Contents

Introduction .................................................. 5
Installation Considerations ................................. 7
Cold Starting .................................................. 27
Back Ends ....................................................... 37
P.T.O. Facilities ............................................... 47
Mounting Systems ............................................ 61
Cooling Systems .............................................. 77
Induction System ............................................. 101
Exhaust System ............................................... 115
Fuel System ................................................... 123
Lubricating Oil System ...................................... 135
Electrical Systems ........................................... 141
Noise Control .................................................. 157
Instrumentation and Controls ............................. 175
Appraisal and Testing ....................................... 181
SECTION 1

INTRODUCTION

The Caterpillar Installation manual has been compiled by Caterpillar Engineering Department to provide practical advice and technical information for installers of all types of Caterpillar engines, except marine. A separate manual entitled the Caterpillar Installation Manual for Marine Engines is also available.

Practical “know-how” and considerable experience of the most common faults occurring with the installation of small high speed diesel engines form the basis of this manual which will enable installers to avoid many of the pitfalls.

This manual is divided into fifteen sections on specific topics with cross-references as required to cover technical specifications, practical recommendations and design features contributing to the overall success of an installation. The Technical Data Section, Section 16 is available separately as a supplement to the manual.

Although a comprehensive source of data, the Installation Manual is not a catalog; information on engine selection, specification options, available accessories, etc., is contained in the appropriate Standard Option Scheme catalog. In addition attention is drawn to the Service Manuals which deal with engine operation, maintenance and overhaul procedures.

The Installation Appraisal Data Sheets used by Caterpillar engineers when recording details of an O.E.M. customer’s engine installation reflect the standards laid down in the Installation Manual. It is strongly recommended that the same information is recorded by all Caterpillar engine dealers and distributors when inspecting their customers’ installations. Foreign language versions of the sheets are available from Caterpillar Sales Companies. A copy of the Data Sheets forms part of Section 15, (Appraisal and Testing).

The opportunity has been taken to correct errors which appeared in the second edition of the General Installation Manual; to clarify wording where this has been found to be necessary; and to up-date material in the light of the latest information and experience.

Care has been taken to ensure that the information in this Installation Manual is correct at the time of issue. Due to the continuing process of development and changing world-wide legislative requirements however, this is subject to modification without prior notice and no responsibility can be accepted for alterations, errors or omissions.

Prepared by:
Technical Standards & Information Section
Engineering Department
Caterpillar Inc.
Peterborough PE1 5NA England
INTRODUCTION
In any application, the engine must be capable of meeting the demands of the particular machine in the conditions in which it will have to operate. The engine must therefore be matched and coupled to the driven load, securely mounted in the frame, protected from the elements, supplied with clean fuel, lubricating oil and air, maintained within the recommended operating temperature range and with the correct degree of engine throttle control.

Other items, such as special starting controls, safety shut down devices, overspeed protection etc., are often necessary, but they will be of little use if the basic engine requirements are not met.

OPERATING ENVIRONMENT
Climactic conditions, i.e. atmospheric pressure, temperature and humidity, will all influence engine performance.

An engine should therefore be selected with sufficient power to meet the load demands under all operating conditions.

The individual effects of these variables are discussed in the following paragraphs.

Air Temperature
High inlet air temperature to the engine can cause loss of power and overheating problems with the cooling system, the lubricating oil, and hydraulic oil systems. This may be either due to high ambient temperatures, or because the engine is working inside a building or within the structure of a machine with insufficient ventilation.

For naturally aspirated engines the loss of power will be approximately 2%–2 1⁄2% for every 10°C (18°F) rise above the reference temperature specified on the power curve.

For turbocharged engines the effect will be dependent upon both the amount of turbocharger boost and the degree of air charge cooling (if any). As a general guide, the power loss for non-charge cooled and air-to-air charge cooled engines is of the order of 2% for every 10°C (18°F) rise above the reference temperature. For air-to-water charge cooled engines however, the power loss is usually neglected.

Some rating standards ignore the power variations caused by air temperature fluctuation.

Engine ratings quoted by Caterpillar against official rating standards are determined by correction to the appropriate reference conditions in accordance with the correction procedures specified in the standards concerned.

For naturally aspirated engines only, accurate temperature correction of power to the BS AU 141a: 1971 reference temperature of 20°C (68°F) may be obtained from the following formula, based on correction charts published by the Motor Industry Research Association (M.I.R.A.):

\[
\text{Temperature correction} \% = (T_0 - T_s) \times 0.00012 \times \left( \frac{Q}{V} \right)^{1.76}
\]

where
\[
\begin{align*}
Q & = \text{Fuel delivery, cu. mm/stroke} \\
V & = \text{Cylinder volume, liters} \\
T_0 & = \text{Observed temp., °C} \\
T_s & = \text{Reference temp., °C}
\end{align*}
\]

Low air temperatures will reduce the ability of the engine to start, but by changing the specifications, e.g. fitting heavy duty starter motor and batteries, and using a starting aid, satisfactory starting can be achieved at much lower temperatures.

SECTION 3, COLD STARTING, describes the various starting equipment available and also the minimum temperature likely to be encountered in different areas of the world.

SECTION 16, TECHNICAL DATA, specifies the cold starting equipment necessary for each engine type to meet specific minimum starting temperatures.

Atmospheric Pressure
For every 25 mm (1 in) mercury drop of barometric pressure within the normal range of variation at sea level, the rated output of a naturally aspirated engine will decrease by approximately 1%–1½%. For turbocharged engines, loss of power within this pressure range is usually considered to be negligible.

Engine ratings quoted by Caterpillar against official rating standards are determined by correction to the appropriate reference conditions in accordance with the correction procedures specified in the standards concerned.

For naturally aspirated engines only, accurate pressure correction of power to the BS AU 141a: 1971 reference pressure of 760 mm (29.92 in) Hg may be obtained from the following formula, based on correction charts published by the Motor Industry Research Association (M.I.R.A.):

\[
\text{Pressure correction} \% = (P_s - P_o) \times 0.00000059 \times \left( \frac{Q}{V} \right)^{2.88}
\]

where
\[
\begin{align*}
Q & = \text{Fuel delivery, cu. mm/stroke} \\
V & = \text{Cylinder volume, liters} \\
P_s & = \text{Reference pressure, mm Hg} \\
P_o & = \text{Observed pressure, mm Hg}
\end{align*}
\]

Note: The above formula is applicable only to the normal range of variation of atmospheric pressure at sea level.

Altitude
Effect on Coolant Temperature
With increasing altitude, there is a decrease in air pressure resulting in the cooling system water boiling at a lower temperature. This can be partly corrected by fitting a spring
loaded radiator cap to raise the pressure in the system, and hence the boiling point of the water.

The relationship of boiling point with different pressure caps at varying altitudes is illustrated in COOLING SYSTEMS, SECTION 7.

**Effect on Power and Smoke**

As the air becomes more rarified at higher altitudes, there will be insufficient oxygen to burn all the fuel being delivered, with consequent loss of power. The unburnt fuel will subsequently be emitted from the exhaust as black smoke.

The loss of power is usually disregarded at altitudes of less than 150 m (500 ft) above sea level. At higher altitudes, the degree of loss of power will depend not only on the altitude, but also on the fuel injection equipment specification and, for turbocharged engines, on the size, type and match of turbocharger.

For reference, the accompanying curves illustrate typical variations of engine power with altitude for naturally aspirated and turbocharged engines at various ambient air temperatures.

* NOTE: For air-to-water CHARGE COOLED Turbocharged engines the variation of power output shown above does not apply. For these engines the reference of 27°C should be used regardless of actual ambient air temperature.

**Torque Converter Matching**

The rarified atmospheric conditions at altitude can also result in poor torque converter matching due to the reduction of engine torque.

This can be serious if the converter is critically matched to a certain engine speed, and the altitude causes the engine to lose enough power to drop below the converter input speed for efficient operation.

**Operation at High Altitude**

Allowance must be made for reduced engine and hence machine performance when operating at altitude, i.e. the machine loads may have to be reduced, or the transmission may require changing.

If the engine is to operate continuously at altitudes higher than 1500 m (5000 ft), the fuel injection pump delivery should be reduced. This will avoid running with an unsatisfactory exhaust condition, which may lead to engine trouble, as well as giving a higher specific fuel consumption.
The required reduced fuel delivery rate necessary for operating at a particular altitude can be obtained from Caterpillar Engines, providing that the information specified below, is submitted.

As a general guide, the following table indicates the approximate amount of defuelling which may be applied to naturally aspirated engines, on a percentage basis, where specific figures for a particular engine rating are not available.

This table is not applicable to turbocharged engines, for which specific advice should be obtained.

<table>
<thead>
<tr>
<th>Altitude m (ft)</th>
<th>Maximum Fuel Delivery Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 600 (0 – 2000)</td>
<td>No change</td>
</tr>
<tr>
<td>600 – 1200 (2000 – 4000)</td>
<td>6%</td>
</tr>
<tr>
<td>1200 – 1800 (4000 – 6000)</td>
<td>12%</td>
</tr>
<tr>
<td>1800 – 2400 (6000 – 8000)</td>
<td>18%</td>
</tr>
<tr>
<td>2400 – 3000 (8000 – 10,000)</td>
<td>24%</td>
</tr>
<tr>
<td>3000 – 3600 (10,000 – 12,000)</td>
<td>30%</td>
</tr>
</tbody>
</table>

Important: Any alteration to the fuel pump setting must be made by an authorized fuel pump specialist or Caterpillar distributor.

**Information Required for Power Assessment at Altitude**

The following information must be provided to the nearest Caterpillar Area Operations Office before an assessment of the engine performance can be provided.

- Engine parts list number or fuel injection pump type number
- Site barometric pressure
- Site ambient temperature and humidity
- Whether or not the machine is working at constant or variable altitude, i.e. moving from one area to another or operating within a given locality.
- Whether conventional gearbox or torque converter is fitted. If the latter, stall speed of the transmission is required.
- If possible horsepower requirements of machine operating at site conditions.

**Humidity**

Extreme humidity has a slight effect on engine performance. It is very rare for high humidity in any part of the world to combine with high temperature to justify more than a 6% derating for humidity.

The accompanying curves show the reduction in power due to humidity at various ambient temperatures.

**Diagram for Estimating Effects of Humidity on Power Output**

*NOTE: When estimating the percentage reduction in power due to humidity, the relative humidity must be coupled with the atmospheric air temperature, and not the inlet air temperature which might be locally heated. The effect of inlet air temperature on power output must be considered separately using diagram 3893.*

Where humidity is expressed in terms of water vapor pressure, the percentage reduction in power can be read directly from the chart.

**High humidity causes problems with electrical equipment, and condensation occurs within the fuel storage tanks and the exhaust system. A large capacity water trap should always be fitted on the suction side of the fuel lift pump.**

Care must also be taken to prevent ingress of water into the open end of the exhaust system.

**Installation Angle and Gradients of Operation**

The angle of installation can be up to 10° on the side and/or up to 7° down at the rear. If it is necessary to install the engine at angles greater than these, or if it must be installed down at the front, advice should be sought from Caterpillar Application Engineering Department.
It must be stressed that this can be little more than a guide and machines may sometimes be required to work at angles more severe than normally expected of them, e.g. pavers on a banked track. This must be taken into account during the selection of engine specifications.

**Sumps**

Standard road vehicle sumps are suitable for operation on gradients of up to 1 in 4 (14° from the horizontal). Industrial and construction machinery are often required to work on extremely steep gradients and it is essential that a suitable engine lubricating oil sump is fitted for the intended operation.

**Air Cleaners**

Most oil bath type air cleaners can be used on gradients of up to 15°, but some are available which are satisfactory for operation at up to 30°. If an oil bath air cleaner is to be used at a gradient exceeding 15°, it must be confirmed from Caterpillar Engines that it is suitable.

**Dusty Conditions**

Machines expected to work in a dust-laden atmosphere, either due to the natural surroundings, e.g. dirt road, sandy conditions, etc., or due to the operation, e.g. stone crushers, earth movers, etc., must use heavy duty air filters to prevent the entry of dust into the intake system of the engine.

**Induction System**

The heavy duty air filters necessary when operating in a dust laden atmosphere are described in SECTION 8, INDUCTION SYSTEMS. Specific filter types for various duties on each engine type are listed in SECTION 16, TECHNICAL DATA.

**Sealed Dipstick and Filler**

A special dipstick and tube should be used to seal the tube entry to prevent dust entry. SECTION 11, LUBRICATING OIL SYSTEM describes the sealed dipstick and sealed lubricating oil filler for use in extremely dusty environments.

**Accessories**

A dust proof alternator and starter motor may be considered necessary, and attention must be given to the suitability of other driven equipment for operating in dust laden atmospheres.

**Explosive Atmospheres**

Diesel engines working in an explosive atmosphere or an area of fire hazard, must be equipped to conform to local regulations. (See SECTION 2.)

The degree of treatment to the engine will depend on the type of atmosphere in which it will be working.

See EXHAUST SYSTEMS, SECTION 9 on exhaust conditioning.

Examples of other requirements are: air inlet flame trap, anti-static fan belt and non electric starting equipment, depending on conditions.
POWER, RATING STANDARDS AND GOVERNING

Engine Selection
The most fundamental requirement for an engine installation is that the engine can provide sufficient power for all conditions likely to be met during the intended operation.

It must be understood that the engine power specified on power curves is usually gross and deductions must be made to obtain the net condition, i.e. power at the flywheel.

Likewise, the power specified on a power curve is to a particular rating standard, i.e. at specified ambient conditions and within a certain tolerance band. The power may have to be corrected to allow for actual ambient conditions. (See SECTION 2.)

The engine may also have to satisfy the local legislation in the area of operations, e.g. on smoke and gaseous emissions, noise, power/weight ratio of vehicle, etc. Some installations may also require engine approval by a Classification Society or Authority. (See SECTION 2.)

It should be noticed that Caterpillar engines are normally only available with low idle speeds of 550, 750 or 1000 rev/min. O.E.M.’s particular low idle speed requirements should be identified, and if necessary discussed with Caterpillar Application Engineering.

Power Requirement
The power required by a particular machine for a certain operation can be established:
- by calculation
- from the equipment manufacturer,
- by comparison with a similar installation,
- from the performance of the original engine in a conversion.

The nature of the application will determine the required engine power, rated speed, torque back-up and governing characteristics.

Rating Standards
The power output of an engine can vary considerably depending on:
- whether the power specified is gross or net,
- the tolerance range allowed on power output,
- the ambient temperature and pressure
- whether output is continuous (allowing a further 10% overload), or not,
- the induction and exhaust restrictions,
- the humidity
- the fuel temperature.

To define these variables, several Rating Standards and Test Codes exist. The power output of an engine must always be qualified by reference to one of these.

The features of the most commonly used standards are summarized in the table on the next page.
# COMPARISON OF MOST COMMON ENGINE RATING STANDARDS AND TEST CODES

(Common fuel setting assumed; gross output expressed as percentage of equivalent BS AU 141 a gross rating)

<table>
<thead>
<tr>
<th>Standard or Test Code</th>
<th>Performance tolerance quoted by Caterpillar</th>
<th>Air inlet temp. °C (°F)</th>
<th>Total barometric pressure kPa (mm/in Hg)</th>
<th>Gross power output Nat. Turbo-charged</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS AU 141 a: 1971</td>
<td>+0 – 5%</td>
<td>20 (68)</td>
<td>101.3 (760/29.92)</td>
<td>100% 100%</td>
<td>See Note 1</td>
</tr>
<tr>
<td>BS 649: 1958 Continuous</td>
<td>+5 – 0%</td>
<td>29.4 (85)</td>
<td>99.9 (749/29.5)</td>
<td>84.5% 86.5%</td>
<td>See Notes 2, 8</td>
</tr>
<tr>
<td></td>
<td>+5 – 0%</td>
<td>29.4 (85)</td>
<td>99.9 (749/29.5)</td>
<td>93% 95%</td>
<td></td>
</tr>
<tr>
<td>BS 5514 Part 1: 1982</td>
<td>+5 – 5%</td>
<td>27 (80.6)</td>
<td>100.0 (750/29.53)</td>
<td>89% 91%</td>
<td>See Notes 3, 8</td>
</tr>
<tr>
<td></td>
<td>+5 – 5%</td>
<td>27 (80.6)</td>
<td>100.0 (750/29.53)</td>
<td>98% 100%</td>
<td></td>
</tr>
<tr>
<td>SAE J270 1.3.4</td>
<td>+0 – 5%</td>
<td>29.4 (85)</td>
<td>99.5 (746/29.38)</td>
<td>97.5% 100%</td>
<td>See Note 4</td>
</tr>
<tr>
<td>SAE J1349 4.2.4</td>
<td>+0 – 5%</td>
<td>25 (77)</td>
<td>100.0 (750/29.53)</td>
<td>98.5% 100%</td>
<td></td>
</tr>
<tr>
<td>DIN 6270A Continuous</td>
<td>+5 – 0%</td>
<td>20 (68)</td>
<td>98.1 (736/29.0)</td>
<td>84.5% 86.5%</td>
<td>See Notes 5, 8</td>
</tr>
<tr>
<td></td>
<td>+5 – 0%</td>
<td>20 (68)</td>
<td>98.1 (736/29.0)</td>
<td>93% 95%</td>
<td></td>
</tr>
<tr>
<td>DIN 6270B Intermittent</td>
<td>+0 – 5%</td>
<td>20 (68)</td>
<td>98.1 (736/29.0)</td>
<td>98% 100%</td>
<td></td>
</tr>
<tr>
<td>DIN 6271 Continuous</td>
<td>+5 – 5%</td>
<td>27 (80.6)</td>
<td>100.0 (750/29.53)</td>
<td>89% 91%</td>
<td>See Note B</td>
</tr>
<tr>
<td></td>
<td>+5 – 5%</td>
<td>27 (80.6)</td>
<td>100.0 (750/29.53)</td>
<td>98% 100%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+0 – 5%</td>
<td>27 (80.6)</td>
<td>100.0 (750/29.53)</td>
<td>98% 100%</td>
<td></td>
</tr>
<tr>
<td>ISO 1585 – 1982</td>
<td>+5 – 5%</td>
<td>25 (77)</td>
<td>100.0 (750/29.53)</td>
<td>97.5%* 98.5%*</td>
<td>See Notes 6, 8</td>
</tr>
<tr>
<td>ISO 2288 – 1979</td>
<td>+5 – 5%</td>
<td>25 (77)</td>
<td>100.0 (750/29.53)</td>
<td>97.5%* 98.5%*</td>
<td>See Notes 7, 8</td>
</tr>
<tr>
<td>80/1269/EEC</td>
<td>+5 – 5%</td>
<td>25 (77)</td>
<td>100.0 (750/29.53)</td>
<td>96.5% 100%</td>
<td>See Note 8</td>
</tr>
</tbody>
</table>

**NOTES:**

1. BS AU 141a: 1971 includes a smoke limitation, and minimum power/weight ratio for engine/vehicle.
2. BS 649: 1958 used for generator sets and similar applications. Published as gross power by Caterpillar. Now superseded by BS 5514.
3. BS 5514 Part 1: 1982 derived from, and identical to, ISO 3046. Published as gross power by Caterpillar.
4. SAE J270 1.3.4 now superseded by SAE J1349 4.2.4.
5. DIN 6270A/B now superseded by DIN 6271.
7. ISO 2288 – 1979 is intended for agricultural tractors and machines.
8. Losses must be deducted to give final net rating.

* Correction factors shown are average values determined by method defined in ISO 1585/2288; exact values dependent on fuel delivery and turbocharger pressure ratio characteristics.
Enquiries about Mines Certification and specialist equipment must be directed to Caterpillar Application Engineering for the latest approved ratings and engine specification for a particular requirement.

**Transmission Losses**
These obviously vary considerably, but as a guide, losses in transmission can be:

- **Vehicle transmission**: Average Loss 15%
- **Bevel gear drives**: Average Loss 12%
- **Spur gear drives**: Average Loss 7%
- **Vee-belt drives**: Average Loss 5%
- **Flat-belt drives**: Average Loss 10%
- **Chain drives**: Average Loss 5%

**Governing**
The degree of control provided by the governor is dependent upon the governor specification. For a given position of the control lever, there is a power/speed relationship (at steady load intervals) which is termed “governor regulation”.

**Percentage Governing**
If the value of 100% is arbitrary assumed for an engine speed when running at normal rated load, releasing this load will permit a “high idle” or “settled no-load” speed may be, say, 4.5% above the rated full load speed.

\[
\text{% Governing} = \left( \frac{N_0 - N_R}{N_R} \right) \times 100
\]

Where:
- \(N_R\) = Full Load Rated or Governed Speed
- \(N_0\) = Settled No Load High Idle Speed

The speed difference between high idle and full load conditions is referred to as percentage governing, and in the circumstances referred to above, the governing would be 4.5%.

**Example:** If full load rated speed is 1800 rev/min and settled no load speed is 1880 rev/min.

\[
\text{Governing %} = \left( \frac{1880 - 1800}{1800} \right) \times 100 = 4.5\%
\]

Mechanical governors which allow only small speed change between full load and no load (tight governing) may be subject to some instability.

A governor is said to be stable if, after a speed change, the new speed is achieved quickly and there is negligible variation of this speed during steady running.

Any governor requires a definite period of time to act and a governor with poor stability continues to oscillate above and below the required speed, or else take an excessive time to cease oscillations.

When a governor continues to oscillate without settling down at all, this is usually called “surge”.

**Caterpillar Governing Categories**
Caterpillar has three governing categories:
- “V” (vehicle) — Suitable for automotive applications. Maximum governing 14%.
- “S” (standard) — General purpose governing, suitable for the majority of agricultural and industrial applications. Maximum governing 10%.
- “T” (tight) — Suitable for applications which require minimum speed variation; generator sets, combine harvesters etc. Maximum governing 5%.

To ensure consistency in production, and to avoid pre-governing, engines are set to the maximum no-load speed for the appropriated governing category.

As it is not possible to predict the residual load when the engine is installed in the machine, the installed no-load speed may differ from that set in the factory.

**Close Governing**
Small changes in governed speed with a direct current (D.C.) electrical generator, do not have the serious effect which occur with alternating current (A.C.) generators. If the engine speed is varied on a D.C. set then the voltage will change in direct proportion, but this can be compensated for over a limited range by the voltage regulator.

However, with A.C. generators (alternators) the speed of rotation governs the frequency of the output and, if varied, many items which are frequency-sensitive will fail to perform correctly.

For example, electric motors will lose speed, radar, T.V. and computer equipment will cease to function, and motor control gear and similar A.C. solenoid control devices will not operate. Overheating in many types of A.C. equipment will also occur with frequency reduction, even though the voltage remains constant.

Therefore speed regulation is extremely important for both types of current generation, but particularly for A.C.

Most countries have standards with which engines intended for electrical generation work have to comply. The appropriate British Standard is BS 5514: Part 4: 1979.
(Note: This has now superseded the previous standard BS 649: 1958.)

**BS 5514: Part 4: 1979**

This defines five classes of governing accuracy as follows:

CLASS A₀ Highest requirements of governing accuracy.
CLASS A₁ High requirements of governing accuracy.
CLASS A₂ Normal requirements of governing accuracy.
CLASS B₁ Normal requirements of governing accuracy over a wide speed range.
CLASS B₂ Reduced requirements of governing accuracy over a wide speed range.

(Note: Class A usually refers to the single speed type of governor.)

Unlike BS 649, BS 5514 does not currently give examples of the types of installation for which the Class A categories of governing are most relevant. However, it can be stated that an external governor will be required for CLASS A₀ and parallel operation.

Customer requirements for CLASS A₁ governing should be discussed with Caterpillar Application Engineering.

CLASSES A₂, B₁ and B₂ should generally be met with standard fuel pump specifications which have been developed to suit the particular applications requiring this degree of control.

For further details reference should be made to BS 5514: Part 4: 1979.

**Paralleling**

Caterpillar cannot guarantee that engines as supplied will give satisfactory parallel running, i.e. that each engine will take an equal share of the loading on part load.

It is usually necessary to fit a remote control governor to give parallel engine operation.

**Remote Mounted Governors**

A remote mounted electronic governor will give virtually isochronous running (constant speed regardless of load up to engine maximum output). For paralleling and load sharing it can be adjusted to give speed governing better than 4½%.

This type of governor can also sense changes in load and/or output frequency of a generator if additional equipment is used.

The magnetic pick-up has a threaded body and is screwed into a suitably drilled and tapped hole in the flywheel housing. This gives a pulse each time a tooth of the flywheel ring gear passes it. The speed counts the pulses and sends a signal to the actuator if the speed is incorrect.

The actuator is triggered electrically and uses fluid power from the engine lubricating system or an electrically operated solenoid to change the fuel pump setting via a mechanical linkage.

**Tailshaft Governors**

A vehicle with a mechanical transmission has the engine and the vehicle road wheels directly connected, so that, as soon as the vehicle changes speed, so also does the engine, and consequently, the drive to the governor. The governor therefore immediately senses any reduction or increase in vehicle speed, and responds accordingly.

In the case of a hydraulic transmission however, there can be an appreciable time lag between a change of vehicle road wheel speed and a corresponding change to engine speed (and therefore to the governor drive).

To overcome this delay, a “tailshaft” governor can be fitted to the transmission output shaft, so that it immediately senses any change in vehicle speed. The tailshaft governor is then connected externally to the engine governor so that this will respond to vehicle speed even though engine speed may not immediately be affected by the change in load.

With such a tailshaft governing arrangement, the engine governor is still driven from the engine, so that it can retain control over idling and rated speeds.

**INSTALLATION REQUIREMENTS**

In most applications, the provision of adequate power is only half the problem, and it is the careful attention to the particular features of each application which will lead to reliability, long engine life and customer satisfaction.

The installation requirements mentioned in this section are to draw attention to the particular features which are required in different types of applications, e.g. mountings, cooling, induction and exhaust systems, etc.

For greater information on each of the topics mentioned, it will be necessary to consult the relevant sections later in the book.
Automotive Power Requirements

Due to the large number of factors to be considered in choosing an engine for a vehicle, no hard and fast rules can be given.

Probably the most important factor is Gross Vehicle Weight, or Gross Combined Weight if semi trailers and/or trailers are to be used. Other points to be considered are: maximum desired road speed; nature of terrain, i.e., gradients and condition of road surface; frontal area of vehicle and body work; altitude of operation if over 1500 meters (5000 ft).

The majority of factors mentioned will also govern the gearbox and axle ratios selected.

Allowance must also be made for any engine driven auxiliary equipment required in addition to the standard fan, generator and exhauster/compressor.

In some countries, legislation specifies the minimum speed at which the fully laden vehicle must be capable of climbing a particular gradient, also power/weight limits.

For advice on vehicle performance prediction, i.e., maximum speed and maximum gradeability, for a given vehicle weight, frontal area, gear ratios, etc., with a specific engine, contact Application Engineering Department, Peterborough.

As a guide, the power/weight ratio will be in the order of:

- Cars and light vans: at least 20 15
- Heavy vans and medium trucks: 10 to 12 7 to 9
- Heavy trucks: 6 to 8 4.5 to 6

Air Compressors

Power Requirement

As compressors are used in many parts of the world, account should be taken of the different operating condition at altitude. It is necessary to have a reserve of engine power at sea level, because at altitude engine power is lost at greater rate than the compressor power-consumption reduces.

<table>
<thead>
<tr>
<th>Altitude above sea level meters</th>
<th>Reduction in power required by compressor</th>
<th>Reduction in power from diesel engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>4%</td>
<td>Up to 9%</td>
</tr>
<tr>
<td>2000</td>
<td>10%</td>
<td>Up to 19%</td>
</tr>
</tbody>
</table>

It is also worth bearing in mind the decrease in power which occurs with increase in air inlet temperature (see AIR TEMPERATURE in this section).

Generally, if an engine has a reserve of power at its rated speed there will be no problems regarding the power output at lower speeds.

The engine power curve flattens off from maximum torque speed upwards, but the power absorption of the air end at full load usually increases fairly linearly with speed, giving a greater reserve of engine power as engine speed reduces down to maximum torque speed. This power reserve is useful when accelerating the engine from idle to rated speed when there is a demand for air.

Certain engines, especially when turbocharged, have steeper power curves which follow more closely the straight line of the compressor power absorption curve. If the reserve at rated speed is marginal, there can be problems when load is put on the engine at idling speed. However, adjustment of the compressor control system can reduce most problems.
The table above gives an assessment of power for the different types of compressor.

Efficiencies of compressors vary considerably and thus the power requirement will vary. Power consumption tests should be conducted to determine this.

**Installation Requirements**

A satisfactory engine installation does not rely merely on matching the horsepower to the compressor air end requirement. The following points should also be noted:

1) Six-cylinder engines have good balance and can generally be solidly mounted into the chassis. It is sometimes necessary, however, to mount three and four cylinder engines on rubber. Naturally, if the air end is directly coupled to such an engine, this item must also be rubber mounted.

