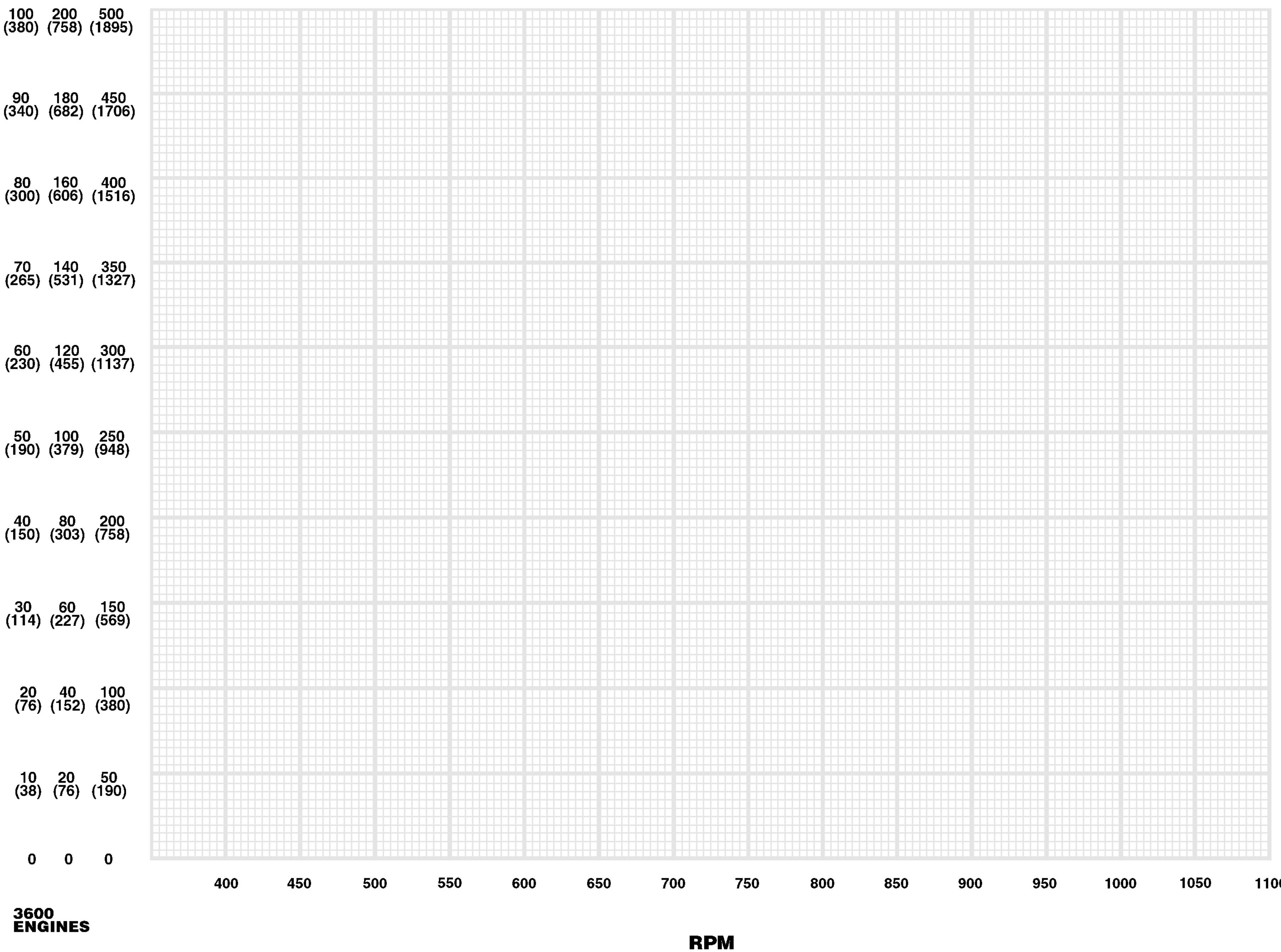


Figure 7

Sea Trial Conditions

Perform sea trial running tests under the following conditions:

- Load the vessel the same as during normal service: 50% to 75% load of fuel, fresh water, cargo, and ships' stores. Properly located ballast may be substituted.
- All gauges, panels, and test instruments must be in good operating condition before conducting tests.
- The engines and reduction gear must be operated under full throttle and load long enough to allow temperatures and pressures to stabilize.
- If the ship operation includes towing or trawling, take sea trial measurements while the vessel is towing its intended load. If testing under actual working conditions is impossible, Bollard pull engine speed and free-running engine speed are required to determine if the engine will attain rated rpm under full load conditions.

Experience has shown that conditions where Bollard pull tests are usually conducted are not ideal for performance of the other engine system tests. Other sea trial measurements should be made under free-running conditions after the Bollard pull engine speed has been measured.

Figure 8 is a sample of a main engine sea trial log sheet.

Record machinery and structure vibration levels at various engine speed and load conditions. The data becomes part of the permanent engine commissioning record.