2) Particular attention should be paid to exhaust and inlet systems. Maximum benefit can be obtained from a silencer of fixed volume by making the length and diameter as equal as possible. If the exhaust outlet is aimed towards the ground in order to reduce noise, be sure that any dust from the ground is not drawn into the compressor or engine inlets. If air inlets are mounted under the canopy, there must be sufficient ventilation to ensure there is no appreciable pressure drop when the machine is working hard, otherwise air starvation will result.

Inlet air must be as cool as possible and trunking from air filters to engine and compressor should not have sharp bends. Keep joints in trunking to a minimum because these may leak and introduce dust. Dry-type air filters have proved to be very superior to oil bath types under bad conditions; maintenance is reduced and such filters will work even if the machine is on a steep gradient.
3) Cold-starting devices must be fitted in the recommended manner. (See SECTION 3, COLD STARTING.)

4) Linkage between throttle and governor should be as simple as possible, with as few joints as possible. As each joint wears there is some lost motion, and the total effect can be considerable if the system has too many.

5) Low-pressure fuel lines must be carefully positioned to reduce joints to minimum. One loose connection can introduce air which may stop the engine.

6) Make the machine easy to service. Position fuel, air and oil filters where they are easily accessible.

Finally, when the machine is completed, it is imperative that a fully instrumented cooling test be carried out. Temperatures of engine oil, compressor oil, cooling water in the radiator top and bottom tanks, and under canopy and air-inlet temperatures must all be recorded and extrapolated to ensure that the machine will work with a safety margin, even in the most extreme ambient temperatures likely to be encountered.

**Engine Protection Equipment**

Many mobile compressors are equipped with devices to shut down the engine automatically in the event of a malfunction in certain systems. Evidence of malfunction can usually be detected by monitoring one or more of the following:

- engine oil pressure
- engine water temperature
- engine oil temperature
- compressor oil temperature
- compressor air temperature (measured at entry into the receiver)

Should any temperature rise excessively, or the engine oil pressure fall below a certain minimum, the engine is shut down by an actuator operating on the fuel pump stop lever.

See INSTRUMENTATION AND CONTROLS, SECTION 14.

**Pumping Sets**

**Power Requirement**

An estimation of the power required for pumping water can be obtained from the formula given below; to this result, 30% should be added to cater for variable site conditions to avoid stalling.

The pump efficiency will vary, according to the pump size, but the following can be used as a guide:

Typical efficiencies for centrifugal water pump:

<table>
<thead>
<tr>
<th>Flow (liter/min)</th>
<th>Flow (U.K. gal/min)</th>
<th>Flow (U.S. gal/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1100</td>
<td>250</td>
<td>600</td>
</tr>
<tr>
<td>Up to 4000</td>
<td>900</td>
<td>2200</td>
</tr>
<tr>
<td>Up to 14,000</td>
<td>3000</td>
<td>6000</td>
</tr>
<tr>
<td>Up to 27,000</td>
<td>6000</td>
<td>14,000</td>
</tr>
</tbody>
</table>

The “total head” comprises the static head, i.e. the vertical distance from the water level at which it is pumped to where it is delivered.

\[
\begin{align*}
\text{Power to Raise Water} \\
\text{kW} &= \frac{\text{Flow (liter/min)} \times \text{Head (meter)}}{6139} \times \text{Pump efficiency} \\
\text{hp} &= \frac{\text{Flow (U.K. gal/min)} \times \text{Head (feet)}}{3300} \times \text{Pump efficiency} \\
\text{hp} &= \frac{\text{Flow (U.S. gal/min)} \times \text{Head (feet)}}{3960} \times \text{Pump efficiency}
\end{align*}
\]

When the “total head” is quoted in terms of “pressure head” (pressure = head x density), the previous equations can be modified as follows:

\[
\begin{align*}
\text{Power to raise water,} \\
kW &= \frac{\text{Flow (liter/min)} \times \text{Pressure (kN/m}^2\text{)}}{60,106} \times \text{Pump efficiency} \\
\text{hp} &= \frac{\text{Flow (U.K. gal/min)} \times \text{Pressure (lbf/in}^2\text{)}}{1430} \times \text{Pump efficiency} \\
\text{hp} &= \frac{\text{Flow (U.S. gal/min)} \times \text{Pressure (lbf/in}^2\text{)}}{1715} \times \text{Pump efficiency}
\end{align*}
\]

**Installation Requirements**

The pump set installation is similar to the compressor set. Features include a medium heavy flywheel, flexible mounts, heavy duty air cleaner, large water trap and flange mounted back end. Reciprocating type pumps require an over-center clutch, whereas the centrifugal pump usually requires a flexible coupling.

Pumping sets used for Sprinkler Systems usually have to satisfy certain specific requirements for achieving full load within a few seconds of starting, and then being able to maintain this continuously for up to six hours. The service requirements must be ascertained and checked out in the installation appraisal tests.

**Generator Sets**

**Engine Power Requirements**

(a) **Direct current**

D.C. machines are rated in kilowatts (kW).

\[
\text{Power required to drive a D.C. generator (kW)} = \frac{\text{Generator rating (kW)}}{\text{Generator efficiency}}
\]

If generator efficiency is not known, a figure of 90% is usually taken.
Alternating current
A.C. generators (alternators) are rated in kilo-volt amperes (kVA).

Power required to drive an alternator (kW) = \( \frac{\text{Alternator rating (kVA) \times Power Factor}}{\text{Alternator efficiency}} \)

Unless stated otherwise, Power Factor is usually taken as 0.8.

If alternator efficiency is not known, a figure of 90% is usually taken.

Installation Requirements
Most countries have standards to which engines intended for electrical generation work have to comply. The appropriate British Standard is now BS 5514 for electrical generating purposes. Normal requirements should be met with standard fuel pump governor specifications which have been developed for this purpose.

However, for very fine governor regulation, e.g. BS 5514: Part 4: 1979 Class A0, an external governor should be fitted.

See also SECTION 2 on GOVERNING.

Cyclic Irregularity
The current British Standard BS 5514 contains no recommendations regarding cyclic irregularity.

However, the flywheel must be of sufficient inertia to ensure that the cyclic irregularity of a direct-coupled engine and generator is within the limits previously specified in BS.649: 1968. See BACK ENDS, SECTION 4.

Torsional Vibration
To avoid resonance, the natural frequency of oscillation of the rotating system when the generator is connected to the electrical system, must not approach the frequency of any engine impulses of significant magnitude.

Caterpillar provides a service to ensure engine and generator compatibility, but before a torsional analysis is carried out, certain information must be provided.

This is listed in P.T.O., SECTION 5.

Couplings
The engine should be coupled to the generator through a suitable coupling which is of adequate capacity for the engine. The parallel and angular alignment must be within the allowed limits of the coupling.

The generator should be flange mounted to the flywheel housing where possible to ensure correct alignment. Two bearing generators are self supporting but a single bearing generator must have the armature shaft located in the flywheel pilot bearing.

Mounting
Generator set engines are usually pedestal mounted on a bed frame with rigid pedestal feet, preferably made of cast iron. The bed plate must be provided with four-point machined mounting pads so that the alignment of engine and generator can be ensured with the use of shims.
Instrumentation
Caterpillar minimum requirements are for a water temperature gauge and an oil pressure warning light. However, an hour-meter should also be used to help determine servicing intervals. If the set is to be left unattended, an engine protection device should be provided to close down the engine when water temperature becomes excessive or the oil pressure drops to a dangerous level. Automatic shut down devices must be of the type that operate directly on the fuel pump stop lever.

Filters
A water trap of adequate capacity should be positioned in the fuel system between the fuel tank and the lift pump where it can be easily seen and serviced. Similarly, the lubricating oil filter should be placed in a convenient and accessible position.

The air cleaner should be selected to suit operating conditions. Paper element or oil bath cleaners can be used, and these should be placed in a position where they can be easily serviced.

Material Handling Equipment
Power Requirement
The engine power required varies considerably according to the size of the machine and the required operation. For example, a slow moving forklift may function adequately with a relatively small engine, whereas an all-purpose rough terrain model may need to be relatively overpowered.

On large machines, which have space for crankshaft driven hydraulic pumps, higher hydraulic loadings can be imposed, but these are only momentary increases while actually “lifting”.

The following graph shows the power range generally used by manufacturers on current models of orthodox forklift trucks, side loaders and straddle carriers used in factories, warehouses and on the dockside. This range is only a guide as power varies considerably for any particular machine size, and some exceptions will fall outside these lines.

When specifying engine speeds for material handling equipment, it is necessary to determine the customer’s interpretation of “maximum rated speed”.

On this type of application it is impossible to absorb full load at maximum speed during normal operation, and hence the full load governed speed cannot be checked. The installed high idle speed which provides satisfactory lift and travel is therefore used for pass-off purposes.

Parasitic loads of up to 20% of the full power requirement can result from drag in the hydraulic and mechanical systems. These can cause a reduction in the high idle speed of up to approximately 100 rev./min. (See illustration.)

Installation Requirements
Mountings — Engines bolted directly to the transmission and axle assembly require a flexible mounting placed vertically each side of the cylinder block at the front of the engine. When 3 or 4 cylinder engines are fitted in this type of machine, vibration in the seat, footplate and steering column can present a problem. If this vibration cannot be overcome by adjusting the flexibility of the front mountings, then attention should be paid to isolating the affected parts.

When the engine, clutch and transmission is connected to the drive axle through a universal joint, or cardan shaft, the engine should be four point mounted.

Back end — To fit the engine into a small space, the design or flywheel and housing must be kept as compact as possible. Forklift trucks are frequently fitted with a torque converter and, having determined the make, it can be checked whether it is “wet” or “dry”. With a “wet” back end, the starter is exposed to oil from the oil-cooled clutch or torque converter, and an oil-sealed starter must be specified.

Cooling — The restricted space often creates a cooling problem. The size of radiator, disposition of fan and the provision of a fan cowl should be carefully studied. To avoid discomfort to the driver who sits over the engine, the air flow

POWER REQUIREMENTS FOR MATERIAL HANDLING EQUIPMENT
is often reversed and pulled from the engine, and pushed out through the radiator and aperture in the truck counter-weight. It must be ensured that:

- air has free access to the engine compartment.
- the aperture in the counterweight is sufficiently large.
- the fan is located at the center of the radiator core and does not sweep over the top or bottom tanks.
- the fan is shrouded.

**Power take-off** — Power take-off hydraulic pumps can be gear driven and mounted on the timing case, or belt driven from the crankshaft pulley. The maximum P.T.O. limits for each engine type are specified in SECTION 16, TECHNICAL DATA. It must be ensured that these limits are not exceeded as timing gear failure can occur if the hydraulic pump pressures are increased beyond Caterpillar recommendations for timing case mounted pumps.

Likewise, a hydraulic pump driven from the crankshaft pulley can impose excessive bending on the crankshaft, and details listed in P.T.O. FACILITIES, SECTION 5 should be submitted to Caterpillar for approval.

**Vibration dampers** — Torsional vibration dampers are offered with 6 and 8 cylinder engines. These are normally required if the engine is fitted with a crankshaft front end power take-off. Before specifying this expensive item however, it is advisable to submit details to Caterpillar Application Engineering who will check if it is necessary.

**Fuel systems** — For most material handling equipment a “sedimen ter” type filter is required before the fuel lift pump, with non-agglomerator fuel filter generally mounted on the engine after the lift pump.

Rough terrain equipment used in the construction industry should always have adequate agglomerator type filters.

Most forklift truck builders in Europe and North America comply with the standards of safety published by the Underwriters Laboratories Inc. These preclude the use of plastic fuel piping and glass bowl filters, as well as specifying certain other safety features for the fuel and exhaust systems.

**Agricultural Wheeled Tractors**

**Power Requirement**

Agricultural tractors normally require good torque back-up (see illustration) to provide lugging power without the engine stalling when running into a clay bed or stones etc. during ploughing.

Many farm duties are carried out at a maximum engine speed, for example, ploughing, rotary cultivating, chisel ploughing etc. The power available to drive the tractor is limited by the adhesion characteristics at the wheels.
Installation Requirements

Fuel system — In view of the adverse operating and storage conditions under which agricultural machines have to work, a heavy duty fuel system with adequate water separation capability must be used.

To prevent dust and straw being carried into the fuel tank during the filling process, it must be ensured that the fuel tank filler incorporates a suitable gauze filter.

Filters — It is virtually important that the air filter is adequate for the envisaged operating conditions of the machine, and the filter must be positioned in such a way that it cannot be damaged when the machine is in operation. The possibility of damage, particularly at the base of tractor engines, must not be ignored. The use of a horizontal or inverted lubricating oil filter can often reduce this danger and provide additional clearance on the underside of the engine.

Electrical systems — Many tractors now feature totally enclosed driver’s cabs, equipped with heating, and in some instances, air conditioning. These features, together with lighting for night operation, are making increasing demands on the electrical system circuit, and the use of higher output alternators is now becoming standard.

Harvesting Machinery

Governing — Harvesting machinery, including combines, windrowers, sugar cane harvesters etc., usually require an engine suited to running continuously at high rated speeds with accurate governing.

Forage harvesters, however, tend to operate at higher load factors but do not require such tight governing.

The efficiency of the combine harvester depends on correct drum speed for the crop being harvested.

The speed of the drum is closely controlled to operate around optimum efficiency, ideally when using about 70% of available engine power.

To achieve this, the governor run-out speed is limited to 5% maximum and, with the engine operating on the governor curve, the engine speed variation is minimal.

Occasionally, the combine does use 90% to 95% of the power available, but only when first entering the crops and until the straw-walkers etc., have freed-off. Wet ground conditions very often limit the power available.

On some machines, where optional straw choppers are fitted, the load factor increases to about 90%.

Power take-off — Harvesting machines often use extensive belt drives from both the front and the rear of the engine. In these instances, it is essential that Caterpillar Application Engineering are informed of the details of the drive (see P.T.O. POSITIONS, SECTION 5), so that a check can be made that the engine crankshaft and main bearings will operate satisfactorily in service. This is particularly necessary in the case of 6 cylinder and V8 engines, since the inertia of the pulleys at the front end can produce torsional problems which necessitate use of particular types of vibration damper.

Induction system — The air filter must be suitable for the operating conditions with a two-stage cleaner and chaff screen.

Fuel systems — A heavy duty fuel system with adequate water separation capability must be specified, due to the adverse operating and storage conditions under which these machines often have to work.

Electrical systems — With cabs now being equipped with heating, and sometimes also air conditioning, lights for night operation etc., it must be ensured that the alternator is capable of meeting the maximum possible demand of the electrical system circuit. It may be necessary to use derated alternators as they will operate satisfactorily in high dust concentrations.
POWER REQUIREMENT FOR CRAWLER DOZERS

POWER REQUIREMENT FOR CRAWLER LOADERS
Earth Moving/Construction Machinery

Power Requirements

Accurate prediction of the actual power requirements for individual machine types is impossible as many variables have to be taken into account. These include:

- Type of transmission — clutch/torque converter/hydro-static
- Type of torque converter, efficiency, and matching to engine
- Type and efficiency of machine hydraulics system
- Machine target cycle time
- Size of bucket or blade
- Digging depth and force
- Total machine weight
- Required road speed

Engine ratings suitable for earth moving and construction machinery are available in both “General” and “Heavy Duty” categories, the choice being dependent upon machine type and duty. Caterpillar should be consulted to ensure selection of the most suitable rating for a particular installation.

In order to establish the net power and torque actually available at the engine flywheel, a deduction should be made from the ratings shown on the gross power curves to compensate for the ancillary losses on the engine, i.e. fan, alternator, hydraulic pumps etc. (These losses are typically of the order of 5% – 8%, depending upon engine size.)

A check should also be made on the engine “flywheel” torque characteristics, to ensure that adequate torque back-up is available to cater for hydraulic system loadings on the engine when the machine is fully loading the engine.

The power selection charts illustrate typical ranges of relationships between flywheel power and machine size for two particular types of construction machine. Similar charts are available for other machine types. Such charts can however only be used as a guide, as power requirements can vary considerably for any particular machine type and size.

Installation Requirements

For reasonable acceleration and performance a medium inertia flywheel will be required according to the type of clutch, fluid coupling, or torque converter. A solid drive line of integral construction should be provided wherever possible to withstand possible twisting and bending stresses when travelling over rough terrain. The sump should be provided with a rear flange to form a rigid connection with the flywheel housing.

Operating gradients — As earth moving and construction machinery are operated at extreme angles of inclination, a higher gradient sump is essential.

This sump should be so desired that the engine can operate with fore-and-aft and side-to-side inclinations without loss of oil pressure, which will occur if the engine oil strainer is uncovered. Air cleaners must also be capable of operation at extreme angles.

Lubricating oil temperatures — Operation at high inclination can lead to increased oil temperatures. The oil temperature should be checked during the cooling test carried out in actual operating conditions. On engines without an integral oil cooler, it may be necessary to introduce a water cooled engine oil cooler if the oil temperature is likely to exceed 121°C (250°F).
The transmission may also require an oil cooler, and an air cooled oil cooler placed in front of the radiator or an oil cooler arrangement in the bottom tank of the radiator should be considered.

**Mountings** — Flexible mountings should be incorporated whenever possible and should be arranged to absorb engine vibration, protect the engine from frame distortion, and cushion the engine when the machine is subjected to shock loading.

**Fuel oil** — Earth moving and construction machinery may have to use fuel from stocks stored on site. The likelihood of excessive water in the fuel is high and the water trap on this type of machine should be of large capacity, and should be placed where it can be easily seen and serviced.

**Air cleaners** — Earth moving and construction machinery are normally exposed to extremely dusty conditions, and heavy duty dry element air cleaners should be fitted. These cleaners should be positioned where they can take in clean air. A position remote from the engine, outside the engine compartment, will also facilitate servicing.

The engine breather pipe can be fitted with an expansion chamber when the machine is used in dusty atmospheres.

**ACCESSIBILITY**

**General Comments**

Engines are frequently installed in as small a space as possible resulting in poor accessibility for the servicing of vital components.

Although the points referred to in this section appear later in the book under their specific topics, they have been brought together here due to their importance.

Poor accessibility of a component, e.g. the dipstick, may result in it being neglected, which can lead to serious engine damage in what might otherwise have been a good installation.

If it is necessary on loaders, etc. to start the engine in order to raise the loader arms before access can be gained to check water, engine oil, etc., the changes are that these items will not be checked, because once in the seat — the driver often stays there!

While the accessibility of components requiring regular maintenance such as air filters, filter elements, etc., is covered in Installation Appraisal Data Sheets, further checks should be completed to ensure that there is accessibility to any components which may require replacing or long term servicing.

**Cooling System**

**Fan Belt**

Space must be provided to allow tensioning or replacement of a worn belt.

**Filler Cap**

This must be located where it can be easily removed and water level checked and topped up.

**Radiator and Fan**

There must be sufficient space so that they can be examined periodically for signs of erosion or sand blasting caused by applications working in dusty environments.

**Lubrication System**

**Sump**

It is an advantage if there is sufficient clearance in the installation for the sump to be removed without having to remove the engine.

There must be sufficient space to remove the drain plug and collect the used oil, although in some cases it may be necessary to use flexible tubes.

On earth moving and construction machinery, the area round the engine sump should be checked periodically to ensure that mud packing is not preventing an adequate air flow, and therefore dissipation of heat from the engine sump.

**Oil Filler**

The oil filler must be in a position where a suitable pourer can be used.

**Dipstick**

This should be on the same side of the engine as the oil filler, in a position where it can be easily seen, and can be removed without risk of touching the hot exhaust.

**Induction System**

**Air Filter**

There must be sufficient space to remove and change the element without the risk of tipping dust and dirt into the engine.

**Air Restriction Indicator**

This must be located so that it can easily be seen if it is a visual unit, or where it can be heard if an audible unit.

**Induction Piping**

This must not be concealed, making regular inspection difficult. Cases have been known of engine damage due to dust entering the induction manifold through loose connections and/or broken piping which have been difficult to detect due to the pipe layout. All hoses must be checked periodically for deterioration.

The hose clips must be checked for tightness to ensure that relaxation of the hoses is not allowing dirt ingress.
Fuel System
Fuel Injection Equipment
There must be sufficient space to allow equipment to be easily maintained, e.g. removal of injectors, bleeding of air from system, etc.

Fuel Filter
There must be sufficient space to remove bowl and change element without spilling fuel on electrical equipment.

Lift Pump
There must be sufficient space to operate priming lever (if fitted) or replace unit if faulty.

Water Trap
This must be in a position where the water can be drained off satisfactorily and the bowl removed for service.

Excess Fuel Button
This must be easily accessible for operation, but care must be taken to meet the relevant legislation. This often requires that the excess fuel cannot be engaged from the driving position.

Electrical System
Starter Motor/Dynamo/Alternator
It must be ensured that these components can be easily serviced and removed.

Battery
This must be accessible for topping up and checking terminals.

Other Points
(a) The operation of the exhaust flap or drain hole should be checked to ensure that this is working satisfactorily.
(b) It is essential that the engine compartment sides or over-head plates do not need removing for accessibility to the dipstick or oil filler. A hinged plate is usually sufficient. It must be possible to remove the cylinder head/cover without displacing major parts of the application.
(c) The installation must permit the engine to be easily removed.
(d) It is important that no part of the engine fouls another part of the installation. This must be checked in both the static and working conditions, e.g. due to engine movement on flexible mountings, or due to operation of the machine.
(e) Hydraulic and transmission systems must be easily accessible for service.
(f) It is important that the installation permits servicing, fitting of replacement parts, etc. with the minimum man-hour involvement, especially:
   Replacement of fan belts, coolant hoses and electrical equipment; carrying out injector changes; tappet clearance checks, etc.

Where a service retorque of the cylinder head is specified for a particular engine type, this is very likely to be ignored, to the subsequent detriment of the engine, unless adequate access is provided in the original design of the installation.

HEALTH AND SAFETY
Legislation Affecting Health and Safety
In ALL COUNTRIES, it must ALWAYS be carefully considered what legislation will affect the intended operation of the installation. For example, in the United Kingdom, Section 2 (i) of the Health and Safety at Work Act 1974 states that, “It shall be the duty of every employer to ensure, so far as is reasonably practicable the health, safety and welfare at work of all his employees”.

Section 6 relates to the safe supply of materials, equipment and substances, in design and research, manufacture, testing and installation.

Responsibilities under Product Liability legislation must also be taken into account by installers.

Installation
The following points must be checked:

- All rotating parts such as flywheel, fan, coupling, shafting and belt systems must be shielded with a protective guard.
- All linkages such as throttle and stop controls, clutch, levers etc. must not protrude or overhang in a dangerous position, and must be accessible to enable the operator to control machinery safety.
- All live electric cables must be covered with a protective insulated cover, and all electrical equipment should be adequately and correctly earthed.
- All exhaust piping must be shielded or lagged where it is a potential hazard.

Legislation Affecting Operation
Specific legislation for each country cannot be detailed in this book, due to the complexity and the continual changes taking place.

However, the topics that are most likely to affect legislation are:

- noise
- emissions
- operating in explosive atmospheres or areas containing inflammable material
- operating where ventilation is limited, or hygiene is important, e.g. in the food industry
- available power, e.g. bhp/ton, etc.
SECTION 3
Cold Starting

INTRODUCTION ................................................................. 28

COLD STARTING REQUIREMENTS ....................................... 28
  Operating Territory ......................................................... 28
  Unaided Starting .............................................................. 28
  Cranking Speeds .............................................................. 28
  Drag Effects .................................................................. 28

STARTING EQUIPMENT .................................................... 29
  Battery ........................................................................ 29
  Starter Leads ................................................................. 29
  Starter Motors ............................................................... 29
  Non-Electric Starters ...................................................... 30
  Flywheel .................................................................. 30
  Starter Pinion/Ring Gear Ratio ......................................... 30
  Lubricating Oil .............................................................. 31

STARTING AIDS .............................................................. 31
  The Fuelled Starting Aid ................................................... 31
  Ether Starting ................................................................. 32
  Glow Plugs .................................................................. 32
  Port Heaters .................................................................. 33
  Excess Fuel Device .......................................................... 33
  Start Advance and Retard Mechanism .............................. 33

INSTALLATION REQUIREMENTS ....................................... 33
  Engine Compartment ...................................................... 33
  Battery Location ............................................................ 33
  Radiator Shutters ............................................................ 33
  Fan ........................................................................ 33
  Lubricating Oil .............................................................. 34
  Fuel Oil ...................................................................... 34
  Anti-Freeze Mixture ......................................................... 34
  Controls and Instructions ................................................ 34

EXTREMELY LOW TEMPERATURES ................................. 34
  Starting without Engine Heating ...................................... 34
  Starting with Engine Heating ........................................... 35
  Battery Warming ............................................................. 36
  Fuel System ................................................................. 36

TEST PROCEDURES .......................................................... 36
INTRODUCTION
Diesel engines are more demanding than spark ignition engines when starting at low ambient temperatures because ignition of the fuel relies on the compression of the air.

Satisfactory starting is the ability of the engine to fire and pick up speed without damage or abuse to the engine, starting equipment or driven machinery. For this it is necessary to:

(a) have starting equipment and engine specifications suitable for the type of engine and intended operation,
(b) use the correct engine fuel and lubricating oil;
(c) ensure that the starting equipment will be operated and maintained correctly.

Particular care must be taken in selecting and installing the relevant equipment, and the necessary information must be provided for the machine operator.

COLD STARTING REQUIREMENTS
The starting performance of different diesel engine models varies due to individual design features, the performance of the batteries and starter motor, the viscosity of the lubricating oil, the inertia of the flywheel, and whether or not a cold starting aid is used.

Cold starting performance data for the Caterpillar range of engines is tabulated in SECTION 16, TECHNICAL DATA. It is based on controlled cold chamber testing of each engine type with various starting equipment of known performance. The temperatures achieved are for engines fitted to manual gearboxes (with the clutch depressed if this increases cranking speed). Torque converter transmissions worsen cold starting performance by approximately 4°C (8°F).

Where specific conditions have not been tabulated, Caterpillar Application Engineering should be consulted.

Operating Territory
The anticipated operating temperature must be known in order that the correct starting equipment can be selected. This is particularly important where machines are likely to be exported. Reference can be made to official meteorological data published for this purpose, but as a guide, the following are considered to be the lowest ambient temperatures for starting purposes in different areas.

European Continent (Temperate zone) minus 15°C (plus 5°F)
European Continent (Cold zone) minus 21°C (minus 5°F)
North America (General) minus 29°C (minus 20°F)
Scandinavia minus 29°C (minus 20°F)
United Kingdom minus 9°C (plus 15°F)

The type of installation may have an influence on the cold starting requirements, e.g. stationary equipment installed in a sheltered building, even if un-heated, may not have such severe starting conditions as an ungaraged mobile machine working nearby.

Special care must be taken with machinery which is liable to be transported and worked at widely spaced locations.

High altitude operation, e.g. at 1500 m (5000 ft) or above, should be treated as a special case. Details listed in INSTALLATION CONSIDERATION, SECTION 2 should be submitted to Caterpillar Application Engineering for advice.

Unaided Starting
Unaided starting limits are given in SECTION 16, TECHNICAL DATA, and it will be seen that the limiting minimum ambient temperatures vary according to engine specifications, electric starting equipment and the engine lubricating oil viscosity. Indirect injection (pre-combustion chamber) engines generally have higher unaided limiting starting temperatures than direct injection.

An engine must never be released into service without a starting aid unless it is certain that it will not be required to start at below the indicated limiting temperature.

If no aid is fitted, the tapped fuelled starting aid boss in the induction manifold must be suitably plugged to prevent the drawing in of unfiltered air.

Cranking Speeds
The minimum engine cranking speed necessary for satisfactory starting, varies according to the engine design features and starting aid. If the required speed is not reached, starting is unlikely to be achieved.

Indirect injection engines generally require higher cranking speeds than direct injection types. Where a combustion heater starting aid is employed, the minimum speed requirement is lower for a particular engine than with unaided starting, and “ether” fluid assisted starting is achieved at a still lower speed.

Drag Effects
The cranking equipment recommendations are usually based on tests either on a “bare” engine, or on one fitted with a typical manually operated gearbox and clutch. If driven equipment is fitted which imposes extra loading during cranking, this drag effect must be compensated for by the use of heavier duty starter motor/battery etc.

Caterpillar will be pleased to advise where necessary.

Manual Gearboxes
These may cause up to 3°C (5°F) reduction in ambient temperature bottom limit compared with a bare engine. It may be helpful to depress the clutch during cranking, and this procedure is always recommended.
Torque Converters
The use of a torque converter drive with automatic or semi-automatic transmissions nearly always causes a significant drop in starting efficiency against a bare engine, due to the oil drag effect. This imposes a penalty of up to 5°C (9°F) on the starting limit compared to the bare engine. The deterioration in starting may be offset by using more powerful cranking equipment.