Take lube oil samples after the completion of the sea trial and the analysis results have been made a permanent part of the engine commissioning record.

Check crankshaft deflections immediately after the engine has been secured following the sea trial. This will help validate engine mounting and insure unrestricted thermal expansion of the machinery.

ENGINE INSTRUMENTATION DATA

Record the following data using field equipment or by recording instrument readings while the engine is at rated conditions and speed:

SHIP NAME: ____________________

DATE: ____________________

TIME: ____________________

ENGINE S/N #: ____________________

MEASUREMENT POINTS	FACTORY SPEC.	ACTUAL READINGS			
Engine operating hours (Hrs.)					
Tachometer (rpm)					
Engine coolant temperature [°C (°F)]					
Air inlet manifold temperature [°C (°F)]					
Air inlet restriction-left [kPa (in. H_2O)]					
Air inlet restriction-right [kPa (in. H_2O)]					
Lube oil pressure [kPa (psi)]					
Lube oil temperature [°C (°F)]					
Lube oil filter diff. pressure [kPa (psi)]					
Fuel oil filter diff. pressure [kPa (psi)]					
Fuel oil pressure [kPa (psi)]					
Crankcase pressure [kPa (psi)]					
Air inlet manifold pressure [kPa (psi)]					
Stack exhaust temp.-left bank [°C (°F)]					
Stack exhaust temp.-right bank [°C (°F)]					
#1 Cylinder exhaust temperature [°C (°F)]					
#2 Cylinder exhaust temperature [°C (°F)]					
#3 Cylinder exhaust temperature [°C (°F)]					
#4 Cylinder exhaust temperature [°C (°F)]					
#5 Cylinder exhaust temperature [°C (°F)]					
#6 Cylinder exhaust temperature [°C (°F)]					
#7 Cylinder exhaust temperature [°C (°F)]					
#8 Cylinder exhaust temperature [°C (°F)]					
#9 Cylinder exhaust temperature [°C (°F)]					
#10 Cylinder exhaust temperature [°C (°F)]					
#11 Cylinder exhaust temperature [°C (°F)]					
#12 Cylinder exhaust temperature [°C (°F)]					
#13 Cylinder exhaust temperature [°C (°F)]					
#14 Cylinder exhaust temperature [°C (°F)]					
#15 Cylinder exhaust temperature [°C (°F)]					
#16 Cylinder exhaust temperature [°C (°F)]					
Fuel rack position (from governor)					

Comments:

Figure 8

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CATERPILLAR®

3600 Marine Engine Application and Installation Guide

● **Reference Publications**

Operation and Maintenance

Operation and Maintenance Manual - 3600 Distillate Fuel Engines	SENR6965
Operation and Maintenance Manual - 3600 Heavy Fuel Engines	SENR6966
Operation and Maintenance Manual - 3612/3616 Fast Vessel	SENR7083
Systems Operation - 3606 and 3608 Engines	SENR3599
Systems Operation - 3612 and 3616 Engines	SENR3593
Maintenance Manual - Schedules for Equipment Maintenance	SEBU6103
Maintenance Management Recommendations - 3600 Distillate Fuel Engines	SELU6965
Maintenance Management Recommendations - 3600 Heavy Fuel Engines	SELU6966
Operation with Damaged Turbocharger Service	SEHS8704
Specifications - 3606 and 3608 Major Components	SENR3598
Specifications - 3612 and 3616 Major Components	SENR3592
Disassembly and Assembly - 3606 and 3608 Engines	SENR3600
Disassembly and Assembly - 3612 and 3616 Engines	SENR3594
Service Manual - 3606 and 3608 Engines	SENR3595
Service Manual - 3612 and 3616 Engines	SENR3590
Special Edition Engine News - Serviceability	SEBD9129
Parts - 3600 Parts	SEBP3600
Parts - 3600 Parts (Microfiche)	SBFY0628
Service Manual - 3161 Governor	SENR3028
Service Manual - 2301 Electric Governor	SENR3585
Service Manual - Heinzmann Governor-Generator Sets	SENR4622
Service Manual - Heinzmann Governor-Marine	SENR4661

Lubrication

Lubrication - Oil and Your Engine	SEBD0640
Lubrication - S•O•S (Scheduled Oil Sampling)	PEDP7036

Fuel

Fuel - Diesel Fuel and Your Engine	SEBD0717
EDS 61.1 Heavy Fuel Contaminant Levels	LEKQ2314
EDS 61.4 Heavy Fuel Operating Procedures for 3600 Engines	LEKQ1177

Miscellaneous

Storage - General - Storage Procedures for Caterpillar Products	SEHS9031
Specification - List of Standard Torques	SENR3130
Special Instructions -	
Spring Isolator Group Installation & Adjustment Procedure	SEHS9162
EDS 64.5 - Fuel Heaters for Cold Weather Operation	LEKQ4065
EDS 159.0 - Electric Jacket Water Heaters	LEKX3301
3600 Marine Monitoring System Owner's Manual	SEBU7134

Component Reusability

Materials and specifications are
subject to change without notice.

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