Hydrostatic Transmissions
These may give fairly high drag, depending on the design characteristics. If direct coupled hydraulic equipment is fitted to the engine, specification of a heavy duty starter motor will be essential for low temperature applications.

In the case of hydrostatic pumps, a fluid by-pass relief circulation arrangement helps to reduce drag.

Driven Machinery
All equipment which has to be motored over together with the engine during cranking will provide some drag effect.

This may be particularly significant with machinery of the reciprocating piston type, those incorporating oil pumps, and other hydraulic/hydrostatic devices.

If a centrifugally operated clutch is used, which isolates the machine from the engine when cranking, it must be made certain, when starting at low temperatures, that the cold engine is capable of turning the machinery over without stalling when the clutch cuts in.

Is some cases, machinery drag may be reduced by the use of a suitable low temperature operation oil or grease, and the equipment manufacturer involved should be encouraged to use lubricants of similar viscosity to the recommended engine oil, specifying multigrade oils as appropriate.

Engine accessories such as hydraulic pumps, air brake and cab refrigeration system compressors, additional water pumps and large output alternators and fans etc. may add significant drag, particularly when several are fitted together.

STARTING EQUIPMENT
It is not practicable to supply an engine fitted with standard equipment to meet all possible starting requirements.

If is therefore, the responsibility of the OEM, in conjunction with the Distributor or Dealer where applicable, to make certain that the engine equipment specified is suitable for the severest cold starting requirements which will be encountered at any time during the engine’s service.

Battery
See also SECTION 12, ELECTRICAL SYSTEMS.

Batteries should conform to an internationally recognized specification. Typical examples are given in SECTION 16, TECHNICAL DATA.

More comprehensive specifications against the Caterpillar battery codes, and recommendations regarding individual battery makes and models, can be supplied on request.

If special batteries such as Nickel-Cadmium and Alkaline type are used, the maker’s advice should be sought regarding suitability for a particular starting duty.

If is sometimes found in installations, particularly conversions from gasoline, that battery space is limited. This must not result in any sacrifice of performance, and if no suitable battery will fit in the original position, then the battery location must be changed.

Besides giving poor starting, in terms of the limiting ambient temperature, the use of a low performance battery can result in cranking motor problems, due to motor overheating under some circumstances after prolonged cranking.

Starter Leads
The starter leads are an important part of the cranking equipment, and installations having perfectly adequate starter motors and batteries may be rendered totally unsatisfactory by poor leads.

Details of the maximum resistance values, and other relevant information, are given in SECTION 12, ELECTRICAL SYSTEMS. It should be remembered that these are maximum values, and every effort should be made to make the total circuit resistance as low as possible — this becomes vitally important on high-drag applications.

Starter Motors
Starter motors can vary considerably in their performance, particularly in the “current draw” during cranking, even when they are of similar size or of the same nominal power output. It is therefore Caterpillar policy to specify the required motor makes and models, and in some cases, also the maker’s relevant performance curve number for particular duties. Caterpillar advice should be sought, concerning the use of any starter motor not referred to in SECTION 16, TECHNICAL DATA.

The recommended motors are on the solenoid operated positive engagement/disengagement type, and are considered suitable for starting Caterpillar engines under normal conditions of operation.

Starter motors of the “Inertia-Drive” or R.O.H. (Run-off Helix) type, where the pinion acts along a helical tooth shaft due to centrifugal action, are not generally preferred. This is due to their sensitivity to engine speed variation over its cycle, often causing early disengagement of the pinion before the engine is self-sustaining.

Their main advantage is in a reduction of body length compared with a conventional co-axial type diesel motor. They must however only be used when agreed to by Caterpillar for a specific engine operating under specified conditions.
Non-Electric Starters

Non-electric starters may be used for various reasons, for example: in flame-proof environments; as a secondary cranking system; to prevent battery theft; or as a low-cost alternative.

Various types of non-electric cranking systems can be specified. Caterpillar does not normally supply these, but can be contacted for advice concerning the proposed use of particular equipment.

Impulse Action

The most common type of impulse starter is the spring starter, with pinion engagement on the flywheel starter ring. The units are self-contained, and are wound up using a cranking handle. Space must therefore be allowed in the installation for operating the handle.

The spring starter is a relatively inexpensive unit, and is favored for use in contractors’ plant where there is a risk of battery theft.

A disadvantage of these devices is that they turn the engine over at high speed for only a small number of revolutions before the stored energy is dissipated. It is therefore very difficult to prime the fuel system, and in practice a slave electric starter and batteries must be used to start the engine if it runs out of fuel.

Hydraulic and Air Operated Cranking Motors

These motors use a conventional pinion, but the motor is powered by compressed air or hydraulic oil under high pressure.

The torque/speed characteristics of these motors are significantly different from those of an electric starter motor. Much higher speeds are achieved, but for a very short duration; even with a substantial reservoir capacity, cranking time never matches that of an electric system.

Charging up of the reservoir is commonly done mechanically by an engine-driven pump during engine running and there is always a supplementary hand-operated pumping system available for hydraulic systems, for which operator accessibility is required. The reservoir and operating equipment is often relatively bulky, and the systems, even in their simplest form, are expensive.

These cranking systems, because of their short cranking duration, do not generally give unaided starting at such low temperatures as electric systems. Ether is the only starting aid which can be used with any non-electric cranking system, and by this means –15°C is readily achieved on most engines with a simple hydraulic or pneumatic cranking system.

Flywheel

See also BACK ENDS, SECTION 4. Minimum flywheel inertia values for each engine at specified conditions are quoted in SECTION 16, TECHNICAL DATA.

A certain minimum rotating inertia is necessary to ensure sufficient speed while the piston is near T.D.C. This assists in providing satisfactory fuel injection, and reduces the chances of premature ignition where advanced timings are used.

Even though the mean (average) cranking speed may be the same using flywheels of different inertia, the cyclic speed variation can be quite different (see illustrations).
ensure that the starter motor pinion has the correct number of teeth to give the required ratio.

The starter motor torque characteristics must match the engine turning requirements during cranking, with sufficient reserve or torque and speed to assist the engine to pick up and run properly after firing has commenced.

**Lubricating Oil**

The lubricating oil has a major effect on starting performance and requires as much care in its choice as does the starter motor and battery. Guidance on the selection of oil viscosity grades is given in SECTION 16, TECHNICAL DATA.

Oil used in equipment which is driven when the engine is cranked is equally important, and equipment manufacturers should be encouraged to specify oil viscosities which are realistic in relation to ambient operating temperature.

**STARTING AIDS**

Diesel engines require an aid to combustion to start satisfactorily below certain ambient temperatures.

Various types of starting aids can be used with Caterpillar engines depending on conditions.

See SECTION 16, TECHNICAL DATA.

**The Fuelled Starting Aid**

The fuelled starting aid is a device for raising the temperature of the air being drawn into the cylinder.

When the heater coil is energized, the valve body is heated and expands to allow the ball valve to open and fuel to flow. The fuel is vaporized and, as the engine is cranked, the fuel/air mixture is ignited, thus raising the temperature of the air entering the cylinder.

The mixture continues to burn as long as the heater coil is energized and fuel is flowing. When the fuelled starting aid is switched off, the incoming air quickly cools the valve body and the fuel supply valve closes.

**Typical Fuelled Starting Aid**

The fuel feed is taken from a clean side port or a clean side vent on the filter, via a pipe of suitable size.

**Position**

The fuelled starting aid is fitted in the induction manifold, air intake connection or adapter. It must be fitted within 20° up or down of the horizontal, and located in an optimum position and depth to satisfactorily heat the air during cranking and ensure an even distribution to each cylinder. It also has to be arranged so that there is low restriction to the engine air supply during normal running. Any arrangement which is not a Caterpillar standard position should be submitted for approval.

**Insulated Return**

The “insulated return system” is the wiring technique wherein two separate cables are used to a piece of electrical equipment, as opposed to the “earth return system”, where the machine chassis acts as a common return.

The fuelled starting aid must be insulated from the manifold and, if a metal fuel supply pipe is used, electrical continuity must be interrupted by inserting a length of pipe of suitable insulating material near the thermostat, or by using an insulated pipe adapter.

**Electricity Supply**

The fuelled starting aid used with Caterpillar engines is arranged for 12 volt supply. The use of the 24 volt fuelled starting aid is not recommended by Caterpillar.
On 24 volt installations the required 12 volts is obtained either:

a) by use of a dropping resistor wired in series with the fuelled starting aid. This must be of an approved type which will not burn out in service. Note that dropping resistors dissipate considerable heat and should be positioned accordingly.

or

b) by means of a 12 volt supply from the battery switched via a relay operated by 24 volts.

Ether Starting

When low temperatures dictate the need for an “ether” type starting aid, a permanently fitted, controlled-flow type, approved by Caterpillar for that particular engine, should be used.

System approval includes: branded start fluid mixture, pressurized supply device or hand pump make and model number, nozzle type including spray orifice arrangement, fluid storage container or capsule capacity size and supply pipe work bore.

Ether starting fluid aid systems must only be used while the engine is cranked (i.e. no pre-application). The only exception to this is where non-electric starting is being used, in which case it is advisable to dispense a small amount of ether before cranking. Also, ether must not be used in conjunction with any form of engine combustion aid.

The use of hand carried aerosol spray cans as a consistent aid to starting is not recommended, due to the danger of over-application.

When selecting a particular system, it must be ensured that the correct fluid supply will be available in the operating area. Each system has to be arranged to supply fluid in the correct quantity, and hence mixture strength, as it is particularly important to avoid over-application which may lead to engine damage due to the creation of excessively high cylinder pressures.

Approved fluid mixtures contain the correct proportions of neat diethyl ether, and also a cylinder lubricant and other necessary additives.

The nozzle should be arranged so that the starting fluid is mixed as thoroughly as possible with the incoming air, and it is therefore usual practice to spray against the direction of air flow. There is usually an arrow or other indication on the nozzle to enable correct positioning, and the system makers usually provide instructions for the fitment of the complete system.

Ether starting fluid aid systems must only be used while the engine is cranked (i.e. no pre-application). The only exception to this is where non-electric starting is being used, in which case it is advisable to dispense a small amount of ether before cranking. Also, ether must not be used in conjunction with any form of engine combustion aid.

The use of hand carried aerosol spray cans as a consistent aid to starting is not recommended, due to the danger of over-application.

When selecting a particular system, it must be ensured that the correct fluid supply will be available in the operating area. Each system has to be arranged to supply fluid in the correct quantity, and hence mixture strength, as it is particularly important to avoid over-application which may lead to engine damage due to the creation of excessively high cylinder pressures.

Approved fluid mixtures contain the correct proportions of neat diethyl ether, and also a cylinder lubricant and other necessary additives.

The nozzle should be arranged so that the starting fluid is mixed as thoroughly as possible with the incoming air, and it is therefore usual practice to spray against the direction of air flow. There is usually an arrow or other indication on the nozzle to enable correct positioning, and the system makers usually provide instructions for the fitment of the complete system.

Ether Starting

When low temperatures dictate the need for an “ether” type starting aid, a permanently fitted, controlled-flow type, approved by Caterpillar for that particular engine, should be used.

System approval includes: branded start fluid mixture, pressurized supply device or hand pump make and model number, nozzle type including spray orifice arrangement, fluid storage container or capsule capacity size and supply pipe work bore.

Ether starting fluid aid systems must only be used while the engine is cranked (i.e. no pre-application). The only exception to this is where non-electric starting is being used, in which case it is advisable to dispense a small amount of ether before cranking. Also, ether must not be used in conjunction with any form of engine combustion aid.

The use of hand carried aerosol spray cans as a consistent aid to starting is not recommended, due to the danger of over-application.

When selecting a particular system, it must be ensured that the correct fluid supply will be available in the operating area. Each system has to be arranged to supply fluid in the correct quantity, and hence mixture strength, as it is particularly important to avoid over-application which may lead to engine damage due to the creation of excessively high cylinder pressures.

Approved fluid mixtures contain the correct proportions of neat diethyl ether, and also a cylinder lubricant and other necessary additives.

The nozzle should be arranged so that the starting fluid is mixed as thoroughly as possible with the incoming air, and it is therefore usual practice to spray against the direction of air flow. There is usually an arrow or other indication on the nozzle to enable correct positioning, and the system makers usually provide instructions for the fitment of the complete system.

Ether Starting

When low temperatures dictate the need for an “ether” type starting aid, a permanently fitted, controlled-flow type, approved by Caterpillar for that particular engine, should be used.

System approval includes: branded start fluid mixture, pressurized supply device or hand pump make and model number, nozzle type including spray orifice arrangement, fluid storage container or capsule capacity size and supply pipe work bore.

Ether starting fluid aid systems must only be used while the engine is cranked (i.e. no pre-application). The only exception to this is where non-electric starting is being used, in which case it is advisable to dispense a small amount of ether before cranking. Also, ether must not be used in conjunction with any form of engine combustion aid.

The use of hand carried aerosol spray cans as a consistent aid to starting is not recommended, due to the danger of over-application.

When selecting a particular system, it must be ensured that the correct fluid supply will be available in the operating area. Each system has to be arranged to supply fluid in the correct quantity, and hence mixture strength, as it is particularly important to avoid over-application which may lead to engine damage due to the creation of excessively high cylinder pressures.

Approved fluid mixtures contain the correct proportions of neat diethyl ether, and also a cylinder lubricant and other necessary additives.

The nozzle should be arranged so that the starting fluid is mixed as thoroughly as possible with the incoming air, and it is therefore usual practice to spray against the direction of air flow. There is usually an arrow or other indication on the nozzle to enable correct positioning, and the system makers usually provide instructions for the fitment of the complete system.

Ether Starting

When low temperatures dictate the need for an “ether” type starting aid, a permanently fitted, controlled-flow type, approved by Caterpillar for that particular engine, should be used.

System approval includes: branded start fluid mixture, pressurized supply device or hand pump make and model number, nozzle type including spray orifice arrangement, fluid storage container or capsule capacity size and supply pipe work bore.

Ether starting fluid aid systems must only be used while the engine is cranked (i.e. no pre-application). The only exception to this is where non-electric starting is being used, in which case it is advisable to dispense a small amount of ether before cranking. Also, ether must not be used in conjunction with any form of engine combustion aid.

The use of hand carried aerosol spray cans as a consistent aid to starting is not recommended, due to the danger of over-application.

When selecting a particular system, it must be ensured that the correct fluid supply will be available in the operating area. Each system has to be arranged to supply fluid in the correct quantity, and hence mixture strength, as it is particularly important to avoid over-application which may lead to engine damage due to the creation of excessively high cylinder pressures.

Approved fluid mixtures contain the correct proportions of neat diethyl ether, and also a cylinder lubricant and other necessary additives.

The nozzle should be arranged so that the starting fluid is mixed as thoroughly as possible with the incoming air, and it is therefore usual practice to spray against the direction of air flow. There is usually an arrow or other indication on the nozzle to enable correct positioning, and the system makers usually provide instructions for the fitment of the complete system.

Ether Starting

When low temperatures dictate the need for an “ether” type starting aid, a permanently fitted, controlled-flow type, approved by Caterpillar for that particular engine, should be used.

System approval includes: branded start fluid mixture, pressurized supply device or hand pump make and model number, nozzle type including spray orifice arrangement, fluid storage container or capsule capacity size and supply pipe work bore.

Ether starting fluid aid systems must only be used while the engine is cranked (i.e. no pre-application). The only exception to this is where non-electric starting is being used, in which case it is advisable to dispense a small amount of ether before cranking. Also, ether must not be used in conjunction with any form of engine combustion aid.

The use of hand carried aerosol spray cans as a consistent aid to starting is not recommended, due to the danger of over-application.

When selecting a particular system, it must be ensured that the correct fluid supply will be available in the operating area. Each system has to be arranged to supply fluid in the correct quantity, and hence mixture strength, as it is particularly important to avoid over-application which may lead to engine damage due to the creation of excessively high cylinder pressures.

Approved fluid mixtures contain the correct proportions of neat diethyl ether, and also a cylinder lubricant and other necessary additives.
Port Heaters
Port heaters are electrical devices which heat the air entering the inlet ports. They can give starting down to very low temperatures, but are less effective in high-drag applications, and need careful positioning near the inlet ports. The main advantage is that no pre-heat is required. Port heaters are also helpful in giving rapid smoke-free run-up after starting.

Excess Fuel Device
Certain engine types incorporate a manual excess fuel device in the fuel pump, which must be actuated by the operator prior to starting from cold below a certain ambient temperature, depending on the engine type.

Many countries have legal requirements regarding these devices, to prevent their operation during normal running, in order to safeguard against the possibility of resulting excessive exhaust emission.

The legal position in respect of these devices should be established by the equipment manufacturer in all cases, and action should be taken to conform to the relevant requirements.

When a remote actuating arrangement is fitted, due to inaccessibility of the device in the installation, care must be taken that this will not result in excessive loads being applied at the fuel pump.

Where a manually-operated excess fuel device is fitted, it must be used even when other starting aids are fitted.

Start Advance and Retard Mechanism
Some fuel injection pumps incorporate either a “Start Advance” or “Start Retard” mechanism for starting, to advance or retard respectively the timing of the fuel injection during cranking, compared with the pump’s normal operation injection timings.

The operation is usually fully automatic, and a combustion starting aid is used at the same time, as necessary.

INSTALLATION REQUIREMENTS
Engine Compartment
The engine compartment should be enclosed as far as is practicable by the blocking of all un-necessary apertures. Some shielding may be an advantage under the sump.

Allowance must however be made for summer cooling requirements, engine aspiration air flow, and general engine accessibility.

Battery Location
The battery must be positioned as close to the starter motor as possible, to minimize the length and resistance of the leads.

It must be protected from the cold, as battery performance deteriorates with decrease of electrolyte temperature (see illustration).

If the battery is encased, there must be adequate ventilation to dispel the emitted gases, with access to the battery for checking and topping up the electrolyte.

See SECTION 3 for BATTERY WARMING.

Radiator Shutters
Radiator shutters will promote quicker engine warm-up and maintain a warmer general under-bonnet condition during machine operation. They must however be of a reliable make and fully automatic, operating thermostatically from the temperature of the engine cylinder head coolant.

Note: The use of radiator shutters may increase the noise emission from the installation.

See also COOLING SYSTEMS, SECTION 7.

Fan
An alternative to the radiator shutter is a thermostatically controlled fan of the viscous drive type, preferably sensing from the cylinder head coolant. The fan and drive arrangement must be of proven reliability and the cooling efficiency must be cleared for the maximum expected summer ambient.
During the majority of operating time in very cold climate areas the engine will be overcooled using a conventional fan/radiator system. However, it is not recommended practice to run without a fan.

See also COOLING SYSTEMS, SECTION 7.

Lubricating Oil
The starting performance details in SECTION 16, TECHNICAL DATA, specify the engine oil SAE viscosity grade necessary with certain starting equipment for a minimum start temperature.

Oil of the correct viscosity range is one of the most critical features to ensure satisfactory starting, as its influence on the engine internal friction and oil pumping requirement will affect the engine turning-over drag, and hence cranking speed. It is also very important to use the recommended oil technical specification for the engine type and duty where applicable, to avoid such engine operating troubles as piston compression ring sticking, excessive component wear and oil sludging, which could cause a deterioration of starting efficiency.

For operation in extremely cold climates, it may be necessary to change the engine lubricating oil and filter more frequently than the standard service recommendation, due to increased sludging effect.

Fuel Oil
The important features of fuel for cold starting and cold running are the “Cold Filter Plugging Point” (CFPP) temperature (which must be lower than the lowest likely operating temperature), cetane number, and viscosity. Filters, particularly those that have been in service for some time may choke at temperatures below the Cloud Point of the fuel. Fuel filter heaters may be essential in some countries.

Starting begins to deteriorate when the cetane number falls below 45, and published starting performance may then not be achieved.

No flow or Cetane improver additive should be added to fuel without the agreement of the oil company.

Applications for despatch to cold climate areas should be filled with suitable fuel.

SECTION 16, TECHNICAL DATA gives details of Caterpillar approved fuel specifications.

Anti-Freeze Mixture
Commercial anti-freeze of an approved ethylene glycol (ethyangediol) type, with corrosion inhibitor, should be used. This will cater for sustained ambient temperature down to –40°C (–40°F).

An engine coolant should never contain more than 50% by volume of anti-freeze, because at stronger concentrations than this the freezing point temperature of the mixture actually rises. Also, owing to the increased viscosity of the coolant mixture, the engine will not be warmed up properly during the pre-warming period, and could suffer from cooling problems during working.

For ambients below –40°C the appropriate anti-freeze manufacturer should be consulted regarding the use of a suitable methanol base anti-freeze for diesel engine operation.

See also COOLING SYSTEM, SECTION 7.

Controls and Instructions
The engine starting controls must be positive in action, easily understood, and arranged for convenient operation. All applications should be fitted with clear instructions giving the correct starting sequence for cold starting.

If the proper procedure is not followed, poor starting performance may result, even if the starting equipment is correct.

See SECTION 14, INSTRUMENTATION AND CONTROLS.

EXTREMELY LOW TEMPERATURES
Temperatures below –30°C (–22°F) usually require special measures to be taken by the O.E.M. to ensure consistent starting. The measures to be taken will depend on the minimum temperature required, and on the type of application.

Various proprietary equipment makers specialize in the “winterizing” of engines and machinery, and should be consulted as early as possible in the machine building stage.

Under extremely low temperature conditions it is particularly important to follow the recommendations on fuel oil and anti-freeze mixture outlined in the paragraphs FUEL OIL and ANTI-FREEZE MIXTURE.

Considerations for engine starting under extremely low temperature conditions fall into two categories, i.e. with and without engine heating.

Starting without Engine Heating
Where engine heating facilities are not available, starting down to –40°C (–40°F) may still be possible with careful choice of cranking equipment and starting aid.

Starter Motor
A 24 volt cranking system is essential for temperatures below –32°C (–26°F). The starter motor should be the most powerful that can be fitted to the engine.

The starter lead resistance should be kept to the absolute minimum — for further information see SECTION 12, ELECTRICAL SYSTEMS.

Batteries
Since the chemical activity within conventional batteries virtually ceases at –40°C (~40°F), it is important to use batteries which are suitable, and battery manufacturers’ recommendations should be sought. As a guide, for use in extremely low temperature, batteries should have a minimum reserve capacity of 200 minutes.
Most modern batteries are reluctant to accept a significant charge if the battery itself is at low temperature. If the battery is remote from any other source of heat, a self-energized battery heater, combined with good insulation would be advantageous. (For further information see BATTERY WARMING.)

**Alternator**
This must be of sufficient output to cover any extra demands made on the electrical system due to the use of engine heating systems, additional cab heater fans, lighting systems, de-icers, etc.

**Lubricating Oils**
Particular attention must be given to the oils used in the engine, transmission and hydraulic systems. No lubricant having a higher viscosity than OW should be used in the moving parts which are in operation during cranking, unless advised otherwise by the equipment supplier. In extreme cases it may be necessary to add a small quantity of fuel oil (10% to 20%) to the lubricant to allow the engine to be cranked.

**Starting Aid**
An ether type starting aid is essential for starting at temperatures below –32°C (–26°F) where no engine heating is available.

The Start Pilot Viso F type hand-operated ether systems are most reliable for very low temperatures, and have M.O.D. approval.

Aerosol-operated ether systems may give poor ether delivery at very low temperatures if partially-filled cans are constantly used, or unless the can is warmed according to the instructions on the can before starting.

At extremely low temperatures a higher flow rate system may be needed than would be recommended above –30°C (–22°F).

**Starting with Engine Heating**
Where engine heating is available, starting should not be a problem, provided that the heating is rated to suit the lowest required temperature and is operated for the correct time. Heating times of less than two hours are unlikely to be fully effective, and it may be more appropriate to leave the heat switched on overnight. The use of radiator shutters and side screens is essential where engine heating is used.

The type of heating system used will depend to a great extent on the facilities available. It is preferable to use one working directly on an AC electrical supply if this is available at the garaging location. Otherwise, fuel burning combustion heater systems give good results, particularly under severe weather conditions. Any system used must be thermostatically controlled to prevent coolant overheating occurring.

For air temperatures down to not lower than –34°C (–30°F), the use of an effective electrical cylinder block heater alone will be adequate, and will give sufficient heat soak to warm the oil in the sump if this is sheltered from the wind. However, the necessary pre-warming time will be longer than if both block and sump heaters are used.

In extreme cases, where the overnight air temperature approaches –40°C, heating may be required continually when the engine is not running.

All adaptations made to the engine must be carefully examined to make sure that no coolant will leak in service.

**Electrical, Sump, and Cylinder Block Heaters**
These are sheathed elements operated at mains voltages, mounted in either the sump or in the block, and supplied from an external supply source. Their use is limited to maintaining the engine temperature while the machine is stationary and, with moving machines, they are connected by a plug which should be designed to automatically disconnect if the machine is driven away without disconnecting.

These heaters are common in extreme cold climates and with standby vehicles such as fire engines, which must rapidly achieve working temperature.

The wiring for these heaters must be independent of the 12 or 24 volt battery circuit, although the circuit may be controlled by the machine supply. The insulation and the routing of the cables must comply with the relevant safety regulations.

**Sump Oil Heater (Electrical)**
A single heating element will usually be sufficient for standard oil pan arrangements.

The heater should be fitted into the sump well if there is one. If the sump is of the plain flat type, it should preferably be positioned mid-way along the engine. It should be situated as low as possible without the element coming into contact with the sump bottom or side walls, and it must adequately clear engine moving parts and the oil pump and suction assembly.

Some larger engine oil sumps have tapped bosses in them for fitting the heater element, but in most cases, it will be necessary for the engine installer to adapt the sump. One method is to utilize a spare drain plug boss. If necessary the sump side wall will have to be suitably bossed and tapped.

In some cases, it may be found practical to use a proprietary sump external heater pad arrangement instead of an immersion heater.

**Cylinder Block Heater (Electrical)**
Many liquid cooled engines have a suitable tapping or reamed core plug position in the side of the cylinder block near the center, with adjacent space in the block coolant passage for the fitting of an electrical heater element.

The heater manufacturer will advise on the correct heater type. One heater is usually adequate for in-line engines of up to about 7 liters (430 in³) swept volume, and two for larger in-line engines and all Vee engines.
**Combustion Heater Device**

This type of device heats up the engine coolant by the burning of diesel fuel, kerosene, or possibly butane or propane, according to the design.

The system’s operation is often battery powered and circulates engine coolant liquid around the burner system to the engine, and also if required through cab heaters, jacketed battery container etc.

The hot liquid is fed into the cylinder block electric heater position, or the water pump suction inlet connection, and out of the cylinder head through a suitable point such as the rear cover. A dual circuit should be used for Vee engines, so that a separate feed is taken through each bank simultaneously.

If the lubricating oil is to be heated, the hot liquid should be fed through the heat exchanger in the sump before passing to the cylinder block.

All connections should be capable of being quickly disconnected and should provide leak proof sealing.

**Battery Warming**

Batteries must be relatively warm for cranking, and provision may be required to heat them when the engine is not running. Whether electric or liquid heating is used, excessive heat at any particular point must be avoided.

The battery manufacturers should be consulted for their recommendations.

For machine operation in air temperatures approaching –40°C (–40°F), it may be necessary to warm the batteries while the machine is working to enable possible engine restarting. This can be arranged by passing the hot engine exhaust gas through a battery container made of suitable anti-corrosion material. The exhaust back pressure must be within the recommended limits, (see EXHAUST SYSTEMS, SECTION 9) and with drain provision for the exhaust gas fluid content.

However, the battery must not be allowed to become too hot, as its condition may deteriorate if its temperature reaches about 50°C (125°F approx.).

**Fuel System**

Refer to SECTION 10, FUEL SYSTEMS, for standard recommendations which generally apply.

Special precautions may be required to ensure that the fuel will be supplied satisfactorily to the fuel injection pump, both at engine starting and during the machine operation.

It will be particularly necessary to prevent fuel waxing effect and/or water content freezing at any point which could block the supply or return lines.

The use of elbow bend connections, banjo connections or sharp bends should be avoided. Filter gauze should not be fitted to any component in the fuel system.

Subject to meeting any applicable insurance requirements, the use of suitable nylon pipe material in a well engineered system may be of advantage due to its thermal insulation property. The fuel return pipe to the tank can be run directly alongside the fuel feed pipe where practicable to conserve warmth.

It may be found necessary to lag the fuel pipelines, either along the whole run from tank to engine lift pump and return (including connections to cater for very severe conditions), or in any particular area exposed to the weather elements. Electrical heating tape which is energized during the engine pre-heating period is a very effective method.

**Sedimentor or Water Trap**

This should be of large capacity and located in a sheltered but accessible and visible position as close to the fuel tank as is practicable.

**Fuel Filters**

These must be fitted onto, or very close to the engine, so as to receive warmth from the engine during pre-heating and machine operation.

Preferably, the filters should not be situated close to the engine fan or directly in the air flow.

Fuel filters heaters are available, and may be essential in some countries.

**Fuel Lift Pump**

Due to the increased fuel viscosity at low temperature it may be necessary, where there is a particularly long fuel pipe run, to fit an electrically operated booster pump at the fuel tank.

**TEST PROCEDURES**

Some Original Equipment Manufacturers (O.E.M.) have cold chamber facilities and conduct their own cold starting tests.

Caterpillar, upon request, will be pleased to provide details of the engine cold test procedure. This will cover such features as the preparation of the engine before placing the machine in the cold chamber, battery conditioning, test procedures with various types of starting aid, and presentation of the test data.

This should ensure that test work carried out by the customer can be compared with similar work on the same engine type at Caterpillar.
FLYWHEELS

The flywheel stores the energy produced during the power stroke and returns it during the rest of the cycle, thereby reducing the cyclic speed variation in the crankshaft and transmission. (See SECTION 4, TORQUE FLUCTUATIONS.) It is particularly important to have adequate flywheel inertia to give satisfactory starting at low temperatures.

(See also COLD STARTING, SECTION 3.)

Inertia

A certain minimum rotating inertia is necessary to ensure sufficient speed while the piston is near T.D.C. This assists in providing satisfactory fuel injection, and reduces the changes of premature ignition where advanced timings are used.

Even though the mean (average) cranking speed may be the same using flywheels of different inertia, the cyclic speed variation can be quite different (see illustrations).

A low inertia flywheel is preferred for automotive type applications, which are subject to relatively high engine over-run speeds and which require fast acceleration and deceleration.

A larger inertia flywheel is required for many constant speed or medium duty, variable speed industrial installations, to reduce cyclic irregularity of the engine or driven equipment. It also reduces the temporary speed change of the engine when load is suddenly removed or applied.

A flywheel of the highest inertia practicable should be used for electric generating sets of other relatively low speed or constant speed engines requiring fine governing, where cyclic irregularity must be maintained at a minimum. It is also suitable for heavy duty applications where maximum assistance from the flywheel is necessary to prevent the engine stalling against sudden load.

Inertia value details are available for all Caterpillar flywheels in the appropriate Sales Catalog.

To these values may be added the inertias of any parts directly coupled to the flywheel, e.g. clutch assembly, etc.

Minimum flywheel inertias for each engine type at specified cold starting conditions are tabulated in SECTION 16, TECHNICAL DATA.

Calculation of Inertia

Moment of Inertia = mass × (radius of gyration)^2 = (mk^2)

The moment of inertia of a flywheel can be calculated as follows:

1. Simplify the flywheel shape into a number of symmetrical cylinders.
2. Calculate the moment of inertia of each cylinder by the formula below.
3. Add the individual values together to obtain the total moment of inertia.

\[ \text{M. of I.} = \frac{1}{8} \times \rho \times \frac{\pi}{4} \times B \times (D^2 - d^2) \times (D^2 + d^2) \]

where \( \rho \) = density of flywheel material.
<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron of S.G. Iron</td>
<td>7197 kg/m³ (0.26 lb/in³)</td>
</tr>
<tr>
<td>Steel</td>
<td>7750 kg/m³ (0.28 lb/in³)</td>
</tr>
</tbody>
</table>

Conversion factors:

\[
1 \text{ kg m}^2 = 3417.6 \text{ lb in}^2 (\text{mk}^2) \\
1 \text{ lb in}^2 = 0.00029264 \text{ kg m}^2 (\text{mk}^2)
\]

The moment of inertia may also be expressed in absolute units of:

**FORCE. LENGTH. TIME²**

\[
1 \text{ lb in}^2 = 0.00259 \text{ lbf in s}^2 \\
1 \text{ kg m}^2 = 10,194 \text{ kgf cm s}^2 \\
1 \text{ kg m}^2 = 1,00 \text{ Nm s}^2
\]

**NOTE:** All the above formula are based on mk²

**Flywheel Effect**

The flywheel effect is mass \( \times (\text{diameter of gyration})^2 = GD^2 \) or \( PD^2 \)

Sometimes this flywheel effect is referred to as moment of inertia, but this can lead to confusion as the flywheel effect is four times greater than the correct mathematical definition of moment of inertia.

**Design and Manufacturing Requirements**

Standard flywheels for different types of engine and application are specified in the appropriate Sales Catalog.

If it is necessary for customers to make their own flywheels, the design and manufacturing requirements must be obtained from Caterpillar Engines. Full details of the intended flywheel must then be submitted to Caterpillar Engines for approval.

**Starter Rings**

It is essential that the gearing ratio between the starter motor pinion and the flywheel ring gear is of a specified optimum value. The ratio is usually within a fairly narrow band, and details for all engines are specified in SECTION 16, TECHNICAL DATA.

As the number of teeth on the flywheel starter ring gear will vary according to the flywheel design, it will be necessary to ensure that the starter motor pinion has the correct number of teeth to give the required ratio.
As the crankshaft rotates, this instantaneous torque varies about the “mean” value, causing the crank to increase and decrease its speed with respect to the mean speed. It is this change of angular velocity effect which is known as “Cyclic Irregularity”. A guide to the ratio of maximum to mean indicated torque for a diesel engine is as follows:

<table>
<thead>
<tr>
<th>Number of Cylinders</th>
<th>Ratio Maximum to Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three</td>
<td>5.0:1</td>
</tr>
<tr>
<td>Four</td>
<td>3.5:1</td>
</tr>
<tr>
<td>Six</td>
<td>2.6:1</td>
</tr>
<tr>
<td>Eight</td>
<td>2.2:1</td>
</tr>
</tbody>
</table>

**Definition of Cyclic Irregularity**

Cyclic irregularity was defined in Clause 2 of BS 649: 1958 as the ratio of the total variation in speed (instantaneous angular velocity) at the flywheel during one engine cycle to the mean speed when the engine is running at any load up to and including rated load and rated speed.

This is conveniently expressed as:

\[
\text{Cyclic irregularity} = \frac{\max \text{ speed} - \min \text{ speed}}{\text{mean speed}}
\]

For example:

\[
\frac{1510 - 1490}{1500} = \frac{20}{1500} = 1/75
\]

It is important that for generating set applications the cyclic irregularity or speed variation is not excessive.

Clause 9a of BS 649: 1958 stated that, for a direct coupled engine and generator, the cyclic irregularity as defined in Clause 2 is independent of the number of poles of the generator, and refers to the angular velocity at the rotor of the electrical machine. For an engine having more than two cylinders, the cyclic irregularity shall not be worse than 1 in 75 for an engine with above 20 impulses per second.

For a three cylinder engine running at 1500 rev/min, the number of impulses per second would be found as follows:

\[
\frac{1500}{2} = 750 \text{ i.e. impulses per minute per cylinder (four stroke engine)}
\]

\[
750 \times 3 = 2250 \text{ impulses per minute for three cylinders}
\]

\[
\frac{2250}{60} = 37.5 \text{ impulses per second for three cylinders}
\]

**Additional Inertia**

The rotating mass of any parts directly coupled to the flywheel, for example the armature of an electric generator, a torque converter, etc., can be included in the total inertia value, with the flywheel inertia for cyclic irregularity purposes.

The starter ring gear will add about 0.176 kg.m²(GD²), 150 lbf in² (mk²) to the inertia of the flywheel.

**Calculation Example**

A 3.86 liter (236 in³) four cylinder engine with a heavy flywheel of 6200 lb in² moment of inertia which was designed for the Holset 0.12 flexible coupling and driving an alternator with a typical inertia of 3000 lb in².

The inertia of the engine has been ignored as this is very small when compared with the inertia of the flywheel and alternator.

\[
\text{System total inertia} = \text{flywheel + alternator inertia}
\]

\[
= \frac{6200 + 3000 \text{ lb in}^2}{2} = 9200 \text{ lb in}^2
\]

**Cyclic Irregularity Curves**

Considering the Cyclic Irregularity Curve for this particular engine, it can be seen that:

for constant speed of 1500 rev/min,

\[
\text{cyclic irregularity} = 1/175
\]

for constant speed of 1800 rev/min,

\[
\text{cyclic irregularity} = 1/340
\]

Since each of the above examples shows that the result is substantially better than the BS 649: 1958 limit of 1/75 the available standard flywheel for generating set applications will meet the requirement.

Cyclic Irregularity curves for each engine are available from Application Engineering, Caterpillar Engines Ltd.
FLYWHEEL HOUSINGS

Flywheel Housing Design

On some applications the flywheel housing carries the rear mounting feet and therefore supports part of the weight of the engine plus most of the weight of the gearbox. It must be strong enough to withstand all the loading due to the machine’s operation.

Heavy or long gearboxes, or torque converters, can produce excessive bending moments at the rear face of the cylinder block and may require separate mountings.

See SECTION 6, MOUNTING SYSTEMS.

Two types of housings are commonly used by Caterpillar, namely “half” and “full” housings.

Half Housings (See illustration) — These suit various proprietary gearboxes, and are very flexible because of the open, unsupported lower part.

Full Housings (See illustration) — These are generally designed with a standard SAE gearbox mounting face. Where rigidity is required, a tied sump should be used, i.e. the lower part of the flywheel housing is bolted to a special sump.

Manufacture

Flywheel housings manufactured by customers must satisfy all Caterpillar requirements which are obtainable from Caterpillar on request. The housings must be fitted as specified in the Workshop Manual for each engine type, with regard to concentricity, alignment, etc. (see Table below).

SAE Dimensions

Various SAE housings are available for Caterpillar engines, depending on the particular engine type.

See the Sales Catalog for availability.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inch</td>
<td>mm</td>
<td>Inch</td>
</tr>
<tr>
<td>4</td>
<td>14.25</td>
<td>362.0</td>
<td>0.004</td>
</tr>
<tr>
<td>3</td>
<td>16.125</td>
<td>409.6</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>17.625</td>
<td>447.7</td>
<td>0.005</td>
</tr>
<tr>
<td>1</td>
<td>20.125</td>
<td>511.2</td>
<td></td>
</tr>
</tbody>
</table>

CONCENTRICITY AND ALIGNMENT OF FLYWHEEL HOUSINGS AND BACK PLATES
Drive Line Vibration

Vibratory loads induced by the rotation of the engine, gearbox or drive shaft cause stresses in the flywheel housing and gearbox which are usually too small to be damaging.

However, a resonant condition may occur within the engine operating speed range, where the natural frequency in bending of the complete engine/housing/gearbox/propshaft assembly coincides with the rotational speed of the engine or the propshaft. The resulting resonance can increase the bending load on the flywheel housing so that, in extreme cases, failure can occur. These critical conditions are normally associated with vehicles having high propshaft speeds, particularly when an overdrive gearbox is used (see SECTION 4, OVERDRIVE GEARBOXES), but it has also been known to occur with a stationary vehicle.

Vibration tests should be applied to all new installations at the prototype stage.

By attaching an accelerometer to the end of the gearbox, the resonant drive line frequency and the maximum “g” levels which are likely to be experienced in service may be determined. If these “g” levels are excessive (say above ±6g), attempts should be made to increase the stiffness of the drive line. In extreme cases of drive line vibration, stiffening and modifications may have to be made to the flywheel housing. This may have to be bolted to the sump rear flange or “bottom brackets” used to tie the housing to the engine.

There are other modes of vibration that can occur, having more than 3 nodes, but the natural frequency of such nodes is usually well above the maximum propshaft speed.
Reciprocating water pumps, air compressors and similar applications which can impose a high starting torque, an immediate load, or have a high rotating inertia, will require a clutch to disconnect the load from the engine. This will allow the engine to start off-load and warm-up before coming onto load.

It is important to select a clutch that has a torque capacity to match the output from the engine, and approval should be obtained for a particular arrangement from the clutch manufacturers, based on the machine design and operating requirements.

The maximum amount of crankshaft thrust loading allowed, due to normal clutch operation for each engine type, is tabulated in SECTION 16, TECHNICAL DATA.

Over-Center Clutches

Over-center clutches are normally operated by hand and the clutch remains in either the “engaged” or the “disengaged” position by the action of over-center toggles.

They are used in applications which require the clutch to be in the disengaged position for considerable periods as, unlike the automotive clutch, the over-center clutch applies no load to the engine crankshaft when disengaged.

Usually, the over-center clutch is incorporated in a complete power take-off, relieving the engine crankshaft of end thrust and bending stresses. Various P.T.O. gear ratios are available from different manufacturers.

Automotive Clutches

Automotive clutches are used not only in road vehicles, but in many other applications, such as agricultural tractors, fork-lift trucks and other mobile machinery. The basic difference between the automotive and over-center clutches is that the automotive type is spring loaded so that the clutch is normally engaged, and a spring loaded pedal must be pressed by the operator to disengage. This results in thrust loading on the crankshaft, and this must not exceed the maximum limits specified in SECTION 16, TECHNICAL DATA. As soon as the clutch pedal is released, the internal spring pressure automatically re-engages the clutch.

The correct size of clutch for a particular engine/application can be recommended by the clutch manufacturer. If very high powers and torques are to be transmitted at high speeds, then it is usual to choose a clutch with more than one friction disc. By this means, the friction area is increased without increasing the clutch diameter.

Basic guide-lines for clutches are:

1. The clutch size should be adequate to meet the most extreme demands without slippage.
2. The combination of lining material and friction face must be correct.
3. The clutch itself must be protected from the elements, but must at the same time be adequately cooled to prevent excessive heat build-up.
4. The clutch should be fitted in accordance with the manufacturer’s recommendations.

Centrifugal Clutches

The centrifugal clutch consists of a driving hub secured to the engine flywheel and carrying flyweights lined with friction material, working inside a drum fitted to the driven machinery.

The clutches are usually free up to 700 or 800 rev/min, allowing the engine to start and idle with the clutch disengaged. As a predetermined speed above this, the clutch becomes fully engaged.
This clutch is suitable for medium or high speed applications, where the starting torque or acceleration characteristics of the load are too great for the engine at low speed. Some electric generating sets, air compressors, water pumps and similar applications requiring an automatic feature of engaging the load can be satisfactorily driven through a centrifugal clutch coupling.

The matching of a centrifugal clutch to the engine and driven machinery is a complex matter, and the recommendations of the clutch manufacturer should always be followed.

**Wet Clutches**

These are automotive type clutches with special clutch facings which operate in a constant stream of lubricating oil usually provided from an external reservoir by an engine driven hydraulic pump. The oil improves the wearing properties of the clutch plates, and plate life is substantially increased due to more effective heat dissipation by the circulating oil.

Wet clutches are used on mobile machinery which experience high clutch usage, and avoids the continual replacement of clutch plates, or the use of an expensive fluid coupling.

Flywheel housings and starter motors used with these “wet” clutches must be oil sealed. Caterpillar supply flywheels and flywheel housings with provision for special oil seals which prevent the clutch oil being drawn into the engine.

**TRANSMISSIONS**

**Vehicle Gearing**

When considering engine and transmission matching, emphasis is generally paid to the vehicle gradeability and designed maximum road speed.

It is necessary to ensure that the selected transmission will have a sufficient number of gears suitable spaced to enable the vehicle to start under load at the designed gradient, and accelerate through the gears to the maximum designed speed. For road vehicles, the gears are spaced so that gear changes are completed without reducing the engine speed below engine peak torque when full power is required. If a gear change is made at low engine rev/min, sufficient power may not be available at the given vehicle speed and load to allow for acceleration.

For buses, pick-ups and lightly loaded vehicles, gear changes below the peak torque will possibly be satisfactory, but the gradeability characteristics of the application must be checked.

Little attention is usually paid to the engine over-run speed, which is a factor that can seriously affect engine life. It is known that low axle ratios (high numerically) will produce extremely high over-running engine speeds, particularly on motorway down gradients when vehicles are heavily laden.

If it is necessary to maintain a high degree of gradeability, then a two-speed axle should be specified.

**Overdrive Gearboxes**

Generally overdrive transmissions are not recommended for fitting to the Caterpillar range of engines, due to the increase in drive shaft speeds. Our experience has proved that high shaft speeds result in propeller shaft and coupling failures, leading to flywheel and clutch housing breakage, particularly in respect of vehicles subjected to sustained high speed operation.

To safeguard against possible service problems full details of any overdrive gearboxes complete with the drive shaft arrangement must be submitted to Caterpillar Application Engineering for approval.

**Fluid Couplings**

Fluid couplings are used with conveyors, cranes, winches, pumps, etc., to absorb shock loads and prevent engine stalling. They also allow engine starting and acceleration against high inertia loads and they reduce the effect of torsional vibration. Fluid couplings usually result in poor cold starting compared with the mechanical clutch due to the effects of oil/drag.
The torque is transmitted hydraulically by the action of oil moving from the impeller on the input shaft to the turbine on the output shaft. A fluid coupling always operates with some slip which means that, when a load is being transmitted, the output turbine is running slower than the engine driven impeller.

Input torque will always equal output torque so that there will never be torque multiplication with a fluid coupling.

**Torque Converters**

A torque converter is an automatic hydraulic transmission which performs a function similar to that of a gearbox; it increases the torque while decreasing the output speed. In a gearbox there are a number of stepped ratios, while a torque converter provides a continuously variable torque ratio up to a maximum of about 3:1 for a single stage torque converter.

The main difference between the fluid coupling and the torque converter is the reaction member in the latter.

The oil circulates in the same manner as in the hydraulic coupling, but while in the hydraulic coupling the blade of the impeller and turbine are straight, in the hydraulic torque converter the blading is curved in all elements — impeller, turbine and reaction member. The reaction member causes the oil to change direction and add its energy to the impeller increasing output torque.

The torque converter efficiency must be kept above 70% throughout the operating range. If the vehicle/machine is operated below 70% efficiency, it will result in loss of power at the converter output shaft, high fuel consumption and over-heating with the coolant system being inadequate to control the heat output.

Matching the torque converter characteristics to those of the engine and the intended duty is critical, and reference must be made to the manufacturers and Caterpillar for advice, to obtain the best operating results.
the hydraulic fluid being transmitted through flexible pipes. This allows great flexibility when designing the transmission layout.

Under extreme cold starting conditions, the fluid viscosity can create severe loading on the engine, causing stalling when the pumps come up to speed, or leaving very little power to drive the machine. A fluid by-pass relief circulation arrangement helps to reduce drag.

**Transmission Noise**

See NOISE CONTROL, SECTION 13.
P.T.O. POSITIONS
Accessories such as compressors, steering pumps, etc., can be driven from various P.T.O. positions on the engine. These positions will vary, depending on engine type, but generally accessories can be:

a) mounted on the engine, and belt driven from a P.T.O. groove on the crankshaft pulley. If the accessory is mounted remotely from the engine, provision must be made for engine movement, e.g. by use of a spring loaded jockey pulley.

b) mounted on the front or back of the timing case, and gear driven from the timing gears.

c) mounted on the engine frame, and driven axially through a coupling from the front of the crankshaft.

d) driven directly off other equipment.

BELT DRIVEN P.T.O.
Crankshaft Pulley
The amount of power available from the crankshaft pulley depends on the distance of the P.T.O. pulley from the face of the cylinder block, and the direction of the resultant loads acting on the pulley.

It will also depend on the pulley material and the type of drive from the crankshaft.

Various crank pulleys are available for each engine type, some with an integral P.T.O. groove, and some accepting a “bolt-on” P.T.O. pulley.

When adding a P.T.O. pulley, it must be ensured that the engine does not have a special pulley/damper which should not be modified. A change of front end pulley in some cases may introduce a torsional vibration problem. (See SECTION 5, TORSIONAL VIBRATION.) Any P.T.O. pulley manufactured by customers must satisfy Caterpillar design requirements.

Material — Depending on the engine type, the standard crankshaft pulley will be made from cast iron, Spheroidal Graphite (S.G.) iron, or steel. S.G. iron and steel pulleys are capable of transmitting higher levels of P.T.O. than cast iron pulleys.

The amount of P.T.O. available from a particular pulley type is specified in SECTION 16, TECHNICAL DATA.

Drive — Three different crankshaft pulley drive arrangements are available, depending on the engine type and the specific P.T.O. requirements:

1. **Keyed pulleys**, usually made from cast iron, are used for low P.T.O. values.

2. **Serrated pulleys** are used for high P.T.O. values.

3. **Double tapered clamping rings** are used for high P.T.O. values.

Tightening Torque — If the crankshaft pulley type is changed, it must be ensured that the correct tightening torque for that pulley is applied.

The tightening torque values are specified in the Workshop Manual for each engine type.

Belt Tension
The correct tension must be applied to any P.T.O. belt driving arrangement, as insufficient installation tension could cause belt slippage at high powers and high speeds, reducing belt life etc.

Excessive installation tension in the water pump drive belt may damage the water pump or generator bearings.

With a P.T.O. drive from the crankshaft, excessive belt tension will result in higher side loadings than necessary, which could result in crankshaft failure.

A practical way of estimating the fan belt tension is by applying pressure in the center of the longest run of belt between any two pulleys, and adjusting the tension until the belt deflects by a given amount (see illustration).

This deflection is given in the handbook for each engine type.

P.T.O. belt tensions should be calculated for all new installations. SECTION 5, TO DETERMINE CRANKSHAFT SIDE LOADING describes an approximate method of determining the belt tensions for a P.T.O. drive arrangement, and the consequent crankshaft side loading.

Idler Pulleys
Idler pulleys used for tensioning the Vee-belts should be on the slack side of the belt, and not smaller than the minimum diameter recommended by the manufacturer for a particular belt. The use of too small a pulley can severely reduce belt life.
A suitable spring loaded pulley is preferable to one that is adjusted and clamped, as it can enable the correct installation tension to be used. This is increasingly more important with larger P.T.O. values, as more installations tension is required to avoid slippage, resulting in a higher side loading/bending moment on the crankshaft.

A spring loaded idler pulley is also very important where there could be relative movement between a flexibly mounted engine and driven equipment mounted on a separate chassis.

**Crankshaft Side Loadings**

The allowable side loadings on the crankshaft depend on the engine type, operating speed and the machine application.

For detailed information on the maximum allowable crankshaft side loadings, and for specific advice on particular installation problems, O.E.M.'s are invited to contact their nearest Caterpillar Area Operations Office. The offices have available to them the full resources of the Application Engineering Department, Peterborough, England.

**Direction of Side Loadings**

The engine can usually accept a greater side loading below the crankshaft than above. Where this is the case the belt drive should be arranged, if possible, so that the driven equipment is below the crankshaft center line.

If two or more belt drives are required and can be arranged in opposite directions, the effects will tend to cancel each other out and minimize the overall side loading on the crankshaft.

**Unsupported P.T.O. Pulley**

When it is essential to have an unsupported P.T.O. pulley, the design must be checked out and approved by Caterpillar.

The following information must be provided:

1) The engine specifications.

2) A drawing of the drive arrangements which should include the following:

   a) the effective diameter of all pulleys in the system,

   b) the distance of the power take-off belt(s) from the front or rear face of the cylinder block,

   c) the number, size and type of belts used,

   d) the position of the driven equipment in relation to the engine,

   e) the method of tensioning the belt(s), for example, adjustable fixed pulley, spring loaded jockey pulley, etc.,

   f) the maximum and continuous power requirements of the equipment.

**P.T.O. Support Bearings**

In those installations where it is necessary to transmit large powers, or numerous belt drives are required, the P.T.O. shafts must be supported by pedestal bearings or an outrigger bearing.

**Outrigger Bearings**

With an outrigger bearing arrangement, the method of coupling the P.T.O. shaft to the flywheel should receive special attention to ensure correct alignment.
The flexible diaphragm plate prevents excessive bending moments being transmitted to the engine. The plate is bolted to the flywheel face, and is centralized in the flywheel by means of a spigot or dowels.

The drive shaft should be as short and stiff as possible.

It is essential that all mating faces are clean and clear of burrs, paint and impediments, because any misalignment of the power take-off housing will cause end loading on the crankshaft which could result in thrust washer or rear main bearing failure.

**GEAR DRIVEN P.T.O. FROM TIMING CASE**

**Limitations**

It must be ensured that the engine specifications are suitable for the P.T.O. equipment to be fitted.

**Weight** — On some engine types, alternative, heavier duty timing cases are available. The overhung weight of some equipment may require that a heavier duty timing case is fitted if there is one available. Otherwise a support bracket from the cylinder block should be used for heavy equipment.

**Cyclic torque** — Some engine types have optional heavy duty timing gears of greater width or different material from the standard gears. It may be necessary on these engine types to specify the heavy duty gears when using equipment with high cyclic torque variations or large P.T.O. requirements.

**Any P.T.O. equipment attached directly to the timing case must be of a Caterpillar approved type.**

**Air Compressors and Exhausters**

Provision to drive air compressors or exhausters can be:

1) from the timing gears,
2) by a belt drive,
3) on some engine types, shaft driven through a coupling.

Before a compressor is fitted it must be ensured that it is of a Caterpillar recommended type. Otherwise details must be submitted to, and approved by Caterpillar, to ascertain that the instantaneous torque loadings are within the capacity of the engine gear train, and that the compressor weight is not excessive.

**Air Cooling of Compressors**

Compressors should be situated in a cooling air stream to provide good air flow over the cylinder head when the vehicle is both stationary and moving. It should if possible be positioned where it will not be substantially affected by radiated heat from the engine exhaust system.

If insufficient air flow is available, a water cooled compressor should be used.

**Water Cooling of Compressors**

Water cooled compressors require an adequate water flow rate at engine idling speed to ensure efficient cooling under all operating conditions, i.e. the air outlet temperature is kept below 200°C.

**Lubrication**

An oil feed and return pipe must be provided for the compressor. Tappings in the cylinder block are available for suitable connections. When compressors are to be belt driven, drawings showing the oil supply and return pipes should be submitted to Caterpillar for approval.

**Air Filters**

If the compressor has an integral air filter, it must be adequate for all intended operating environments. Integral air filters tend to be neglected during engine servicing, so it must be ensured that the filter is serviced at the required intervals.

If the compressor has a separate air filter, it must be adequately supported and the induction port must not be restricted. When intake air is taken from the engine induction system, it should be downstream of the air filter and preferably not from the inlet manifold, as the high depression at the compressor can lead to oil carry over.

However, in some engine types, it may be necessary to supply air direct from the manifold.

**Suction Pipework**

Suction pipework should be selected to provide an acceptable depression at the compressor inlet of not more than 510 mm (20 in) water gauge for a new installation, or 760 mm (30 in) water gauge for a used installation. Depressions greater than 760 mm (30 in) water gauge can increase oil carry over to an unacceptable level, and also reduce compressor operating efficiency.

Under no circumstances should the inlet to the compressor be taken from a positive pressure source. For turbocharged engine, the compressor air feed should be taken from the induction pipework between the air filter and the turbocharger.

**Delivery Pipework**

Compressor delivery pipe length must be adequate to ensure that the temperature of the air at the rubber hose does not exceed 100°C; usually a minimum length of 2 m (6 ft) of steel tubing should be used from the delivery port, and situated in a cooling air stream whenever possible.

Sharp bends and restrictions will increase the compressor working pressure, resulting in a rise in operating temperature.

This can lead to oil carry over and carbon deposits on the delivery pipe until failure of the compressor occurs due to overheating.

Any installation which has suffered from overheating problems due to the formation of carbon must have the delivery pipes and components between compressor and reservoir...
stripped and cleaned internally. Failure to carry out this operation could result in overheating of the serviced or replacement compressor.

**Hydraulic Pumps**

A wide variety of hydraulic pumps are available for use with Caterpillar engines, with various types of flange fittings and drive shaft connection.

Hydraulic pumps are generally supplied to and fitted by the customer, who must consider the following points for satisfactory performance:

a) **Engine/pump compatibility**

   Advice on the suitability of pumps proposed for use with Caterpillar engines can be obtained from Application Engineering Department.

b) **Power and torque limits**

   The maximum power and torque available from different P.T.O. positions on each engine type is given in SECTION 16, TECHNICAL DATA. Depending on engine speed, either power or torque may be the limiting factor.

   Neither limit must be exceeded at any speed.

c) **Alignment and clearance**

   Correct alignment of the pump must be ensured to prevent excessive axial and/or radial loads being imposed.

   The pump must not foul any part of the installation under operating conditions, i.e. with a fully equipped engine installed in chassis.

d) **Cooling**

   Overheating can arise with the pump or pipework being placed too near the exhaust system.

   Where hydraulic oil coolers are used in engine cooling circuits and the overall installation cooling performance has been approved, subsequent changes to the system (e.g. the fitting of increased capacity pumps, modifying the hydraulic oil circuit, etc.) could affect the overall cooling performance, which would then require reappraisal.

e) **Oil leakage**

   Correct jointing and seals must be provided between the engine and pump to prevent oil leakage. Hoses and pipework must be capable of withstanding the pressures and temperatures to which the installation will be subjected.

f) **Manufacturers’ recommendations**

   The respective hydraulic pump manufacturers’ installation, operating and maintenance instructions must be followed, and also their recommendations regarding the type of oil to be used in the system.

---

**AXIAL DRIVEN P.T.O.**

**Crankshaft End Thrust**

If anything is fitted to the engine that imposes an end loading on the crankshaft, e.g. an automotive type clutch, torque converter, etc., it must be ensured that the end loading of the crankshaft does not exceed the maximum allowable values for the particular engine type. These are specified in SECTION 16, TECHNICAL DATA.

The manufacturer should be contacted for details of the operating end thrust of their equipment when this information is not known.

**Couplings**

Some applications use a solid coupling to connect the engine to the driven unit, e.g. a close coupled generator set.

However, in such applications, the supports and mountings for both the engine and the driven equipment must be of a rigid type, capable of maintaining accurate alignment.

Flexible couplings are preferred for direct coupled applications, as these will tolerate some axial and angular misalignment.

However, it is important to have the best possible alignment in order to reduce the load on the flexible coupling, and to ensure that there is no bending moment or pressure on the engine.

---

**Fluid couplings** — See BACK ENDS, SECTION 4.
**Drive Shafts**

If a petrol engine is being replaced by a diesel engine of similar power, stronger drive line components (clutch, gearbox, universal joints, drive shafts differentials, etc.) could be required in order to accommodate the higher cyclic torque.

However, if a Caterpillar diesel engine is to be fitted in a petrol engined vehicle which already offers a diesel engine of similar power as an option, the drive line should be satisfactory, having been designed to cover the higher cyclic torque of the diesel.

**Universal Joints**

In some layouts, it may be necessary for the engine to be installed at a different angle to the driven unit, or parallel but with a different axis.

In these cases, universal joints are required.

- **AXES OF INPUT AND OUTPUT SHAFTS-PARALLEL**

- **AXES OF INPUT AND OUTPUT SHAFTS BISECT**

It is essential that only universal joints of reputable quality are used, and the manufacturers’ recommendations must be followed regarding specifications and installation.

The following notes are given for guidance:

(a) Universal joints should always be used in pairs. A single joint must not be used.

(b) The joint angles at each end of the intermediate shaft should be within 0.5° of each other.

(c) Operating angles of universal joints vary with joint size and speed.

(d) If angles in more than one plane are involved, then the manufacturers’ advice must be obtained.

(e) When universally jointed shafts are manufactured, they are assembled such that the yokes on the intermediate shaft are in-line. The alignment is then marked with arrows at the sliding spline assembly. This alignment must be maintained in order to obtain constant velocity.

(f) It is always preferable to have a small operating angle on a needle roller bearing universal joint. This angle should not be less than 1°. This allows the needles to roll slightly and prevents the highly stressed contact area being in the same position at all times. Where no joint angle is allowed, the roller may, under high torque conditions, “bed” into the races and journals.

If these requirements are not observed, and if operating standard joints through off-set angles both in plan and elevation, difficulty may be experienced in the correct phasing of the joints. Due to changes in velocity, excessive noise, vibration and rapid wear of the bearings and sliding spline may result.

**TORSIONAL VIBRATION**

**Introduction**

The diesel engine, plus its driven equipment (driven from either front or rear) is made up of rotating masses connected by a series of shafts. This forms a torsional mass-elastic system, which will vibrate at its own natural frequency when acted upon by an exciting torque.

A resonant condition will occur when the frequency of the exciting torque is equal to the natural frequency of the system, or one of its harmonics. This condition will result in high vibratory stress, which can lead to damage of the crankshaft or any driven shafting. It is therefore necessary to ensure that the characteristics of the total system i.e. engine and driven machinery (including front end P.T.O. if fitted) are such that excessive torsional vibration stresses will not occur.

The size and position of the P.T.O. pulley or coupling are important because of their effects on torsional vibration characteristics of the system. Crankshaft pulley loosening can result if these characteristics are not tuned to match the operating conditions of the installation.

The necessary tuning can be achieved by changing the inertia or stiffness of the system, by altering the rubber mix of a flexible coupling, or by using a special damper on the crankshaft pulley.

As a general guide all axially driven inertia should be as low as possible in order to minimize the effects of vibratory torque. Driven equipment which introduces damping into the system (e.g. hydraulic pumps) will have a beneficial effect on the torsional vibration characteristics. The use of a flexible coupling in the system will have a similar beneficial effect, and coupling manufacturers are usually able to give guidance in this respect.

**Vibration Dampers**

These have the effect of reducing the amplitude of vibration and the resultant stresses in the crankshaft. They are used where a resonant condition is likely to occur in the operating speed range, and are therefore particularly suited to variable speed applications. They may however not be required on constant speed applications such as generating sets, which operate at one synchronous speed.

The two types of vibration damper in general use are:

- Rubber tuned damper
- Viscous untuned damper
Rubber Tuned Dampers

This type of damper is suitable for the vast majority of applications requiring a damped pulley, and is almost always used for automotive engines. The pulleys are tuned to be most effective at high engine speeds, but are also suitable for use where torsional vibration analysis indicates that a damped pulley is required for a low speed application.

The disadvantages of rubber damped pulleys are that they are attacked by oil (especially fuel oil) and high temperature.

Viscous Untuned Dampers

The viscous damper pulley is suitable for engines used in hot, oily environments such as are found in marine applications. They are generally unsuitable for vehicle applications due to the overspeed requirements involved.

They are more expensive than rubber dampers, and they must be handled carefully as they are easily damaged.

Torsional Vibration Analysis

It is difficult to detect the amount of torsional vibration present in a system without the use of special equipment. Excessive vibration will show itself eventually in the form of noisy gear trains, damaged flexible couplings or mountings, or failure of the engine or driven shafting. Any change of engine or axially driven equipment can constitute a new vibratory system which may require analyzing for critical conditions.

Calculations can be carried out to check the possibility of torsional vibration problems on particular installations if full details are given of the inertias, stiffnesses and minimum shaft diameters between inertias for the driven system. Alternatively, detailed drawings of the driven system should be supplied.

In addition, all bolted on Caterpillar parts used in the drive system (flywheel, crankshaft pulley, etc.) should be identified by part number.

Typical information required for an engine/generating set analysis is indicated on the next page.

The next paragraph shows a quick and simple method for calculation of the critical speed of gensets having flexible rubber couplings between the engine and the generator. The method is not however applicable to other engine/genset arrangements.

Generator Set Critical Speed Calculations

The calculation procedure described below is applicable only to generator sets having a flexible rubber coupling between the engine and the generator.
The generator set is treated as a simple mass-elastic system of two masses and one torsional spring.

\[ J_E = \text{Mass-polar moment of inertia (engine).} \]

\[ J_G = \text{Mass-polar moment of inertia (generator).} \]

\[ K = \text{Spring constant.} \]

Critical speed is given by the formula

\[ n_c = \frac{9554}{N} \sqrt{\frac{K(J_E + J_G)}{J_E / J_G}} \]

Where \( n_c \) = critical speed (rev/min)

\( N \) = excitation pulses per revolution (vib/rev) (see note (b)).

and the units \( K, J_E \) and \( J_G \) correspond as follows:

<table>
<thead>
<tr>
<th>Item (As Diagram)</th>
<th>Polar Moment of Inertia</th>
<th>Stiffness</th>
<th>Minimum Diameter of Shaft (Inches or mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Crankshaft pulley or damper</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>B. Flywheel and starter ring</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>C. Coupling</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>D. Section of Shaft</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>E. Fan</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>F. Section of shaft</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>G. Section of shaft</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>H. Rotor</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>I. Section of shaft</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>J. Section of shaft</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>K. Exciter</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**NOTES**

(a) The conversion from mass-length² units to force-length-time² units is as follows:

\[ 1 \text{ kg m}^2 (\text{mk}^2 \text{ or GD}^2) = 10.19714 \text{ kgf cm s}^2 \]

\[ 1 \text{ lb in}^2 (\text{mk}^2 \text{ or GD}^2) = 0.000259 \text{ lbf in s}^2 \]

(b) The following values apply for \( N \) in 4 stroke engines.

<table>
<thead>
<tr>
<th>No. of cylinders</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

(c) For modern 4 pole generators with multi-coil windings and static electrical excitation, only the engine cyclic excitation is of significance.

For generators of an older design or with special excitation characteristics, the critical speed calculation should be discussed with the Application Engineering Department, Peterborough.

(d) It is important that all the units in the equation are of the same system (i.e. all Imperial or all S.I.)

**Evaluation of Results**

The coupling can be approved if the critical speed lies at least 100 rev/min above or below an operating speed.

This must apply not only to rated full load speed but also to cranking and low idle speeds. If the critical speed is closer than this, a full torsional vibration analysis of the system should be requested through Application Engineering Department, Peterborough.
TO DETERMINE CRANKSHAFT SIDE LOADING

Side Loading Calculation

O.E.M.s are invited to contact their nearest Caterpillar Area Operations Office for the maximum allowable crankshaft side loadings for a particular engine type and specification.

A calculation can be undertaken to give an approximate indication of how close an arrangement is to this maximum side loading limit. If the calculation shows that the arrangement is close to, or above the limit, all details listed in SECTION 5, CRANKSHAFT SIDE LOADINGS, should be sent to the Area Operations Office for a full investigation.

The following assumptions have been made to simplify the calculations:

1. The application is at constant speed, i.e. acceleration rates, inertias etc., have been ignored.

2. Centrifugal tension is ignored. Although centrifugal tension will increase the tension in the belt, this will not be transmitted to the pulley as a side load, as the centrifugal force tends to lift the belt from the pulley.

Bending Moment/Side Loading

The bending moment is the product of the resultant load “R” acting as a distance of “d.”

Bending moment: \[ B.M. = R \times d \]

The face of the cylinder block is used as the datum point for bending moments, both front and rear.

Some cylinder blocks have an integral flywheel housing.

When this is the case, it must be ensured that when the distance of a P.T.O. pulley from the engine is determined; the rear face of the block is used as the datum point (DISTANCE d) rather than to the face of the flywheel housing (DISTANCE Y).
For an application having several belt drives, the operating requirements of the machine will indicate which combinations of belt drives may be used simultaneously. These combinations can then be checked to establish whether any critical conditions could occur.

An additional belt drive can be beneficial if it is acting in an opposite direction, as it will reduce the overload on the crankshaft.

To determine belt speed

Belt speed V (m/s) = \( \frac{\pi \times D \times N}{60,000} \)

where

- \( D \) = diameter of pulley (mm)
- \( N \) = engine speed (rev/min)
- \( \pi \) = 3.1416

or

Belt speed C (ft/min) = \( \frac{\pi \times D \times N}{12} \)

where

- \( D \) = diameter of pulley (in)
- \( N \) = engine speed (rev/min)

### Tension Difference

\[ T_1 - T_2 = \frac{kW \times 1000}{V} \]

where

- \( kW \) = power take-off
- \( V \) = belt speed (m/s)

or

\[ T_1 - T_2 (\text{lbf}) = \frac{hp \times 33,000}{C} \]

where

- \( hp \) = power take-off
- \( C \) = belt speed (ft/min)

### Tension Ratio

\[ \frac{T_1}{T_2} = e^\mu \cosec \alpha \]

where

- \( e \) = 2.718
- \( \mu \) = coefficient of friction
  - \( = 0.16 \) for vee belts
  - \( = 0.22 \) for raw edge vee belts
  - \( = 0.30 \) for flat belts
- \( \alpha \) = angle in radians
- \( \approx = \) half the pulley groove angle

i.e. if pulley groove angle
- \( \approx = 36^\circ \)
- \( \approx = 18^\circ \)
- \( \cosec \approx = 3.24 \)

NOTE: FOR FLAT BELTS \( \cosec \approx = 1 \)

To determine tight side tension \( T_1 \) and slack side tension \( T_2 \) from Tension Difference and Tension Ratio

EXAMPLE:

If tension difference
\[ T_1 - T_2 = 200 \text{N} \]  \( (1) \)

If tension ratio
\[ \frac{T_1}{T_2} = 5 \] \( (2) \)

Therefore from (2),
\[ T_1 = 5 \times T_2 \]

Substitute in (1),
\[ 5T_2 - T_2 = 200 \text{N} \]

Therefore
\[ T_2 = 50 \text{N} \]

Therefore
\[ T_1 = 250 \text{N} \]

The result load “\( R \)” is the vector sum of \( T_1 \) and \( T_2 \)

If they act in parallel directions \( T_1 \) and \( T_2 \) can be added together to give the resultant, which acts in the same direction.

If loads \( T_1 \) and \( T_2 \) are not parallel, the resultant can be determined:

1) by drawing \( T_1 \) and \( T_2 \) in the correct directions and with their tensions to scale. On completing the parallelogram of forces, the diagonal represents the resultant, and can be scaled off in direction and magnitude.

or
2) by using the cosine formula
\[ R^2 = T_1^2 + T_2^2 - 2T_1T_2 \cos(180° - \theta) \]

**NOTE:**
\[ \cos(180° - \theta) \text{ is equal to } -\cos\theta \]

Therefore;
\[ R^2 = T_1^2 + T_2^2 + 2T_1T_2\cos\theta \]

The angle \( \phi \) at which the resultant load acts can be calculated from the Sine Formula.

\[ \frac{R}{\sin(180° - \theta)} = \frac{T_2}{\sin \phi} \]

The direction of the resultant load should be referred back to Top Dead Center, or to the vertical center line of the block.

**Bending Moment/Side Loading**

The bending moment is the product of the resultant load “R” at a distance of “d.”

Bending moment: \( B.M. = R \times d \)

The face of the cylinder block is used as the datum point for bending moments, both front and rear.

A multi-belt P.T.O. arrangement will give bending moments acting in several directions.

To calculate a single resultant from these, each is broken into its horizontal and vertical components.
CONSIDERING THE THREE MOMENTS

\[ M_1, M_2 \text{ and } M_3 \]

\[ M_1: \quad x_1 = M_1 \sin \theta \]
\[ y_1 = M_1 \cos \theta \]

\[ M_2: \quad x_2 = M_2 \sin \phi \]
\[ y_2 = M_2 \cos \phi \]

\[ M_3: \quad x_3 = M_3 \sin \chi \]
\[ y_3 = M_3 \cos \chi \]

To ensure that the values are vectorially correct, i.e. that moments acting in opposite directions cancel each other out, it is essential that signs are correct.

The \( y \) values can be added together:
\[ = \sum y \quad (\text{e.g. } +2000 \text{ N•m}) \]

Resultant \( R = \sqrt{\sum x^2 + \sum y^2} \)

\[ \text{e.g. } R = \sqrt{5000^2 + 2000^2} \]

\[ \text{Resultant } R = 5385 \text{ N•m} \]

THE DIRECTIONS OF RESULTANT BENDING MOMENT

\[ \tan \beta = \frac{5000}{2000} = 2.5 \]

\[ \beta = 68^\circ \text{ B.T.D.C.} \]

The reference datum is usually taken as T.D.C. for in-line engines, or the cylinder block vertical center line for Vee engines.

EXAMPLE OF A CRANKSHAFT SIDE LOADING CALCULATION

Engine rating : 2500 rev/min
Driver diameter : 150 mm
Driven diameter : 250 mm
P.T.O. requirement : 12 kW
Direction of P.T.O. : 90° A.T.D.C.
Distance of P.T.O. pulley to face of cylinder block : 110 mm
Pulley : 36° Vee
Belt : Premium
Angle of lap at crankshaft pulley

\[
\sin \theta = 0.125 \\
\theta = 7^\circ 12' \\
\theta = 180^\circ - 2\theta \\
\theta = 165^\circ 36' = 2.89 \text{ radian}
\]

Belt speed \( V \)

\[
V = \frac{\pi \times D \times N}{60,000} \\
= \frac{\pi \times 150 \times 2500}{60,000} \\
= 19.6 \text{ m/s}
\]

Tension Difference

\[
T_1 - T_2 = \frac{kW \times 1000}{V} \\
= \frac{12 \times 1000}{19.6} \\
= 612 \text{ N (1)}
\]

Tension Ratio

\[
\frac{T_1}{T_2} = e^{\mu \frac{\theta}{\csc \alpha}} \\
e^{0.16 \times 2.89 \times 3.24} \\
= e^{1.5} \\
\frac{T_1}{T_2} = 4.49 \text{ (2)}
\]

Form (2) \( T_1 = 4.49 T_2 \)

Substitute in (1) \( 4.49 T_2 - T_2 = 612 \text{ N} \)

\[
3.49 T_2 = 612 \text{ N} \\
T_2 = 175 \text{ N}
\]

Form (2) \( T_1 = 787 \text{ N} \)

These are the minimum tensions required to avoid belt slippage.

Off-load, the tensions are distributed equally.

\( i.e. \ T_1 = T_2 \)

\( T_1 + T_2 = 787 + 175 = 962 \)

Therefore minimum installation tension required to avoid belt slippage.

\[
= \frac{962}{2} = 481 \text{ N}
\]

Resultant load on crankshaft pulley

COSINE FORMULA:

\[
R^2 = T_1^2 + T_2^2 - 2 \times T_1 \times T_2 \times \cos 165^\circ \\
= 787^2 + 175^2 - 2 \times 787 \times 175 \times \cos 165^\circ \\
R = 957 \text{ N}
\]

Direction of resultant load

SINE FORMULA

\[
\frac{R}{\sin (165^\circ)} = \frac{T_1}{\sin \alpha} \\
\sin \alpha = \frac{T_1}{R} \sin 165^\circ \\
= \frac{787 \times 0.259}{957} \\
\alpha = 12^\circ
\]

If line of action of \( T_2 \) slack side belt acts at \( 10^\circ \) above center line, resultant will act at \( 12^\circ - 10^\circ = 2^\circ \) below center line i.e., \( 92^\circ \) after cylinder block vertical center line.

Bending moment

The resulting load \( = 957 \text{ N} \)

Distance of pulley to face of block \( = 110 \text{ mm} \)

\(. \) Resultant Bending Moment = \( 957 \times 0.11 = 105 \text{ N} \times \text{m} \)

Resultant bending moment = \( 105 \text{ N} \times \text{m} \) acting at \( 92^\circ \) after vertical center line

This is with the minimum installation tension of 481 N, necessary to avoid belt slippage.

Known installation tension

If a known installation tension of, say 600 N, is applied to the belt, the side load is calculated as follows:

Off-load \( T_1 = T_2 = 600 \text{ N} \)

On-load, \( T_1 \) and \( T_2 \) distribute themselves such that \( T_1 + T_2 = 600 + 600 = 1200 \text{ N (3)} \)
Using previous example:

**Tension Difference**

\[
T_1 - T_2 = \frac{12 \times 1000}{19.6} = 612 \text{ N (1)}
\]

Equation (3) \( T_1 + T_2 = 1200 \text{ N} \)
Equation (1) \( T_1 - T_2 = 612 \text{ N} \)

Adding (3) and (1) \( 2T_1 = 1812 \text{ N} \)
\[
\begin{align*}
T_1 &= 906 \text{ N} \\
T_2 &= 294 \text{ N}
\end{align*}
\]

The resultant load and subsequent bending moment can be worked out from these tensions, as in previous example.

**Check for slippage**

\[
\frac{T_1}{T_2} = \frac{906}{294} = 3.1
\]

This is within the limiting tension ratio of 4.49 previously calculated, so that slip will not occur at the installation tension of 600 N.
## SECTION 6
Mounting Systems

<table>
<thead>
<tr>
<th>Section Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>62</td>
</tr>
<tr>
<td>THE NATURE OF ENGINE VIBRATION</td>
<td>62</td>
</tr>
<tr>
<td>TYPES OF MOUNTING SYSTEMS</td>
<td>62</td>
</tr>
<tr>
<td>SOLID MOUNTING SYSTEMS</td>
<td>63</td>
</tr>
<tr>
<td>FLEXIBLE MOUNTING SYSTEMS</td>
<td>64</td>
</tr>
<tr>
<td>Requirements</td>
<td>64</td>
</tr>
<tr>
<td>Basic Theory</td>
<td>64</td>
</tr>
<tr>
<td>FLEXIBLE MOUNTING CONFIGURATIONS</td>
<td>66</td>
</tr>
<tr>
<td>Number of Mounting Points</td>
<td>66</td>
</tr>
<tr>
<td>Location of Mounts</td>
<td>66</td>
</tr>
<tr>
<td>Orientation of Mounts</td>
<td>66</td>
</tr>
<tr>
<td>Vertical Mounting Systems</td>
<td>67</td>
</tr>
<tr>
<td>Inclined Mounting Systems</td>
<td>67</td>
</tr>
<tr>
<td>Types of Flexible Mount</td>
<td>68</td>
</tr>
<tr>
<td>FLEXIBLE MOUNTING SELECTION</td>
<td>70</td>
</tr>
<tr>
<td>Choice of Mountings</td>
<td>70</td>
</tr>
<tr>
<td>Choice of System Natural Frequency</td>
<td>70</td>
</tr>
<tr>
<td>Particular Installation Considerations</td>
<td>70</td>
</tr>
<tr>
<td>General Considerations and Recommendations</td>
<td>72</td>
</tr>
<tr>
<td>SUMMARY OF DESIGN PROCEDURE FOR FLEXIBLE MOUNTINGS</td>
<td>74</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>74</td>
</tr>
<tr>
<td>Method of Calculating Back End Bending Moment</td>
<td>74</td>
</tr>
<tr>
<td>Relationship Between Configuration and Properties of Vertical Mounting Arrangements</td>
<td>74</td>
</tr>
<tr>
<td>Relationship Between Configuration and Properties of Inclined Mounting Arrangements</td>
<td>75</td>
</tr>
</tbody>
</table>
INTRODUCTION

Reciprocating machines, including the majority of internal combustion engines, are inherent sources of vibration due to the nature of their piston and connecting rod motions. While this inherent vibration can be minimized by careful design and manufacture, some will nevertheless remain due to imbalance, the nature and magnitude of which will depend upon engine configuration.

This vibration can cause failure of components in the remainder of the installation, as well as significant operator discomfort. It is therefore important that the engine should be mounted in such a way as to reduce to an acceptable level the transmission of engine vibration to the supporting structure.

THE NATURE OF ENGINE VIBRATION

The motion of each piston and connecting rod creates out-of-balance external forces and couples. In a multi-cylinder engine, some of the effects produced by the components of one cylinder may cancel out those from another cylinder, but some of the effects may be additive.

Thus, for a conventional 4-cylinder in-line engine, most of the significant external out-of-balance effects cancel out, and only a vertical secondary force remains, i.e. a force having a frequency twice that of engine speed.

On the other hand, for a 3-cylinder in-line engine, all the external forces are balanced, but primary and secondary couples are unbalanced, i.e. couples having frequencies equal to both engine speed and twice engine speed.

Table 1 summarizes the balance characteristics inherent in the various engine configurations of the Caterpillar range.

These unbalanced forces and couples would, if unrestrained, produce translational (i.e. linear) and rotational vibratory movements along and around the principal axes of inertia of the power unit assembly. The six basic modes of vibration, or Degrees of Freedom, are illustrated. It is a major function of the engine mounting system to resist and control these movements with minimum transmission of disturbance to the supporting structure.

It is particularly important to ensure that an adequate mounting system is provided for 4-cylinder engines not fitted with secondary harmonious balancers, especially if the mass of the machines in which they are installed is not substantial.

TYPES OF MOUNTING SYSTEMS

The two basic types of mounting systems are:

a) Flexible
b) Solid

Flexible mountings enable the supporting structure to be isolated from engine vibration, the forces generated by the engine being counteracted by allowing the engine itself to move bodily.

Solid mountings are used where the movement of a flexibly-mounted engine is not acceptable, or where the engine itself is an integral part of the machine structure (e.g. as in many agricultural tractors).

### TABLE 1

Inherent balance characteristics of 4-stroke reciprocating engines

<table>
<thead>
<tr>
<th>Cylinder Arrangement</th>
<th>3-Cylinder in-line</th>
<th>4-Cylinder in-line</th>
<th>6-Cylinder in-line</th>
<th>8-Cylinder 90° Vee</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crank diagram</strong> (arrow indicates direction of rotation)</td>
<td><img src="image" alt="Crank diagram 3-Cylinder" /></td>
<td><img src="image" alt="Crank diagram 4-Cylinder" /></td>
<td><img src="image" alt="Crank diagram 6-Cylinder" /></td>
<td><img src="image" alt="Crank diagram 8-Cylinder" /></td>
</tr>
<tr>
<td><strong>Firing order</strong></td>
<td>1-2-3</td>
<td>1-3-4-2</td>
<td>1-5-3-6-2-4</td>
<td>1-8-7-5-4-3-6-2</td>
</tr>
<tr>
<td><strong>Firing impulses per engine rev.</strong></td>
<td>1 ½</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Engine balance</strong></td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
</tr>
<tr>
<td><strong>External forces:</strong></td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
</tr>
<tr>
<td>Primary</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
</tr>
<tr>
<td>Secondary</td>
<td>(unless harmonic balancer incorporated)</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
</tr>
<tr>
<td><strong>External couples:</strong></td>
<td>Unbalanced</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
</tr>
<tr>
<td>Primary</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
</tr>
<tr>
<td>Secondary</td>
<td>Unbalanced</td>
<td>Balanced</td>
<td>Balanced</td>
<td>Balanced</td>
</tr>
</tbody>
</table>
Is some cases, a combination of solid and flexible mountings may be used. The four main arrangements for mounting of a total installation are:

a) Engine and machine rigidly connected; complete assembly flexibility mounted.

b) Complete machine solidly mounted on a sub-frame which is itself flexibly mounted onto a solid base.

c) Engine flexibly mounted, independently of machine; engine and machine coupled by means of a drive shaft.

d) Engine and machine independently solidly mounted on a common solid base.

The choice of mounting system will be based upon the relationship required between engine and machine. Where practicable, however, the engine and driven machine should be assembled as one rigid unit, either by flange-mounting or by means of sub-frames, so that all power transmission reactions are balanced within the unit.

The vibration characteristics of the total installation will depend on the combined weight of the engine and installation, and on the rigidity of the mounting system.

**SOLID MOUNTING SYSTEMS**

Solid mounting is not generally recommended, but may sometimes be considered necessary for the reasons given in TYPES OF MOUNTING SYSTEMS.

In any solid mounting arrangement, the following considerations should be taken into account:

a) Mounting brackets and fixings and mounting frame or base, must be as rigid as possible.

b) Alignment of engine and driven machine must be carefully controlled (if necessary with provision for adjustment) in order to minimize loading on the coupling, flywheel and flywheel housing.

c) If the engine is mounted via the flywheel housing, the back end bending moment should be calculated, as detailed in the APPENDIX, METHOD OF CALCULATING BACK END BENDING MOMENT. This can be then checked against the permissible value for the particular engine/application combination (see GENERAL CONSIDERATIONS AND RECOMMENDATIONS, Item 8).
d) For mobile applications, dynamic shock loadings on the mountings must be considered. This subject is dealt with in detail in GENERAL CONSIDERATIONS AND RECOMMENDATIONS.

e) Where a four cylinder engine is required to be solidly mounted, a balancer unit is sometimes specified in the engine build in order to minimize the secondary out-of-balance forced inherent with this engine configuration.

f) Instruments, radiators, etc. used in the installation should always be flexibly mounted separately from the engine, as vibration transmitted through solid mountings can cause damaging sympathetic vibrations.

g) Where an engine is to be solidly mounted in such a way as to be a load-carrying part of the total machine structure (e.g. frameless tractors), it must first be ensured that the engine structure is capable of withstanding the loads to which it may be subjected.

FLEXIBLE MOUNTING SYSTEMS

Requirements of Flexible Mountings

These can be summarized as follows:

a) At all engine speeds the mountings must isolate the frame of the machine from as much engine vibration and structure-borne noise as possible.

b) For a successful installation the mountings must be able to withstand, without excessive deflection, the static loadings due to the weight of the system being supported.

c) The mountings, must, under all working conditions, control to within acceptable limits the movement of the engine in all linear and rotational directions.

d) The mountings (and brackets) must be strong enough to withstand all dynamic loadings which may be induced by the type of application.

e) The mountings should protect the engine from any stresses caused by distortion of the frame on which they are located.

Basic Theory of Flexible Mounting System

1. Free Vibration

A simple flexible mounting system can in theory be represented by a mass and a spring. If the mass is displaced linearly from its equilibrium position and then released, the system will vibrate freely at its natural frequency.
b) A mass flexibly supported on a base which is itself subjected to a vibration input of known magnitude and frequency. This is the situation on a mobile application subject for example to road surface excitation — in this case the vibration transmitted through the mounts results in oscillation of the engine.

(a) VIBRATION INPUT APPLIED TO MASS

VIBRATION RESPONSE CHARACTERISTICS OF FORCED VIBRATION SYSTEMS WITH VARYING DEGREES OF DAMPING

From the vibration response diagram it can be seen that:

a) When the forcing frequency coincides with the natural frequency of the mass/spring system, then resonance of the system occurs, giving very large vibration amplitudes. The actual magnitudes of these resonant vibrations will depend on the damping properties of the mounting system.

A resonant condition should obviously be avoided due to the large amplitudes and forces generated, and the consequent risk of physical damage to the mounts and supports, and also to other parts of the machine which may set up sympathetic vibration.

b) The value of the Transmissibility, or ratio of response to input vibration, is equal to unity at very low frequencies, and also at \( \sqrt{2} \times \text{natural frequency} \) for the mass/spring system. At higher frequencies the magnitude of the vibration response becomes less than that of the input.

Thus, at a frequency twice that of the natural frequency, the magnitude of the vibration response could be as low as 0.3 times that of the input. Expressed another way, the isolation under these conditions would be approximately 70%.

For this reason, it is recommended that a flexible mounting system should be chosen such that its natural frequency is not greater than half the lowest disturbing frequency likely to be encountered.

c) High damping is primarily required when it is necessary to operate at a frequency close to resonance, or if transition through the resonance conditions takes place very slowly, with the consequent risk of larger than normal vibration amplitudes.

If however the frequency ratio is favorable (i.e. not less than 2), and resonance conditions are passed through relatively quickly, then low damping is to be preferred, since damping represents energy loss. Excessive damping causes a build up of heat in the rubber, resulting in
a reduction in its capacity to absorb energy as well as a need for cooling in order to prevent degradation of the rubber.

Also, high damping tends to make the rubber less responsive at higher frequency ratios, with consequent impairment of the isolation capacity of the mounts.

**FLEXIBLE MOUNTING CONFIGURATIONS**

**Number of Mounting Points**

Flexible mounting systems may be of the 3, 4, 5, or 6 point type. The number of mounting points chosen depends on the dimensions and weight disposition of the engine and bolted on driven parts, and the arrangement and duty of the application in which they are to be installed.

Schematic examples of typical mount arrangements are illustrated below.

The 3 and 4 point systems are generally preferred because of difficulties in ensuring correct alignment of systems employing larger numbers of mounts, and the consequent risk of excessive bending loads on the back end of the engine. It is recognized however, that in some installations, 5 or 6 point systems may be necessary because of the length and mass of the bolted-on driven parts. The advice of Caterpillar should however be sought in such cases.

**Location of Mounts**

The locations of mounts are often predetermined, i.e. engines, transmissions, etc., may already be provided with mounting pads.

Where a choice is available, however, the mountings should ideally be symmetrically arranged about the combined center of gravity of the engine and bolted-in equipment. This reduces the excitation of other modes of vibration when the system is vibrating in one particular direction.

An example of the method of calculating the longitudinal location of the combined center of gravity in the relation to the centers of gravity of the engine and bolted-on equipment is illustrated below.

![Diagram illustrating the calculation of the longitudinal location of the combined center of gravity](image)

The particular properties of these arrangements are discussed more fully in the following paragraphs.
Vertical Mounting Systems

For a simple symmetrical system, the stiffness of the combined system are as follows:

- Total vertical stiffness \( = 2K_y \) (expressed in units of force deflection)
- Total lateral stiffness \( = 2K_x \)
- Torsional stiffness \( = 2K_y \times d^2 \)

VERTICAL MOUNTING ARRANGEMENT

The values of the vertical stiffness, \( K_y \), and the lateral stiffness, \( K_x \), are specified by the mount supplier.

The case of the unsymmetrical vertical mounting system is slightly more complicated and is summarized in APPENDIX 6, RELATIONSHIP BETWEEN CONFIGURATION AND PROPERTIES OF VERTICAL MOUNTING ARRANGEMENTS (a).

Inclined Mounting Systems

An effective mounting system may be achieved by means of pairs of inclined flexible mounts. The required vertical, lateral and torsional stiffness of the system are obtained by choice of geometry (positions and angles of inclination of mounts) and compression and shear stiffness.

Inclined Mounting Arrangement (End View)

An important feature of any inclined mounting system is the “elastic center”, which is always located at a point above the mount, but below the geometrical intersection of their compression axes. Its precise position can be determined mathematically from knowledge of the mounting configuration and of the axial and shear stiffness of the individual mounts (see APPENDIX 6, RELATIONSHIP BETWEEN CONFIGURATION AND PROPERTIES OF INCLINED MOUNTING ARRANGEMENTS).

The properties of the elastic center are such that a linear force applied in any direction passing through the elastic center will cause translation (i.e. linear movement) but no rotation of the supported mass. Similarly, a couple applied about this center will cause no linear movement of the supported mass. The principal modes of vibration through and about the elastic center are therefore decoupled.

In order to take full advantage of these properties, the mounting system should be designed such that its elastic center lies on the Roll Axis, or Axis of Minimum Inertia, of the engine and bolted-on parts. (See APPENDIX 6, RELATIONSHIP BETWEEN CONFIGURATION AND PROPERTIES OF VERTICAL MOUNTING ARRANGEMENTS, and RELATIONSHIP BETWEEN CONFIGURATION AND PROPERTIES OF INCLINED MOUNTING ARRANGEMENTS.)

Although the axis will always pass through the combined center of gravity of the complete mounted system, its precise orientation is difficult to determine except by experiment. A very close approximation can however be obtained from a line joining the center of gravity of the engine and of the bolted-on driven assembly.

ROLL AXIS OR AXIS OF MINIMUM INERTIA

In the case of vehicle applications, the roll axis of the engine and gearbox assembly, will typically be inclined at an angle of 15° to the crankshaft center line. Where however, the bolted-on equipment is much more substantial, e.g. as with compressors or generator sets, the angle of inclination is likely to be correspondingly smaller.

Although inclined flexible mounting arrangements may in some circumstances be completely unsymmetrical, in practice they usually fall into one of the following categories:
1. Two equal mounts, symmetrically located and oriented (as in Figure 1).

2. Two equal mounts, symmetrically located and oriented, and with their major stiffness principal axes perpendicular to each other (Figure 2).

3. Two equal mounts, not necessarily symmetrically located or orientated, but having their major stiffness principal axes perpendicular to each other (Figure 3).

4. Two equal mounts located on the same horizontal axis, unsymmetrically orientated, but having their major stiffness principal axes perpendicular to each other (Figure 4).

The three arrangements, (2), (3), and (4), in which the major stiffness axes are perpendicular to each other, all possess the special property that the effective stiffness at their elastic center is the same in any direction in the plane of the mounts. This may sometimes be advantageous.

Mathematical expressions relating the stiffness properties and the location of the elastic centers for each of these mounting arrangements are given in APPENDIX 6, RELATIONSHIP BETWEEN CONFIGURATION AND PROPERTIES OF INCLINED MOUNTING ARRANGEMENTS.

Types of Flexible Mount

These are almost invariably of the rubber-to-metal type which are marketed in a variety of configurations. A typical selection is illustrated.
(a) and (b) are simple mounts of metal/rubber/metal sandwich construction, while (c) has a metal insert to give increased stiffness. These types may be used either in pure compression or, more commonly, inclined to the vertical in pairs in order to give the required directional stiffness characteristics by means of a combination of their compression and shear properties.

A more complex type of mounting embodying the same combination of properties in a single unit is illustrated in (d).

Type (e) is used for light-to-medium direct compressive loads where some lateral flexibility is also required. Type (f) is a conical mount design for maximum load capacity combined with a large deflection in an axial direction. The high loading for a given size is obtained by utilizing the rubber in both compression and shear. Type (g) possesses much higher stiffness as the rubber is in compression only. Types (f) and (g) are both available with provision for overload and rebound control.

Flexible mounts working on hydrostatic principles are also marketed by some suppliers.
FLEXIBLE MOUNTING SELECTION

Choice of Mountings

Although the required mounting properties for a particular installation can be determined by purely theoretical methods, the practical selection of suitable flexible mountings to give these properties is an extremely specialized subject. This is particularly true if an optimized system is required which not only minimizes transmission of engine noise and vibration to the vehicle or machine structure, but also controls bodily vibration of the complete power unit and bolted-on driven equipment. Consideration must also be given to minimization of excitation to bolted-on auxiliary equipment e.g. filters, coolers, etc.

The problem to the installer lies in identifying, from mount manufacturers’ published data, the required physical properties of the mounts, namely stiffness (in various directions) and damping characteristics and tolerances. For this reason, it is strongly recommended that intended mount suppliers should be consulted in the early stages of an installation design, since they are best qualified and equipped to give specialist advice on the properties and application of their own products.

Caterpillar Application Engineering Department will also be pleased to advise in cases of difficulty, and the following further notes are included as practical guidelines for the mounting of particular installations.

Choice of System Natural Frequency

As explained in BASIC THEORY OF FLEXIBLE MOUNTING SYSTEM for minimum movement of an engine on its mounts, a flexible mounting system should be chosen such that its natural frequency is not more than half the minimum significant disturbing frequency likely to be encountered. This is normally the firing frequency under low idle speed conditions. The characteristic frequencies for various engine arrangements are as tabulated below.

<table>
<thead>
<tr>
<th>Number of cylinders</th>
<th>Cycles per engine rev</th>
<th>Cycles per minute</th>
<th>Cycles per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.5</td>
<td>900</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1200</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>1800</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>2400</td>
<td>40</td>
</tr>
</tbody>
</table>

Minimum disturbing frequencies for 4-stroke engines

Thus, for a low idle speed of 600 rev/min, the recommended natural frequency of the mounting system should range from not more than 7.5 cycles/second for a 3-cylinder engine, to not more than 20 cycles per second for an 8-cylinder engine. This means that very much stiffer mounts can be tolerated on a large engine than on a small one, although, as explained in BASIC THEORY OF FLEXIBLE MOUNTING SYSTEM, differences in mass also influence the natural frequency of the mass-spring system.

In practice, a fair estimate of the required mount stiffness properties required for a given installation can be obtained from mounting manufacturers’ charts, a typical example of which is illustrated. It should be noted that in this context “deflection” refers to static deflection in the vertical plane of the mounts in their installed position, while “vibration” refers to vibration in the vertical mode only.

N.B. For detailed information on the properties of specific mounts the manufacturers should always be consulted.

RELATIONSHIP BETWEEN VIBRATION TRANSMISSION, DISTURBING FREQUENCY AND MOUNT DEFLECTION

Diagram by courtesy of Dunlop Limited, Polymer Engineering Division, Leicester, England.

Particular Installation Considerations

The choice of mounting system will depend on the inherent vibration characteristics of the engine, the layout of the installation, and the conditions under which it will be required to operate.

The following notes are intended to give guidance in the flexible mounting of engine in particular application types. A summary of the main features is tabulated at the end of this section.
a) Vehicle and related installations:

Since vibration in vehicles is particularly likely to give rise to criticism and dissatisfaction, the following points should be particularly noted:

— The engine should be controlled to oscillate about the roll axis, by ensuring that the elastic centers of the mounts lie on the roll axis (see APPENDIX 6, RELATIONSHIP BETWEEN CONFIGURATION AND PROPERTIES OF VERTICAL MOUNTING ARRANGEMENTS).

— The mounting layout should give flexibility in the bounce and roll modes.

— There is adequate flexibility to ensure that the natural frequency is below the running range.

— Connections of services and controls between engine and chassis are sufficiently flexible to give good isolation.

— Some form of overload control may be necessary in order to withstand the effects of external loads (e.g. control forces, clutch operation, etc.)

In practice, the most effective vehicle engine mounting systems are of the 3-point type (for small 4-cylinder engines in passenger cars and light vans) and 4-point type for larger vehicles. In both cases, inclined front mountings are recommended, as illustrated.

b) Earthmoving and construction machinery:

Mounting arrangements may be of the 4, 5, or 6 point types, depending upon the bulk of the transmission and other bolted-on equipment.
In the normal 4-point system, the required characteristics can usually be obtained by means of cone-type mounts located in pairs at the front of the engine and at the flywheel housing. In 6-point systems, an additional pair of cone-type mounts is located at the rear end of the supported assembly. The 5-point system is similar except that the rear support is provided by a single compression mount. Provision should be made where necessary for rebound control.

As previously stated, extreme care should be taken on 5 and 6 point arrangements to ensure correct mount alignment.

c) **Forklift trucks:**

It is common practice for the rear (i.e. flywheel) end of the engine to be bolted rigidly to the transmission and drive axle, the front of the engine being flexibly mounted by means of cone-type mounts. These provide some degree of isolation, while being sufficiently stiff to withstand the torque reaction from the drive axle. With this type of arrangement it is very important that the engine/transmission line should be very rigid, and for this reason sumps and flywheel housings are often “tied” together.

In cases where the engine and transmission are connected to the drive axle through a universal joint or car-dan shaft, the engine should be 4-point mounted by means of cone-type mountings at front and rear.

d) **Combine harvesters**

These may be 3, 4, 5, or 6 point mounted. Relatively stiff compression mounts are usually acceptable, the objective being to reduce harshness by attenuation of high frequency vibration, rather than to isolate from low frequency bodily movement of the engine.

e) **Other mobile or portable equipment:**

4-point cone-type mounting systems are adequate for most requirements. In the case of portable equipment which may be towed, provision should be made for longitudinal restraint to allow for breaking loads.

f) **Stationary equipment:**

Flexible mounting of the 4-point cone-type is often advisable in order to isolate the machine from its surroundings. It may also be used to compensate for small irregularities in foundations, but great care must be taken to avoid undue stressing of mounts.

### General Considerations and Recommendations

1. It should be noted that calculated stiffnesses assume:
   
   a) Stiff mounting brackets, cross members, etc. The weight of the chassis or frame should also be substantially greater than that of the engine. If these requirements are not met, then the vibration characteristics of the installation may be completely changed.
   
   b) No restraint from exhaust pipes, hoses, linkages, etc., although in practice, this cannot be entirely eliminated. Care, however, should be taken to minimize their effects as paths for transmission of noise and vibration.

2. Required mount stiffnesses determined by calculation are dynamic. For correct design it is therefore necessary to establish from suppliers the approximate relationship between the dynamic and static stiffnesses of the mounts being considered. The ratio of Dynamic to Static stiffness may be in the range 1.05 – 1.25:1 for best quality natural rubber compounds up to 60 durometer.
hardness, but may be as high as 3:1 for natural rubber with high damping, and even 8 or 9:1 for some synthetic grades.

3. Estimates of dynamic deflection should, where applicable, allow both for full torque wind-up and for maximum bump conditions. These can produce vertical accelerations of up to ±6g, depending upon application type, i.e. the dynamic forces due to vertical acceleration of an engine assembly can be up to six times the magnitude of the force due to its static mass. Typical values of vertical dynamic loads are indicated in the table.

4. The whole of the rubber in a mount should be stressed as uniformly as possible, to ensure the highest possible ratio between resilience and the weight of rubber employed. Stress concentrations should be avoided as these could lead to early local failure.

5. The use of a large quantity of soft rubber is preferable to a smaller quantity of hard rubber, as the harder grades contain non-elastic additives which have an adverse effect on their mechanical properties. However, excessively soft rubbers should also be avoided as these can lead to bonding problems during manufacture.

6. Natural rubber compounds are generally recommended for their good overall mechanical properties over a fairly wide temperature range (~20 to +70°C) although synthetic rubbers may be preferable in some instances for oil-resistance or high temperature conditions.

7. The use of interleaves to form compound sandwiches enables mounts to be made stiffer in compression without appreciable affecting shear stiffness. There is however an adverse effect of noise transmission properties.

8. Large static bending moments in the vertical plane at the cylinder block/flywheel housing interface should be avoided at all times, since these can lead to broken flywheel housings and damaged cylinder blocks. The magnitude of the bending moment is dependent upon the positions of the mountings, and can be calculated by taking moments about the cylinder block/flywheel housing interface. The calculation procedure illustrated in APPENDIX 6, METHOD OF CALCULATING BACK END BENDING MOMENT.

The accompanying table gives an indication of static bending moment values which should not be exceeded for safe operation.

NOTE: Arrangements using a stiffened cylinder block and “tied” sump can tolerate higher bending moments. For advice on these installations, contact the Caterpillar Applications Engineering Department.

9. Having determined the required properties of a mounting system, it should be realized that, due to manufacturing difficulties with rubber components, production variations in their mechanical properties may be of the order of ±15%.

10. Provision must be made where necessary for protection of rubber mounts from oil contamination and excessive heat, e.g. by means of suitable shielding.

<table>
<thead>
<tr>
<th>Application Type</th>
<th>Vertical Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>“On-highway” vehicles</td>
<td>±4g</td>
</tr>
<tr>
<td>“Off-highway” vehicles</td>
<td>±6g</td>
</tr>
<tr>
<td>Generator sets</td>
<td>±2g</td>
</tr>
<tr>
<td>Marine applications (including auxiliary equipment)</td>
<td>±6g</td>
</tr>
<tr>
<td>Forklift trucks</td>
<td>±3g</td>
</tr>
</tbody>
</table>

Typical vertical dynamic loads

These figures refer to dynamic loading. In order to obtain the total loading (i.e. dynamic and static) on the mountings under dynamic conditions, they should be increased by 1g for downward loading and decreased by 1g for upward loading.

Where high dynamic loads can be expected, it is advisable to fit overload rebound washers, or to incorporate a built-in “snubber” to limit excessive deflections.

On mobile and portable equipment, allowance should also be made for cornering, which can give high lateral horizontal loads, and for braking which can give up to 1g in the forward direction.

<table>
<thead>
<tr>
<th>Type of application</th>
<th>3-cylinder and small 4-cylinder engines</th>
<th>Other in-line</th>
<th>V8 engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>“On-highway” vehicles</td>
<td>450 N m 4000 lbf in 46.1 kgf m</td>
<td>680 N m 6000 lbf in 69.1 kgf m</td>
<td>900 N m 8000 lbf in 92.2 kgf m</td>
</tr>
<tr>
<td>“Off-highway” vehicles</td>
<td>340 N m 3000 lbf in 34.6 kgf m</td>
<td>510 N m 4500 lbf in 51.8 kgf m</td>
<td>680 N m 6000 lbf in 69.1 kgf m</td>
</tr>
<tr>
<td>Generator sets</td>
<td>790 N m 7000 lbf in 80.6 kgf m</td>
<td>1130 N m 10,000 lbf in 115.2 kgf m</td>
<td>1470 N m 13,000 lbf in 150.0 kgf m</td>
</tr>
<tr>
<td>Marine applications including auxiliary equipment</td>
<td>340 N m 3000 lbf in 34.6 kgf m</td>
<td>510 N m 4500 lbf in 51.8 kgf m</td>
<td>680 N m 6000 lbf in 69.1 kgf m</td>
</tr>
<tr>
<td>Forklift trucks</td>
<td>565 N m 5000 lbf in 57.6 kgf m</td>
<td>850 N m 7500 lbf in 86.4 kgf m</td>
<td>1130 N m 10,000 lbf in 115.2 kgf m</td>
</tr>
</tbody>
</table>
SUMMARY OF DESIGN PROCEDURE FOR FLEXIBLE MOUNTINGS

The following notes are included primarily as a check-list to assist in ensuring that all necessary considerations are covered at the design stage. Wherever possible, however, the mounting design procedure should be carried out in collaboration with the mounting manufacturer, in order to ensure optimum matching of mounting properties with design requirements.

a) Establish position of CG and weight of both engine and gearbox.

b) Establish minimum axis of inertia position.

c) Establish positions of front and rear supports relative to CG of either engine or gearbox.

d) Take moments about one support to find the load on the other and vice-versa in the static condition.

e) Calculate torque reaction at mountings, and check against manufacturers’ figures for maximum permissible deflections.

f) Take moments about rear face of cylinder block to calculate bending moments in the static condition at the rear of cylinder block/flywheel housing interface.

g) Decide upon the “g” factor value for the particular application.

h) Calculate dynamic load on supports, bending moment at cylinder block/flywheel housing interface etc.

i) Select suitable mountings to withstand both static and dynamic loadings with required deflection.

j) Calculate natural frequency of selected mountings.

k) Establish the disturbing frequency for engine being considered.

l) Establish degree of isolation from mount supplier’s graph of disturbing frequency plotted against mounting deflection.

m) Ensure that the selected mounting material is satisfactory for the environment.

n) Ensure that the selected mounting arrangement can be accommodated in the space available in the application.

APPENDIX

Method of Calculating Back End Bending Moment

The static mounting reactions $R_1$ and $R_2$ can be determined from the above information.

If a tail support is fitted, $R_3$ will have a predetermined value. (NOTE: $R_3 = 0$ if no tail support is fitted).

$$W_e = \text{total weight of engine}$$
$$W_t = \text{total weight of transmission}$$

Both these values will be about their respective centers of gravity.

Taking moments about $R_1$ to find $R_2$,
$$R_2 = \frac{W_e (L_1) + W_t (L_4) - R_3 (L_5)}{L_3}$$

Similarly taking moments about $R_2$ to find $R_1$, 
$$R_1 = \frac{W_e (L_3 - L_1) - W_t (L_4 - L_3) + R_3 (L_5 - L_3)}{L_3}$$

To find the bending moment ($M_x$) between the flywheel housing and cylinder block interface
$$M_x = R_2 L_6 + R_3 L_8 - W_t L_7$$

As a check for $M_x$,
$$M_x = R_1 L_2 - W_e (L_2 - L_1)$$

N.B. The above values will be in the STATIC CONDITION.

Relationship Between Configuration and Properties of Vertical Mounting Arrangements

a) General case — two unequal vertical mounts

For the mounting system shown, where B and D define the locations of the mount axes relative to the elastic axis of the system,

P and Q are the principal (compression and shear) axes of the mounts,
L and R are suffices defining left-hand and right-hand mounts.

\( K_p \) and \( K_q \) are combined and shear stiffnesses respectively.

\( K_x \) and \( K_y \) are combined lateral and vertical stiffnesses respectively.

Then \( \frac{K_p}{K_p} = \frac{B}{D} \)

and \( K_y = K_{pL} + K_{pR} \)

For a given system, \( B, D \) and the required value of \( K_y \) are already defined. \( K_p \) and \( K_q \) can therefore be calculated.

Also, Roll stiffness = \( K_{pL} \cdot B^2 + K_{pR} \cdot D^2 \)

\( K_{QL} \) and \( K_{QR} \) can be chosen independently to give the required total lateral stiffness

\( K_x = K_{QL} + K_{QR} \)

b) **Symmetrical system**

In this case, \( B = D, k_{pL} = K_{pR} \) and \( K_{QL} = K_{QR} (= K_q) \)

The above relationships then become:

Total vertical stiffness = \( 2K_p \)

Total lateral stiffness = \( 2K_q \)

Roll stiffness = \( 2K_p \cdot B^2 \)

**Relationship Between Configuration and Properties of Inclined Mounting Arrangements**

a) **General case — two unequal mounts, unsymmetrically located and orientated**

\[ \begin{align*}
\text{Combined vertical stiffness} &= K_{pL} \cdot \cos^2 \theta + K_{qL} \cdot \sin^2 \theta + K_{pR} \cdot \cos^2 \beta + K_{qR} \cdot \sin^2 \beta \\
\text{Combined roll stiffness} &= B(B + D) \cdot K_{pL} \cdot K_{qR} \\
\text{Combined lateral stiffness} &= D(B + D) \cdot K_{pR} \cdot K_{qR} \cdot \sin^2 \beta
\end{align*} \]

c) **Two equal mounts, symmetrically located and orientated**

\[ \begin{align*}
\text{Combined vertical stiffness} &= 2(K_p \cdot \sin^2 \theta + K_q \cdot \cos^2 \theta) \\
\text{Combined lateral stiffness} &= 2(K_p \cdot \cos^2 \theta + K_q \cdot \sin^2 \theta) \\
\text{Combined roll stiffness} &= 2B^2 \cdot K_p \cdot K_q \\
\end{align*} \]

d) **Two equal mounts on the same horizontal axis, perpendicular to each other**

\[ \begin{align*}
\text{Combined vertical stiffness} &= K_{pL} \cdot \cos^2 \theta + K_{qL} \cdot \sin^2 \theta + K_{pR} \cdot \sin^2 \beta + K_{qR} \cdot \cos^2 \beta
\end{align*} \]
If the horizontal distance between the mount centers is $2R = (B + D)$, and the elastic center is at a distance $X$ from the mid-point of the mount center line.

Combined vertical stiffness

$= \text{Combined lateral stiffness}$

$= K_p + K_q$

Combined roll stiffness

$= 2R (R - X) K_p$
### INTRODUCTION

### COOLING SYSTEM OPERATING PARAMETERS
- Coolant Temperature
- Pressure Cap Setting
- Lubricating Oil Temperature

### COOLING SYSTEM FILLING, VENTING AND DE-AERATION
- Filling
- De-Aeration
- Causes of Aeration
- Effects of Aeration
- Acceptance Requirements, Coolant Loss on Hot Shut Down and Aeration Level
- Venting and De-Aerating Systems
- De-Aerating Radiator Top Tank Design
- Radiator Top Tank/Auxiliary Header Tank Capacity
- Location of Radiator Inlet and Outlet Connections
- Cross-Flow Design

### COOLING SYSTEM LAYOUT
- Cooling Air Flow — General Considerations
- Direction of Air Flow
- Fan Cowls
- Fan/Cowl Relationship
- Cooling Fan Spacers/Distance Pieces
- Cooling Fan Tip Clearance
- Cooling Fan/Radiator Core Location
- Prevention of Cooling Air Recirculation
- Cooling System Pipework Hoses
- Heater Connections and Pipework

### RADIATOR CONSTRUCTION AND MOUNTING
- Radiator Construction
- Pack Type Core
- Fin and Tube Type Core
- Special Requirements for Earthmoving Equipment
- Radiator Mounting Arrangement
# RADIATOR SELECTION

- Introduction ................................................. 90
- Radiator Selection Procedure ............................. 90
- Application Type and Operating Environment .......... 90
- Ambient Temperature Clearance Requirement ............ 90
- Total Heat Dissipation Requirement ....................... 90
- Torque Converter Heat Load .................................. 90
- Engine Coolant Flow Rate .................................... 90
- Cooling System Pressure Drop (Waterside) ................. 90
- Cavitation ..................................................... 90
- Cooling System Air Flow, Power Requirement and Noise Emission .............................. 90
- Radiator heat Dissipation Characteristics .................. 91
- Radiator Selection Using Specific Dissipation Characteristics .............................................. 91

# COOLING FAN SELECTION

- Introduction ................................................. 93
- Fan Speed ..................................................... 93
- Reduced Speed Fan Drives .................................... 93
- Fan Speed Limitations ......................................... 93
- Fan Diameter .................................................. 93
- Types of Fan ................................................... 93
- Fan Selection Using Fan Performance Curves ............... 94
- Speed Modulating or Clutching Fan Drives ................... 94

# ENGINE OIL COOLERS

- Introduction ................................................. 95
- Oil Cooler Types .............................................. 95
- Water/Oil Type ............................................... 96
- Oil Cooler Restriction ......................................... 96
- Oil Cooler Adapter ............................................. 96
- Advantages of Water/Oil Type Cooler ....................... 96
- Disadvantages of Water/Oil Type Cooler ..................... 97
- Air/Oil (Air Blast) Type Cooler ............................... 97
- Additional Heat Load — Coolant Circuit ..................... 97
- Advantages of Air/Oil Type Cooler ........................... 97
- Disadvantages of Air/Oil Type Cooler ....................... 97
- Pipework, Engine to Oil Cooler — Waterside ............... 97
- Pipework, Engine to Oil Cooler — Oilside ................. 97
- Attachment of Accessories .................................... 97

# CHARGE AIR COOLER — T6.3544 VEHICLE APPLICATIONS

# COOLING SYSTEM PROTECTION

- Corrosion Inhibition .......................................... 99
- Antifreeze Mixture ............................................ 99
- Use of Proprietary Additives ................................. 99
- Coolant Water Quality ......................................... 100

# RADIATOR SHUTTERS

- ................................................................. 100
INTRODUCTION

The heat energy released by the combustion of fuel in a diesel engine is distributed approximately in the proportions shown below.

The function of the cooling system is to dissipate to the environment that part of the heat energy which is not converted into power, or passed directly to atmosphere by the exhaust gases or by radiation from the engine surfaces. In addition, depending on the application type and design, it may also be required to dissipate heat rejected from the transmission, water cooled exhaust manifolds, etc.

Cooling system details vary widely according to the application, but in all cases the system must be designed to maintain engine temperatures within the specified limits under the most extreme conditions of ambient and operation that the machine will encounter.

For details of the applicable Caterpillar ambient temperature clearance requirements worldwide, see SECTION 15, APPRAISAL AND TESTING.

COOLING SYSTEM OPERATING PARAMETERS

Coolant Temperature

The curves below show the boiling point of water against altitude, for an unpressurized system and for systems using 27.6 kN/m² (4 lbf/in²) (0.3 bar) and 48.3 kN/m² (7 lbf/in²) (0.5 bar) pressure caps.

Based on this, the table below shows Caterpillar maximum permissible coolant temperatures for an unpressurized system, and for systems using 27.6 kN/m² (4 lbf/in²) (0.3 bar) and 48.3 kN/m² (7 lbf/in²) (0.5 bar) pressure caps, at sea level, and at altitudes of 1500 meters (4920 ft) 2500 meters (8200 ft) and 3500 meters (11,480 ft).

In order to allow for the possibility of faulty pressure cap setting and/or sealing, and for localized areas in the cooling system which may be at a higher temperature level than at the measuring point, maximum temperature at engine outlet must not exceed a level 8°C below that shown on the curves for the applicable system operating pressure.

<table>
<thead>
<tr>
<th></th>
<th>Sea Level</th>
<th>1500 m (4920 ft)</th>
<th>2500 m (8200 ft)</th>
<th>3500 m (11,480 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non Pressurized System</td>
<td>92°C (197.6°F)</td>
<td>87°C</td>
<td>83°C</td>
<td>79°C</td>
</tr>
<tr>
<td>4 lbf/in² (27.6 kN/m²) (0.3 bar)</td>
<td>99°C (210°F)</td>
<td>95°C</td>
<td>92°C</td>
<td>89°C</td>
</tr>
<tr>
<td>7 lbf/in² (48.3 kN/m²) (0.5 bar)</td>
<td>103°C (217.4°F)</td>
<td>100°C</td>
<td>97°C</td>
<td>94°C</td>
</tr>
</tbody>
</table>

NOTE: For V8.640 engine, all above temperatures must be reduced by 8°C.
**Pressure Cap Setting**

The maximum pressure cap value approved by Caterpillar for the determination of cooling system clearance is 48.3 kN/m² (7 lbf in²) (0.5 bar).

If higher pressure cap settings are used, the additional pressure may not be used in calculating cooling clearance, and experience has shown that settings higher than 103 kN/m² (15 lbf in²) (1 bar) should not be used, due to the possibility of leakage at seals, gaskets, hoses, etc.

**Lubricating Oil Temperature**

The normal maximum permissible lubricating oil temperature, measured in the main oil pressure rail, or at the oil filter head, is 121°C. It may however be considered necessary for the maximum oil temperatures to be measured prior to the oil cooler in heavy duty construction machinery applications.

If the engine never operates at its maximum speed for more than one hour at a time, the maximum permissible oil temperature may be increased to 132°C.

Examples of such applications are:

- Goods and passenger vehicles operating in territories which do not have motorways or similar high speed, limited access roads.
- Forklift trucks
- Straddle carriers, side loaders, etc.
- Mobile cranes
- Tow tractors
- Road sweepers
- Road rollers
- Rubber tired compactors
- Truck mixer auxiliary engines.

For applications such as combine harvesters and 360° excavators, where application approval is based respectively on tests at 75% load on the governor curve and 80% power at rated speed, the lower oil temperature of 121°C applies. If tested at 100% engine power on a dynamometer or test rig, the higher value of 132°C is permitted.

**De-Aeration**

In addition to meeting the requirement for satisfactory filling as detailed, it is desirable that features should be included in the cooling system design which will permit continuous de-aeration, i.e. removal of entrained air, from the coolant while running.

NOTE: In the case of the V8.640 engine, it is essential that the cooling system should be of a positive de-aerating type. This is necessary in order to ensure the high standard of cooling system reliability and performance required for this premium, long life engine.

**Cause of Aeration**

Aeration of the coolant may take place for the following reasons:

1. It is difficult in practice to ensure that all air is expelled from the system during filling.
2. In systems using an open (non-baffled) radiator top tank, the high velocity of the coolant entering the tank causes turbulence, and a tendency for air to be drawn into the tubes together with the coolant.
3. It is possible for combustion gases to become entrained in the coolant in the event of faulty cylinder head gasket sealing.

**Effects of Aeration**

Aeration of the coolant is likely to result in the following:

1. Possibility of local boiling, and high metal temperatures.
2. Excessive coolant loss on hot shut down.
3. Deterioration in water pump performance, resulting in a reduction in flow rate and an adverse effect on cooling. In severe cases, an almost complete breakdown in coolant flow may occur.
Acceptance Requirements, Coolant Loss on Hot Shut Down and Aeration Level

Caterpillar requirements for satisfactory system operation, and details of the applicable test procedures, are detailed in SECTION 15, APPRAISAL AND TESTING.

### Venting and De-Aerating Systems

The following diagrams show typical arrangements, as employed in various application types.

**NOTE:**

1. In all cases where cab heaters or other cooling system components are positioned at a higher level than the rest of the system, a vent valve or plug must be fitted, at the highest point in the system.

2. In cases where engines have been installed in a “front end down” attitude, it is necessary to provide a special venting/bleed line arrangement, in order to clear air which would otherwise be trapped in the rear of the cylinder head(s). It should be noted that “front end down” installations are not normally approved by Caterpillar, and it is essential that the Application Engineering Department, Peterborough should be consulted in such cases.

### BASIC ARRANGEMENT

**Venting:**
Vent valve (jiggle pin) or notch in thermostat/thermostat housing.

**De-Aeration:**
Does not incorporate positive de-aerating features.

**BAFFLED RADIATOR TOP TANK**

**Venting:**
Vent valve (jiggle pin) or notch in thermostat/thermostat housing.

**De-Aeration:**
Incorporates positive de-aerating capability. Coolant “bleed” through standpipe allows air carried in bleed to “settle out” in non-turbulent area above baffle.

**AUXILIARY HEADER TANK ARRANGEMENTS**

In the systems shown, the auxiliary tank is mounted remote from the radiator, as in many vehicle installations where “head room” above the radiator is limited. Where space is available, the auxiliary tank may be incorporated in the radiator as a separate, upper tank.
Venting: Vent valve (jiggle pin) or notch in thermostat/thermostat housing, and "bleed" from top of radiator to auxiliary tank.

De-Aeration: Incorporates positive de-aerating capability. Air carried with bleed from top of radiator "settles out" in non-turbulent conditions of auxiliary tank.

---

Venting: Vent valve (jiggle pin) or notch in thermostat/thermostat housing, and bleed to auxiliary tank from highest point in system on radiator side of thermostat.

De-Aeration: Incorporates positive de-aerating capability. Air carried with bleed "settles out" in non-turbulent conditions of auxiliary tank.
De-Aerating Radiator Top Tank Design

The diagram shows a twin inlet design, suitable for use with Vee form engines. The single inlet design remains the same, except for the deletion of one of the connections.

An alternative design where increased de-aerating ability is required is shown below. This utilizes a fully sealed baffle and an external filling/return line.

Alternative de-aerating top tank arrangements are possible, but in all cases, effectiveness with regard to de-aerating performance can only be assessed by testing in the particular application. See SECTION 15, APPRAISAL AND TESTING.
Radiator Top Tank/Auxiliary Header Tank Capacity

It is essential that the radiator top tank/auxiliary header tank should be of adequate capacity, in order to ensure that a satisfactory coolant level will be maintained under all conditions.

After allowance for expansion loss, and loss on hot shut down, coolant level after cooling down to ambient temperature should not be less than 32 mm (1\(\frac{1}{4}\) in) above the top of the radiator tubes, or level with the top of the baffle, in the case of a baffled radiator design.

In the case of an auxiliary header tank system, coolant level should not fall below 32 mm (1\(\frac{1}{4}\) in) above the base of the tank.

The illustration below shows diagrammatically the header tank volume allowance which must be made for expansion loss, hot shut down loss, and "working" volume respectively.

Location of Radiator Inlet and Outlet Connections

In order to ensure full utilization of the radiator core, the inlet and outlet connections in the top and bottom tanks should ideally be located diagonally opposite to each other, or at least be well displaced, one from the other. In cases where the connections must be located on the same side of the radiator, a baffle should be fitted in the bottom tank in order to achieve a satisfactory flow distribution.

Cross-Flow Design

Radiators installed where there is a severe height restriction may be of cross-flow design with transverse tubes and tanks at each side. Filling, venting, and de-aerating tend to be difficult and a remote header tank similar to the auxiliary tanks shown on earlier pages will generally be required.

The installation of V8 engines with twin water outlets is particularly difficult. The shape and size of the remote header tank needed may make this impracticable to locate in a suitable position. Cross flow radiators are not generally recommended therefore for V8 installations.

Coolant System Layout

Cooling Air Flow — General Considerations

It is important to appreciate that in addition to the restriction incurred across the radiator core, the total cooling system resistance as "seen" by the cooling fan includes any additional restriction to flow imposed either up stream or down stream of the fan. It is important, in order to minimize
cooling system power loss and noise emission, that restriction should be kept to a minimum, and attention should be given to the following:

1. **Radiator grilles**

   If the radiator grille is fitted, the total “open” area should be at least equal to that of the radiator core, and should preferably be 10 to 20% greater.

2. **Outlet area**

   It is important that adequate area should be allowed for the cooling flow outlet. This should be at least equal to the total inlet area, and in order to allow for the increased cooling air volume due to rise in temperature through the radiator, the exit area should ideally be at least 20% greater than the inlet area.

3. **Cooling air flow path**

   The cooling air flow path should be as unobstructed as possible, particularly in the locality of the cooling fan inlet in the case of pusher fan installations.

   Abrupt changes in flow area section and direction should be avoided as far as possible.

**Direction of Air Flow**

Cooling air flow may be in either direction through the radiator core, depending on the type of cooling fan used. It is important however that consideration should be given to the following factors when deciding on the most suitable flow direction for a particular installation:

1. **When possible, the direction of flow should be such that air temperature at entry to the radiator is as close as possible to ambient temperature.**

   In general, this requirement will be met most satisfactorily by the use of a “puller” i.e. suction type fan, since the case of a “pusher” (pressure) type fan, preheating of the cooling air will take place due to passage over the engine surfaces.

2. **In mobile applications with significant forward velocity, the flow direction should be chosen to take advantage of the resulting “ram” effect.**

3. **Cooling fan efficiency and noise output is greatly affected by flow conditions at the fan inlet. In general, less obstructed flow conditions and improved inlet conditions will be achieved with a puller type fan, since this is not subjected to the obstruction imposed by the engine in the case of a pusher fan installation.**

4. **Although the use of a puller (suction) fan will in general result in a more efficient cooling system, the following factors should be taken into account:**

   a) In the case of enclosed installations, under bonnet/engine enclosure air temperature will be relatively high.

   b) For certain applications, e.g., earth moving and construction machinery, operating in high sand/dust environments, the use of a “puller” fan is not normally suitable, due to the likelihood of radiator plugging and sand blasting.

   c) In a number of applications a puller fan is not suitable, since due to the layout of the machine, the operator would be subjected to high temperatures due to the warm air leaving the radiator.

   d) In rear engined applications with significant forward speed, the “ram” effect due to forward motion tends to oppose the flow of cooling air from a “puller” fan (if the engine faces towards the rear), and careful ducting of the cooling air flow is necessary in order to prevent possible adverse effects.

**Fan Cowls**

In all installations, the use of an efficient fan cowl is essential, since this will enable the most effective use to be made of the available core area, and will also assist in the prevention of recirculation of cooling air.

The use of an efficient cowl will, in many cases, make it possible to use a lower cooling air flow rate, while still achieving satisfactory cooling, and so reduce the cooling fan power requirement and noise emission.

The various types of fan cowl are illustrated.

**Type 1**

This is the simplest, and least expensive type of cowl, and is suitable for general use in installations where the system restriction (and hence fan working pressure) is relatively low.

Normally, this will apply to installations where radiator pressure drop is low, due to the use of a low number of tube rows, and moderate cooling air flow rate.

**Type 2 and 3**

In cases where the system pressure drop is higher, as in installations using radiator cores with a higher number of tube rows, and possibly also close fin spacing, greater efficiency will be achieved by the incorporation of a fan “ring” on the cowl, as shown. This assists in the prevention of air “leakage” at the fan tip, and allows the fan to build up the required working pressure. The width of the ring should be equal to approximately half the projected fan blade width.

In general, optimum results will be obtained with the “shaped” cowl design (3) due to the improved flow distribution over the radiator core, but this type is more expensive to produce.

**Type 4**

In installations where there is considerable relative movement between the fan and radiator cowl, as in the case of some flexibly mounted engines, the arrangement shown may be used, in order that fan tip clearance may be kept to a minimum (see COOLING FAN TIP CLEARANCE).
TYPICAL FAN COWL TYPES

1
"BOX" COWL

2
"BOX" COWL WITH RING

3
"SHAPED" COWL

4
ENGINE-MOUNTED FAN RING WITH FLEXIBLE GAITER

MINIMUM FAN TIP
CLEARANCE [6mm] 1/4 in.
APPROX.

ENGINE MOUNTED RING

FLEXIBLE GAITER
**Fan/Cowl Relationship**

The position of the cooling fan relative to the cowl has a considerable effect on efficiency. In many cases, the optimum position will be established by adjustment during cooling tests, but in general, the relationships shown in the diagrams below have been found to give satisfactory results.

**Cooling Fan Spacers/Distance Pieces**

Spacers of various thicknesses are available to suit both water pump and crankshaft mounted fans, in order to enable the optimum fan/cowl relationship to be achieved.

In order to avoid excessive loading of the water pump bearings, and excessive run-out (i.e. lack of concentricity) at the fan, a total distance piece thickness of 51 mm (2.0 in) should not normally be exceeded. If it is required to exceed this thickness, details of the proposed installation and of the cooling fan should be sent to the Application Engineering Department, Peterborough, for assessment.

**Cooling Fan Tip Clearance**

It is very important, particularly when system restriction is relatively high, that the radial clearance between the fan blade tip and the fan cowl aperture or fan ring should be kept to a minimum.

In general, clearance should not exceed 12.5 mm (0.5 in). Difficulties exist however in many flexibly mounted engine installations, where engine movement may take up this clearance, and in such cases, for optimum results the engine-mounted fan ring arrangement. Type 4 (reference FAN COWLS) should be used.

This allows relative movement between the engine and radiator, without affecting tip clearance.

**Cooling Fan/Radiator Core Location**

The cooling fan should be located centrally with the radiator core, and it must be ensured that the fan does not “overlap” the sides of the radiator core, or the top and bottom tanks. This condition imposes fluctuating loadings on the fan blades, and can result in fatigue failure. For the same reason, care must be taken to ensure that support bracketry, hosework, etc., is not located within the “sweep” of the fan blades.

In general, within the limitations of the space available, the radiator should be located as far forward as possible from the fan. This enables the best distribution of cooling air over the radiator core.

If, due to lack of space, the fan/core clearance must be minimized, the fan must not be positioned closer than 25 mm (1 in) from the core. This dimension must of course be increased if the movement of the engine and/or radiator on their individual flexible mountings will result in a reduction in clearance under operating conditions.

**Prevention of Cooling Air Recirculation**

When the engine and radiator are mounted inside an enclosure, it must be ensured that recirculation of the cooling air cannot take place. Suitable barrier and ducting arrangements are illustrated.

The upper illustration shows a suitable arrangement for an installation in which a puller (suction) fan is used. If a pusher (pressure) fan is used, it is essential that the grille should...
extend over the whole of the front of the enclosure, in order to avoid turbulent air conditions inside the canopy at the cooling air exit from the radiator.

The lower illustration shows an arrangement which suits both puller and pusher fan installations. This arrangement is recommended for vehicle applications, as the inlet duct will maximize the “ram” effect due to the forward motion of the vehicle.

Cooling System Pipework Hoses
Hoses used in the cooling system must be of adequate duty to meet working conditions with respect to temperature, pressure, and resistance to anti-freeze and contamination by fuel and lubricating oils.

Only plain bore hose should be used. The internally convoluted flexible type of hose should not be used, since this is highly restrictive, and may result in excessive pressure drop. The use of plain bore hose with internal coil spring insertions to provide a degree of flexibility, and to prevent local closure of the hose, is not approved, since experience has shown that service problems are likely due to the spring insert moving out of position.

Hose runs should be kept as short as possible, and should be suitably supported/secured if necessary to prevent chafing.

All radiator connections, remote header tank connections, oil cooler connections (waterside), and any other connections used in conjunction with hoses, should have beaded ends, for improved sealing and security.

Heater Connections and Pipework
Tappings are provided on all engine types to take cab heater feed and return connections — the position of these is shown in the appropriate engine handbook or general arrangement drawing. It is important that only the specified points should be used.

Hoses should be suitably secured to prevent the possibility of damage. Where the heater is positioned at a higher level than the rest of the system, a vent valve or plug must be fitted at the highest point in order to allow air to be expelled during filling.

RADIATOR CONSTRUCTION AND MOUNTING

Radiator Construction
Radiator construction must be adequate to withstand the loadings and conditions that will be met in service. Special requirements also apply for machines operating in environments where there is a high sand or dust contamination of the cooling air, e.g. earth moving equipment.

Typical methods of radiator core construction are illustrated.

Pack Type Core
This “Pack” type of construction has relatively low mechanical strength, and is susceptible to “plugging”, i.e. choking of the core, where any significant contamination of the cooling air is present.

In general, this form of construction is suitable only for applications where shock loading and vibration are low, and where there is no appreciable dust or other contamination of the cooling air. Typical usage is in light duty automotive applications.

Fin and Tube Type Core
This type of construction has greater mechanical strength, and is suitable for all application types.

Important restrictions apply however with regard to the maximum density of fin spacing (i.e. closeness of fin pitch) which
should be used to avoid “plugging”, in various application types. In general, fin spacing should not be closer than that shown below, for the various application types.

<table>
<thead>
<tr>
<th>Application Type</th>
<th>Fin Pitch (mm)</th>
<th>Fins/inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light duty Automotive</td>
<td>1.7</td>
<td>15</td>
</tr>
<tr>
<td>Commercial Vehicle (on-highway)</td>
<td>2.0</td>
<td>12</td>
</tr>
<tr>
<td>General Industrial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Agricultural</td>
<td>3.0</td>
<td>9</td>
</tr>
<tr>
<td>Vehicle (off-highway)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth Moving Machinery</td>
<td>4.0</td>
<td>6</td>
</tr>
<tr>
<td>Combine Harvester</td>
<td>6.0</td>
<td>4</td>
</tr>
</tbody>
</table>

**Special Requirements for Earth Moving Equipment**

In order to withstand the operating conditions met in service by this type of equipment, the radiator should incorporate the following features:

1. General construction should be “heavy duty”, to withstand operational shock loadings.
2. Radiator tube rows should preferably be “in line”, to assist in prevention of plugging. If “staggered” tube rows are used, the spacing between tubes and tube rows must be adequate to provide a free air passage through the core. Normally also, the radiator should not have more than 7 rows of tubes.
3. In applications operating in extreme conditions of sand/dust concentration, e.g. Crawler Loaders, Dozers, etc., the first row of tubes on the cooling air inlet side should be protected by a shield to prevent erosion due to sand blasting (see illustration).
4. Fin spacing not to be closer than 4.0 mm pitch (6 fins/in).
5. Thickness of fins should not be less than 0.99 mm (.0035 in) and the edges of the fins facing the cooling air flow should be “wrapped” in order to increase strength (see illustration).

**Radiator Mounting Arrangement**

In order to avoid possible failure of the radiator core, it is important to protect the radiator from excessive vibration and/or shock loading.

Typical flexible mounting arrangements are shown below. These are used in conjunction with rubber bushed fixings at the side and/or flexible mounted stays at the top of the radiator.
RADIATOR SELECTION

Introduction
In most cases, the selection of a suitable radiator will be carried out in conjunction with the radiator manufacturer, who will have available information on stock radiator sizes and types, and the applicable radiator dissipation characteristics, etc.

It is important however to appreciate that:

1. The correct choice of cooling system “package” can have a considerable effect on noise emission and cooling system power requirement.

2. In all cases, due to the effects of features of the cooling system layout, air flow conditions, duty cycle, etc., the actual cooling system “clearance” (i.e. the maximum ambient temperature for which the cooling system is suitable) can only be established by full cooling tests, as detailed in SECTION 15, APPRAISAL AND TESTING.

Radiator Selection Procedure
The following items must be considered during the selection procedure:

1. Application type and operating environment.
2. Ambient temperature clearance requirement.
3. Total heat dissipation requirement.
4. Engine coolant flow rate.
5. Space availability for radiator.
6. Radiator heat dissipation characteristics.

Application Type and Operating Environment
The application type and operating environment will determine the most suitable form of radiator core construction, and the maximum acceptable fin density and number of tube rows, in order to avoid the possibility of core “plugging” (See RADIATOR CONSTRUCTION AND MOUNTING).

Ambient Temperature Clearance Requirement
Caterpillar ambient temperature clearance requirements related to operating territory are shown in SECTION 15, APPRAISAL AND TESTING.

Total Heat Dissipation Requirement
Full load heat to coolant values for the current engine range, at the ratings applicable to the various application categories, are included in SECTION 16, TECHNICAL DATA.

To these values must be added any additional heat input to the cooling system, rejected from the transmission, hydraulic system, braking system, water cooled exhaust manifolds, air conditioning systems etc., depending on the design details of the particular application type.

Torque Converter Heat Load
Where heat is rejected to the cooling system from a torque converter transmission, determination of the additional heat load must be based on an estimate of the mean torque converter efficiency over the duty cycle. Allowance must be made for an additional heat dissipation requirement equivalent to the power “lost” in the transmission.

Engine Coolant Flow Rate
Coolant flow rates for the current engine range, with a fully open thermostat and typical system pressure drop, (see COOLING SYSTEM PRESSURE DROP (WATERSIDE), are included in SECTION 16, TECHNICAL DATA.

Cooling System Pressure Drop (Waterside)
Pressure drop incurred by the coolant in flowing through the total external cooling system, i.e. radiator, pipework, “in-line” oil cooler if fitted (see WATER/OIL TYPE and OIL COOLER RESTRICTION), should not exceed 35 kN/m² (≈ 5 lbf/in²) at maximum rating.

This is an essential requirement in order to maintain adequate flow rate through the engine, end to prevent cavitation taking place at the water pump inlet. (See CAVITATION.)

Cavitation
Cavitation will occur if the pressure at the water pump inlet is reduced to the point when local boiling can take place, and will result in the following detrimental effects:

a) Reduction in coolant flow rate. This in turn will lead to a higher coolant temperature, and further aggravate the situation.

b) Damage to the water pump impeller and casing, and possibly also to the coolant passages in the engine water jacket.

Cooling System Air Flow, Power Requirement and Noise Emission
It is important, when deciding the most suitable radiator and cooling fan specification to meet a given heat dissipation requirement, to appreciate the following relationships:

Cooling Air Power Requirement is proportional to Cooling Air Flow x Air Pressure Developed Across System.

Cooling System Noise Emission is proportional to Cooling Air Flow Rate x Pressure².

These relationships indicate the following requirements in order to minimize cooling system power loss and noise emission:

1. Cooling air flow volume should be kept to a minimum, compatible with achieving the required cooling clearance.

2. Pressure developed, i.e. restriction incurred, across the system should be kept to a minimum.

3. In order to minimize the cooling air flow rate, and also reduce the pressure developed across the system, the heat dissipation efficiency of the radiator should be as high as possible, within the limitations set by the application type, operating environment and cost.
Radiator Heat Dissipation Characteristics
The specific heat dissipation characteristics of a radiator core are dependent on the following:

a) Type of construction and material of core
b) Type of finning and fin density
c) Core thickness (number of tube rows)
d) Coolant flow rate
e) Velocity of cooling air flow through core

The characteristics of a particular core type are normally presented by the radiator manufacturer in graphical form as illustrated. Typical characteristics are shown for two row and five row core “thickness”.

It should be noted that in order for the dissipation rates shown to apply, waterside (i.e. coolant) flow rate must be equal to or greater than the minimum value quoted on the curve of characteristics.

The diagrams show the heat dissipation performance per square meter of core area, against cooling air velocity through the core, based on a temperature differential of 50°C between the mean coolant temperature in the core and the temperature of the cooling air venting the radiator.

The characteristic curves show specific dissipation for a range of fin spacings; and also, in the lower diagrams, static air pressure drop across the core against cooling air velocity through the core again for a range of fin spacings.

Radiator Selection Using Specific Dissipation Characteristics
It is stressed that the successful selection of a radiator and cooling fan combination to give a particular ambient temperature clearance is a matter demanding considerable experience and knowledge of previous similar installations. This is particularly the case in applications working on variable duty load and speed cycles, and in many cases, the final specification will be developed ultimately as a result of modifications made as a result of a number of cooling tests.

As a guide however, the procedure is as follows:

1. Establish frontal area of radiator core

As a general rule, the largest possible core area should be specified, consistent with the installation space available.

This allows the cooling air flow volume for a given heat dissipation requirement to be minimized, and so reduces noise emission and power loss.

NOTE: It is essential, in order to make full use of the available core area, that an efficient fan cowl should be fitted (see FAN COWLs).
2. **Establish most suitable fin spacing**

The closest possible fin spacing should be specified, compatible with the application type and operating environment (see SECTION 7, RADIATOR CONSTRUCTION AND MOUNTING).

This will result in an increased specific heat dissipation for the radiator core, and will again assist in reducing the cooling air flow requirement.

3. **Establish specific dissipation requirement and apply to characteristic curves**

The radiator specific heat dissipation characteristics are quoted in the curves in the following units:

\[
\text{Specific Heat Dissipation} = \frac{\text{Total heat dissipation requirement}}{\text{System Factor (SF)}}
\]

In practice, it is necessary to apply the factor shown, SF, to take into account the degree of uniformity of cooling air flow distribution over the radiator core. This is dependent on a number of factors, including cooling system layout, flow direction, i.e. puller or pusher fan, and the type of fan cowl fitted (see SECTION 7, COOLING SYSTEM LAYOUT).

The factor varied from unity (1) for optimum flow conditions, to 1.3 approximately for a poor combination of conditions.

Finally, **Specific Heat Dissipation**

\[
= \frac{\text{Total heat dissipation requirement}}{\text{minute (kW) \times 40 \times SF}}
\]

\[
\text{Mean temperature difference (°C) \times core frontal area (m)}
\]

**System Factor (SF)**

For limiting conditions, i.e. when engine coolant outlet temperature is at the maximum permissible value related to the pressure cap in use, and for a normal coolant temperature differential through the radiator of 5/6°C, then

\[
\text{Mean Coolant Temperature} = \frac{\text{Maximum permissible engine outlet temperature} - 3°C}{\text{(Approx)}}.
\]

**Air temperature entering radiator core**

This may be equivalent to the required ambient temperature clearance if little or no pre-heating of the air takes place before entering the core, or may be substantially above this, as in the case of an enclosed “pusher” fan installation.

2. **Establish most suitable fin spacing**

The closest possible fin spacing should be specified, compatible with the application type and operating environment (see SECTION 7, RADIATOR CONSTRUCTION AND MOUNTING).

This will result in an increased specific heat dissipation for the radiator core, and will again assist in reducing the cooling air flow requirement.

3. **Establish specific dissipation requirement and apply to characteristic curves**

The radiator specific heat dissipation characteristics are quoted in the curves in the following units:

\[
\text{Specific Heat Dissipation} = \frac{\text{Total heat dissipation requirement}}{\text{System Factor (SF)}}
\]

In practice, it is necessary to apply the factor shown, SF, to take into account the degree of uniformity of cooling air flow distribution over the radiator core. This is dependent on a number of factors, including cooling system layout, flow direction, i.e. puller or pusher fan, and the type of fan cowl fitted (see SECTION 7, COOLING SYSTEM LAYOUT).

The factor varied from unity (1) for optimum flow conditions, to 1.3 approximately for a poor combination of conditions.

Finally, **Specific Heat Dissipation**

\[
= \frac{\text{Total heat dissipation requirement}}{\text{minute (kW) \times 40 \times SF}}
\]

\[
\text{Mean temperature difference (°C) \times core frontal area (m)}
\]

**System Factor (SF)**

For limiting conditions, i.e. when engine coolant outlet temperature is at the maximum permissible value related to the pressure cap in use, and for a normal coolant temperature differential through the radiator of 5/6°C, then

\[
\text{Mean Coolant Temperature} = \frac{\text{Maximum permissible engine outlet temperature} - 3°C}{\text{(Approx)}}.
\]

**Air temperature entering radiator core**

This may be equivalent to the required ambient temperature clearance if little or no pre-heating of the air takes place before entering the core, or may be substantially above this, as in the case of an enclosed “pusher” fan installation.
COOLING FAN SELECTION

Introduction

In all stationary applications, and in mobile applications where there is not significant “ram” air assistance due to forward motion, the cooling fan must deliver the total required air flow volume, as determined from the radiator dissipation characteristics. This requirement also applies in the case of many commercial vehicles, where there will be a demand under certain conditions for full engine output while operating in a low gear ratio, e.g. when climbing fully laden in mountainous terrain.

Exceptions to this are some light vehicle applications, e.g. cars and light vans. The extent of “ram” air assistance in these cases is however very dependent on the frontal design of the vehicle, i.e. flow conditions at the radiator inlet, and in general can only be assessed during cooling tests under operating conditions. Fan selection in this section is based on the full cooling flow requirement being provided by the fan only.

Fan Speed

In many cases, fan speed will be decided by the application design, which will influence the fan drive ratio, i.e. whether the fan must be water pump, crankshaft or remotely mounted.

In order to reduce noise emission, when a choice of fan drive ratio is available, the lowest practicable fan speed should be used, compatible with air flow volume requirement and system restriction.

Reduced Speed Fan Drives

Certain engine types are available with fan drives at ratios below crankshaft speed. These may be either co-axial with the water pump, as shown in the following diagram, or may be mounted separately, remote from the water pump.

In addition to reduced noise emission, the lower fan speed available with these drives will, in many cases, allow better coverage of the radiator core, since a larger diameter fan may be used. This is a particularly valuable feature in machines using large radiator cores, and where limited space restricts the depth of the fan cowl, which would make effective use of the core difficult with a smaller diameter fan.

Earth moving machinery

The reduced air velocity through the core when a large low speed fan is used is particularly desirable in the case of machines working in high dust/sand environments, in order to reduce sand blasting of the core, and sand disturbance by the cooling air flow.

Fan Speed Limitations

When using a fan which was not specified by Caterpillar for the particular application and operating speed range, it is necessary to obtain the manufacturer’s approval to avoid the possibility of failure.

Fan Diameter

In general, in order to achieve the best coverage of the radiator core, the fan diameter should match the dimensions of the core as closely as possible.

Care should be taken that the fan does not overlap the sides of the core, or the top and bottom tanks, in order to avoid fluctuating loading of the fan blades, which may lead to failure.

Types of Fan

A range of four, six and eight bladed fans of “puller” and “pusher” types with varying blade angle (pitch) and blade widths as well as diameter is offered in the Sales Catalogs to match the air delivery requirements of the Caterpillar engine range. The standard range of fans are pressed steel or aluminum construction.

Molded plastic fans are used on some applications.

Fans for crankshaft pulley mounting are supplied with a flexible drive hub.

NOTE: The approval of Application Engineering Department must be obtained for the use of fans not already supplied or recommended by Caterpillar Engines Ltd.

It is particularly important to ensure that the natural frequency of vibration of the fan blades cannot be excited by the “blade-passing frequency”, i.e. the frequency at which the blades pass obstructions in the air flow path, as this can lead to resonant vibration of the blades, and hence fatigue failure.
**Fan Selection Using Fan Performance Curves**

Typical fan performance curves are illustrated.

**FAN PERFORMANCE CURVES**

![Performance Curves Diagram]

**Stall line**

For a given fan speed, if the fan working pressure is increased, due to increased system restriction, beyond the point on the fan characteristic denoted by the stall line, severe disturbance in flow conditions at the fan will occur, resulting in a major reduction in air flow and an increase in noise emission.

The fan must be selected using the performance curves to give the required cooling air flow against the total system restriction, without running into a “stall” condition.

It should be noted that in addition to the restriction incurred across the radiator core, as determined from the radiator dissipation characteristics, the total system restriction includes any additional restriction incurred in the cooling air flow path. This varies widely according to the installation layout, type of radiator grille, inlet and outlet areas, etc. and is difficult to estimate.

As a general guide, in order to make allowance for the restriction incurred in the remainder of the system, the pressure drop incurred across the radiator should not account for more than 70% of the available “working” part of the fan characteristic.

This applies to systems with a relatively unrestricted flow path. For more restrictive installations, this figure must be reduced accordingly.

**IMPORTANT:**

Fan performance curves as published by the manufacturers normally relate to test results obtained with the fan operating in a tunnel or duct, with relatively low tip clearance. In the working conditions which will apply in service, fan performance is likely to be significantly lower than indicated by the curves. In order to allow for this the air flow requirement, as derived from the radiator dissipation characteristics, should be increased by 15 to 20% before application to the fan performance curves.

**Speed Modulating or Clutching Fan Drives**

In some applications, there may be considerable advantages in terms of reduced noise emission and power saving by the use of proprietary fan drives.

These may be controlled by coolant temperature, or by cooling air temperature leaving the radiator, or may be purely speed reducing drives, introducing a degree of viscous “slip” in the fan drive. This latter type is suitable in certain cases for use where “ram” air provides a major part of the cooling air flow, e.g., cars, and possibly light vans.

Where a fan drive which does not appear in these catalogs is considered, full details should be submitted to the Application Engineering Department, Peterborough, in order that the suitability of the drive, and the possibility of additional loading of the water pump bearings etc., may be evaluated.
ENGINE OIL COOLERS

Introduction

Maximum acceptable lubricating oil operating temperature related to the application type and duty is detailed in LUBRICATING OIL TEMPERATURE.

In the case of engines having integral oil coolers as part of the original build, oil temperature will be held within these limits providing the cooling system is adequate to maintain coolant temperature within the specified limits.

When an integral oil cooler is not incorporated, it will be necessary in some cases to fit a suitable oil cooler, in order to maintain oil temperature within the specified limits at the applicable maximum ambient temperature clearance requirement. The principal factors which have an influence on engine oil temperature, and which will determine whether an oil cooler will be necessary, are as follows:

1. Installation Layout

A major proportion of the heat dissipated from the lubricating oil is by radiation from the sump, and this in turn is influenced by the degree or air movement over the sump.

Vehicle applications

If possible, obstructions should be avoided in front of and below the sump, in order to take advantage of the cooling air flow due to the forward motion of the vehicle.

2. Engine Speed

Heat rejected to the lubricating oil increases rapidly as engine speed increases. Applications in which the duty/operating cycle will result in sustained high operating speed, are therefore more likely to require an oil cooler, particularly if the installation layout etc. is such that heat dissipated from the sump is low.

It is emphasized however that, in any particular case, the necessity for an oil cooler, and the ambient temperature clearance, i.e. maximum safe ambient operating temperature, can ultimately only be determined by full cooling tests, as detailed in SECTION 15, APPRAISAL AND TESTING.

Oil Cooler Types

Two types of oil cooler are in general use:

1. Water/Oil type
2. Air/Oil (“Air Blast”) type

Each of these cooler types has relative advantages and disadvantages, and the choice of cooler type must be made to suit the particular application type and duty.

Enclosed applications

If possible, the location of the cooling air inlet/outlet apertures should be such that part of the cooling air path is over the engine sump.
**Water/Oil Type**

A typical cooler of this type is illustrated. Coolant is fed internally through the tube stack, while oil is fed over the external surfaces. Baffles are fitted in order to maximize oil contact with the tubes, and so improve heat transfer.

A typical arrangement using this type of cooler is shown diagrammatically on the previous page, the cooler being inserted in the pipe run from radiator outlet to water pump inlet. The mounting of remote oil coolers in high positions should be avoided wherever possible, as this can lead to drain-back of oil from the engine through the cooler to the sump.

An alternative type of water/oil cooler is shown above, this being a plate type cooler installed in the radiator bottom tank. This type of cooler has useful installation advantages, as follows:

1. The cooler is less susceptible to damage and, although the radiator bottom tank must be deeper than normal in order to accommodate the cooler, there is no other additional space requirement.
2. Waterside pipework is not required.

**Oil Cooler Restriction**

It is important that the cooler should not impose an excessive restriction to flow, on either the coolant or oil sides.

Maximum restriction incurred across the cooler, at full engine speed and operating temperature, should not exceed the following:

- **Waterside:** 7.0 kN/m² (1 lbf/in²).

  NOTE: It is important that the restriction incurred across the cooler should not exceed this value, in order that the cooler does not make an excessive contribution to total system pressure drop (see COOLING SYSTEM PRESSURE DROP (WATERSIDE)) and, in the case of oil coolers installed in the bottom hose run, to avoid cavitation (see CAVITATION).

- **Oilsode:** 35 kN/m² (5 lbf/in²)

**Oil Cooler Adapter**

(Applies to All Cooler Types)

In all cases, lubricating oil feed to the oil cooler, and return to the engine from the cooler, should be carried out by means of an approved oil cooler adapter, fitted between the lubricating oil filter and the filter facing on the cylinder block.

Suitable adapters are available for most engine types, and details of these are shown in the appropriate engine literature, or are available from Caterpillar Application Engineering Department.

**Advantages of Water/Oil Type Cooler**

Lubricating oil temperatures is directly related to coolant temperature, minimizing lubricating oil "cold sludge" formation which can occur if oil is overcooled under low ambient temperature conditions.
Disadvantages of Water/Oil Type Cooler
1. Relatively large size requirement for moderate degree of cooling.
2. Relatively high cost.

Air/Oil (Air Blast) Type Cooler
Air/Oil (“Air Blast” Type
OIL COOLER ARRANGEMENT

A typical arrangement using this type of cooler is shown below:

This type of cooler may be used in installations using either “puller” or “pusher” fans, but for maximum effect in the case of a pusher fan, the cooler should be positioned either between the fan and the radiator, or in the air stream to the fan.

In order to avoid uneven loading of the fan blades, as the fan “sweeps” the cooler, the cooler should be located to present as uniform a restriction as possible.

The cooler must not impose an excessive restriction to air flow, and for this reason, and also to minimize fouling in service, widely spaced finning of the Spirogill or similar type is preferred.

Additional Heat Load — Coolant Circuit
It should be noted that the use of an oil cooler will normally result in additional heat rejection to the cooling system, and coolant “clearance” will be affected accordingly.

Exceptions to this are installations using air/oil type coolers as below:
1. Pusher fan installations with the oil cooler is mounted at the radiator front.
2. Installations where the oil cooler is mounted remote from the radiator in vehicle applications. This arrangement, which relies entirely on “ram” air movement due to the forward motion of the vehicle, can give satisfactory results, particularly in light duty applications where the heat rejection requirement is relatively low.

Advantages of Air/Oil Type Cooler
1. Depending on cooler design, normally very effective in terms of heat dissipation ability for a given cooler size.
2. Relatively inexpensive.

Disadvantages of Air/Oil Type Cooler
In view of the relatively high effectiveness of this type of cooler, and since oil temperature is not related to coolant temperature in the manner applicable to the water/oil type coolers previously discussed, there is a danger of over cooling of the oil taking place under certain circumstances.

This applies particularly in the case of vehicle applications on short journey stop/start schedules, e.g., delivery vans, operating in low ambient temperature conditions.

Consistent operation at low oil temperature can lead to the formation of “cold sludge” and consequent engine damage.

Pipework, Engine to Oil Cooler — Waterside
In the case of water/oil coolers, waterside pipework must conform to the same standard as the rest of the cooling system. Long runs of pipe should be avoided, and the oil cooler and pipework must be suitably secured to prevent failure in service.

Pipework, Engine to Oil Cooler — Oilside
Pipework should be either metal, or if flexible pipes are used, these must be of oil resistant armored construction, and able to withstand working conditions with respect to temperature and pressure.

Only screw type pipe connections should be used, hose connections and clips are not approved for lubricating oil pipes.

Long pipe runs should not be used, and the pipes must be of adequate internal diameter to avoid excessive pressure drop. The pipes must be suitably secured to prevent chafing and damage in service.

Attachment of Accessories
Oil coolers should not be used as locations for attachment of accessories (e.g. oil filters) except as part of the design, as this can cause excessive bending loads on brackets, fixings, etc., especially under dynamic conditions on mobile applications.

Where oil filters are attached as part of the design, but it is required to fit larger filters, the advice of Caterpillar Application Engineering Department should be obtained.

CHARGE AIR COOLER — T6.3544
VEHICLE APPLICATIONS
All T6.3544 engines in vehicle applications must be fitted with a charge air cooler which meets Caterpillar requirements with regard to heat dissipation ability and pressure drop.
Heat dissipation and boost pressure requirements

The charge air cooler must be capable of maintaining the air temperature in the induction manifold, i.e., after the cooler, at a level not greater than that specified on the engine rating curve.

Similarly the boost pressure in the induction manifold at maximum power output must be not less than that specified on the engine rating curve. The total pressure drop across the charge cooler and connecting pipework must therefore be such as to enable this boost pressure requirement to be met (see SECTION 16, TECHNICAL DATA).

Design and construction

The Application Engineering Department, Peterborough, will supply the data required for charge air cooler design purposes.

It should be appreciated however that the design of charge air coolers is a specialized subject, and references should be made to a reputable manufacturer of heat transfer equipment.

The charge cooler should have the same core dimensions as those of the radiator and should be positioned close to and directly in front of it, the two cores being mounted together as a composite assembly.
In order to avoid excessive restriction to cooling air flow, charge cooler fin spacing should ideally not be closer than 3.5 mm pitch (7 fins/in).

**Charge cooler pipework**

Turbocharger to charge cooler pipework should be at least 65 mm (≈ 2.5 in) I/D, and capable of withstanding pressures and temperatures of at least 103 kN/m² (15 lbf/in²) and 160°C respectively.

It is recommended that steel tube should be used, with hose connections to absorb engine movement. Hose connections must be of a suitable material specification to withstand the operating conditions [see SPECIFICATION REQUIREMENT, PLAIN (UNREINFORCED) HOSES].

Charge cooler to induction manifold pipework should be at least 65 mm (≈ 2.5 in) I/D, and capable of withstanding pressures and temperatures of at least 103 kN/m² (15 lbf/in²) and 100°C respectively.

**COOLING SYSTEM PROTECTION**

**Corrosion Inhibition**

The use of corrosion inhibitors at all times is recommended for prevention of rust and metal attack, and of cavitation erosion of liners and water pump impellors. They also have a controlling effect on the pH (acid/alkali) condition of the coolant.

The table (based on information contained in BS 4959) illustrates corrosion inhibitor additives which are commonly used to protect multi-metal systems. They are preferably used combined in solutions of not less than three additive components, and the formulation should ensure that protection is given to all metals and alloys found in the cooling system.

From Caterpillar experience the following combination of constituents can be recommended:

- Sodium benzoate 10-15 grams/liter
- Sodium nitrite 1-2 grams/liter
- Benzotriazole 0.5 gram/liter

Together with a pH control additive.

For more information on use of proprietary additives, see USE OF PROPRIETARY ADDITIVES.

**Antifreeze Mixture**

The only solutions recommended by Caterpillar are those manufactured from ethylene glycol (ethanediol).

As a general guide, the physical and chemical properties should conform with the following:

- Specific gravity, 60/15.6°C (60°F) 1.110-1.145
- Pour point (undiluted) –18°C
- Boiling point (undiluted) 150°C
- pH (undiluted) 6-10
- Freezing point 50% in distilled water –37°C
- pH 50 vol. % in distilled water 7.0-8.5
- Reserve alkalinity 10

For information on use of proprietary additives, see USE OF PROPRIETARY ADDITIVES.

**Use of Proprietary Additives**

Based on experience, formulations which satisfy the performance and chemical requirements of the following national standards are acceptable to Caterpillar, provided that the pH level is maintained within the range 7.0 to 8.5.

- BS 3151: 1959
  “Ethanediol Antifreeze — Type B, Sodium Benzoate and Sodium Nitrite Inhibited.”
- ASTM D3306-74 (U.S.A.)
  “Ethylene Glycol Base Engine Coolant”.
- AS 2108-1977 (Australia)
  “Antifreeze Compounds and Corrosion Inhibitors for Engine Cooling Systems”.

Requests for further information and advice on this subject should be referred to Application Engineering Department, Peterborough.

In order to ensure the best possible results from additives, use of soft water is desirable (see COOLANT WATER QUALITY).

### COOLING SYSTEM ADDITIVES

<table>
<thead>
<tr>
<th>Additive</th>
<th>Cast Iron</th>
<th>Steel</th>
<th>Copper/Alloys</th>
<th>Solders</th>
<th>Aluminum/Alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzotriazole</td>
<td>NA</td>
<td>NA</td>
<td>P</td>
<td>NA</td>
<td>*</td>
</tr>
<tr>
<td>Sodium benzoate</td>
<td>NA</td>
<td>P</td>
<td>NA</td>
<td>P</td>
<td>NA</td>
</tr>
<tr>
<td>Sodium chromate</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Sodium nitrite</td>
<td>P</td>
<td>P</td>
<td>NA</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sodium phosphate</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>V</td>
</tr>
<tr>
<td>Sodium silicate</td>
<td>V</td>
<td>V</td>
<td>NA</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Sodium borate</td>
<td>V</td>
<td>V</td>
<td>P</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Triethanolammonium phosphate</td>
<td>V</td>
<td>P</td>
<td>C</td>
<td>*</td>
<td>P</td>
</tr>
</tbody>
</table>

Key to effects: P = protective  C = corrosive  V = variable  NA = no action  * = no data
Coolant Water Quality

The use of soft water is desirable in order to minimize scale formation and corrosive effects, and to ensure the best possible results from additives. The quality of water used should if possible meet the following requirements:

- pH (acid/alkali condition) 6.5-8.0 range
- Chloride concentration .01% max.
- Sulfate concentration .01% max.
- Dissolved solids (total) .04% max.
- Hardness (total) .03% max.

RADIATOR SHUTTERS

It is possible under extreme conditions, that the engine will not attain normal working temperature, particularly when operating on a light load cycle.

Under these conditions, it may be beneficial to fit a radiator shutter or louvers at the radiator front.

Only thermostatically controlled types should be used, actuated by a probe sensing coolant temperature in the cylinder head. The probe setting should be such that the shutters remain fully closed until the coolant temperature has reached the fully open temperature of the thermostat. Beyond that point the shutters should open progressively, until they achieve the fully-open position at a temperature of 5 – 8°C (10 – 15°F) above the coolant thermostat fully-open temperature. By this means, once the engine is warmed-up from cold, coolant temperature will normally be thermostatically controlled by operation of the radiator shutters alone.

Manually operated radiator blinds are not approved for the following reasons:

1. Operation depends on monitoring of coolant temperature by the operator, and this can lead to overheating and possible engine failure if the operator’s attention is distracted.

2. A partially open radiator blind results in fluctuating loading of the fan blades, and can lead to fan blade failure.
SECTION 8
Induction System

INTRODUCTION .................................................. 103

AIR FILTERS — CATERPILLAR APPROVAL ................. 103

AIR FILTER DUTY CLASSIFICATION .......................... 103
  Standard Duty .............................................. 103
  Heavy Duty .................................................. 103
  Dust Holding Capacity (Dry Type Filters) ................... 104
  Examples of Air Cleaner Types ........................... 104

AIR FILTER ACCESSORIES .................................... 106
  Stack Caps ............................................... 106
  Pre-Cleaners ............................................. 106
  Pre-Screeners ............................................ 106

AIR FILTER FEATURES ........................................ 106
  Safety Elements ........................................... 106
  Treated Elements ......................................... 106
  Vacuator Valves .......................................... 106
  Air Filters with Exhaust-Assisted Pre-Filter Evacuation .... 107

AIR FILTER FLOW RATING/INDUCTION SYSTEM RESTRICTION .... 107
  Introduction .............................................. 107
  Engine Induced Air Flow Requirement ...................... 107
  Maximum Induction System Restriction .................... 107
  Measurement of Induction System Restriction .......... 108
  Air Filter Restriction Indicator ........................ 109
  Restriction Indicator Setting ........................... 109
INTRODUCTION

It is not always appreciated that the induction system is one of the most important aspects of an engine installation, since it can have a direct effect on engine output, fuel consumption, exhaust emission and engine life.

With this in mind, the installed induction system must be designed to supply clean, dry and cool air to the engine, with a minimum of restriction.

The system must be designed to withstand the shock loadings and working conditions that will be met in service, and must provide reliable sealing and durability with a minimum of maintenance.

AIR FILTERS — CATERPILLAR APPROVAL

A very wide range of air filter makes and types is available worldwide. In order to ensure the necessary standard of filtration efficiency and durability, however, only air filters which have Caterpillar approval may be used.

A full list of approved air filters is held by Application Engineering, Peterborough, and a list of recommended suppliers is also included in SECTION 16, TECHNICAL DATA.

Oil Bath Filters

It is not always appreciated that successful operation of an oil bath air filter is dependent on careful matching to suit the engine type and operating speed range. Incorrect matching may result in a poor filtration efficiency, and/or oil “carry-over” from the filter into the engine.

This is particularly true for turbocharged engines, for which paper filter elements are always preferred, provided that elements of sufficient quality are available.

Oil bath filters are also subject to a limit on gradability, i.e. the maximum angle of inclination possible before oil carry-over will take place.

For these reasons, it is essential that only filters which have been approved for the engine type and operating speed range under consideration should be used.

Various oil bath filters manufactured by Burgess and Mann & Hummel are approved by Caterpillar for intermittent operation at angles of inclination up to 15°. Certain filter types may also be used at angles in excess of this, but reference should first be made to the Application Engineering Department, Peterborough.

AIR FILTER DUTY CLASSIFICATION

Caterpillar classifies air filters according to duty, which relates to dust-holding capacity. The choice of duty depends upon the engine type, the dust concentration in which it will operate, and the service life required.

The main duty categories are shown below, together with an indication of their usage. It should be appreciated, however, that these usage recommendations are given as a guide only, and that it may be necessary, due to the particular conditions of operation, etc., which may apply in certain cases, to specify a filter of a “heavier” duty classification than that indicated.

For details of technical specifications, and list of recommended air filter suppliers, see SECTION 16, TECHNICAL DATA.

Standard Duty

Normally fitted remotely from the engine and generally with an internal or external pre-cleaner.

For use on and off-highway in areas where there are no significant dust concentrations, e.g. on-highway trucks, gensets in buildings, F.L.T.’s in normal factory conditions.

Typical preferred air filters in this category are of the dry element type, with an integral centrifugal pre-cleaner stage.

For on-highway vehicles, or for operation in soot-laden atmospheres, a treated main element should be fitted.

For off-highway applications, the use of a safety element, together with an untreated main element, is strongly advised.

A restriction indicator, correctly positioned and of the correct setting should always be fitted with Standard Duty filters (see AIR FILTER RESTRICTION INDICATOR).

NOTE: Exceptionally, Light Duty pancake-type air filters can also be accepted, for passenger car and light van applications only, operating on metalled roads.

Heavy Duty

Normally, incorporate a highly efficient pre-cleaner arrangement, in some cases with automatic dust unloading.

For use in all dusty or dirty environments. An untreated main element is normal practice, but a treatment safety element should always be fitted.

A restriction indicator, correctly positioned and of the correct setting should always be fitted with Heavy Duty filters (see AIR FILTER RESTRICTION INDICATOR).

N.B. For operation in extremely arduous conditions, e.g. aluminum foundries, brickworks, etc., the advice of Caterpillar Application Engineering Department, should be obtained.
Dust Holding Capacity (Dry Type Filters)

Air filter duty classification is closely related to dust holding capacity, i.e., the amount of dust that can be retained by the filter before restriction reaches the point when servicing must be carried out (see MAXIMUM INDUCTION SYSTEM RESTRICTION). Specifications for the minimum dust holding capacity for the various filter duty categories are detailed in SECTION 16, TECHNICAL DATA.

An air filter selected according to the recommended duty classification will have a satisfactory dust-holding capacity provided that the filter air flow rating is adequate for the engine type and rating under consideration.

Examples of Air Cleaner Types

Representative air filter types are shown in the following diagrams:
HEAVY DUTY AIR FILTERS

ROTOPAMIC TYPE FILTER

TO ENGINE AIR INLET

AUTOMATIC EMPTYING OF PRE-FILTER STAGE BY CONNECTION TO EXHAUST SYSTEM.

EXHAUST GAS FLOW

DONALDSON DONACLONE

DUO-DRY TYPE FILTER

FILTER ELEMENT

PRE-FILTER STAGE
AIR FILTER ACCESSORIES

Stack Caps

These are fitted to the air filter inlet (or inlet extension, if fitted) to provide protection against the ingress of rain, snow, leaves, etc.

Pre-Cleaners

These are fitted to the air cleaner inlet or extension pipe, in applications where significant dust or other contamination is encountered, e.g. earth moving machinery and certain industrial and agricultural applications.

They extend the service life of the main filter, by removing a large part of the dust or other contaminant before passage through the filter.

Pre-cleaners which operate on a cyclonic principle should not be oversized relative to the rate of air flow for which they are intended, as this will reduce the air velocity, and hence also reduce the cyclonic dust-separating effect.

Pre-Screeners

In agricultural and other applications where contamination from chaff, lint or other coarse material is encountered, a pre-screener should be fitted to prevent choking of the air filter. A detachable screen is fitted, which is removed for cleaning as necessary.

Certain stack cap and pre-cleaner types are available from Caterpillar, and information on these is available from the Application Engineering, Peterborough. Alternatively these items, and pre-screens if required, may be obtained from the manufacturers of the approved air filter types shown in SECTION 16, TECHNICAL DATA.

AIR FILTER FEATURES

Safety Elements

Certain air filter types, e.g. Donaldson Cyclopac filters, are available with a safety element as an optional feature.

This consists of an additional element fitted inside the main element, the purpose being:

1. To protect the engine in the event of accidental perforation of the main element.

2. To safeguard the engine against dust ingress during removal and servicing of the main element, particularly where this must be carried out under adverse service conditions, the safety element being left in place during routine servicing.

The safety element will itself require servicing at less frequent intervals, and arrangements may then be made for this to be carried out under improved conditions.

Safety elements are recommended for use in all earth moving applications, and in agricultural and industrial applications where filter servicing must be carried out under adverse conditions.

Treated Elements

Certain dry filter types are available with specially treated elements, to minimize the effects of contamination by exhaust and other products, in order to increase service life.

These are recommended for use in certain “on-highway” automotive applications where a low level air intake position may result in exhaust contamination from other vehicles, and for all agricultural and earth moving applications.

Treated elements may also give a longer service life in some industrial applications operating in confined spaces.

Vacuator Valves

A vacuator valve is available as an optional feature on some dry cleaner types, to provide automatic emptying of dust and water from the filter, and so increase service life.
This is a rubber valve, actuated by the pulsating nature of the induced air flow.

NOTE: Vacuator valves are available from the filter manufacturers in different grades of rubber hardness, in order to allow matching to suit the engine type and operating speed range. In general, rubber hardness should be reduced as the number of engine cylinders is increased, in order to allow the valve to respond to the smoother nature of the induced air flow. Vacuator valves fitted to air filters included in SECTION 16, TECHNICAL DATA, will operate successfully with the engines for which they are recommended.

If air filters other than these are selected by the customer from the approved range, the filter manufacturer should be consulted in order to establish the most suitable rubber hardness.

Care should be taken in siting the air filter, in order to ensure that the dust/water ejected from the vacuator will not cause damage. Care must also be taken to ensure that there is no possibility of water, etc. being drawn into the filter due to the valve becoming immersed.

**Air Filters with Exhaust-Assisted Pre-Filter Evacuation**

Certain heavy duty air cleaners, e.g. Rotopamic type, have this feature.

An aspirator tube (see diagram of Rotopamic filter) is installed at the exhaust system outlet, the aspirator tube being designed to produce a drop in pressure due to a venturi effect, resulting in evacuation of the dust from the pre-filter stage.

Care is necessary however in order to ensure satisfactory installation and operation of this arrangement, and reference should be made to Caterpillar Application Engineering Department, for advice on the subject.

**AIR FILTER FLOW RATING/INDUCTION SYSTEM RESTRICTION**

**Introduction**

It is essential that the air filter should be of adequate capacity to suit the induced air flow requirement of the engine type and rating under consideration. For all engine types, published engine rating conditions apply at a maximum depression, measured at the inlet manifold or turbocharger inlet, of 305 mm (12 in) W.G.

In order to meet this requirement, and to make allowance for restriction incurred in the induction system pipework in the case of remote-mounted air filters, the restriction incurred across the air filter with a clean element, or when freshly serviced in the case of an oil bath filter, should not exceed 203 mm (8 in) W.G. at maximum engine rating.

In the case of specific air filter types detailed in SECTION 16, TECHNICAL DATA for the various engine types and ratings, this requirement has been taken into account. However when selection of an air filter is made from the general list of approved proprietary filter types included in Section 16, reference must be made when deciding the appropriate filter size to the manufacturer’s filter restriction curves, in conjunction with the applicable engine-induced air flow requirement.

**Engine Induced Air Flow Requirement**

Induced air flow requirements for the various engine types are included in SECTION 16, TECHNICAL DATA.

To these values must be added any additional air flow requirement for a compressor, etc., if this is connected to the induction system.

**Maximum Induction System Restriction**

Induction system restriction, measured at the induction manifold or turbocharger inlet, is the total restriction due to:

- air filter restriction
- resistance to air flow due to pipe friction
- air velocity effects.

Air velocity effects are usually relatively low for naturally aspirated engines, but can be substantial in the case of turbocharged engines.
A higher total inlet restriction is therefore allowed for turbocharged engines, but this does not affect the restriction allowable across the air filter alone.

The maximum permissible total restriction, at which air filter servicing must be carried out, differs between engine types and is shown in SECTION 16, TECHNICAL DATA.

Measurement of Induction System Restriction

Measurements should be made by means of wall-static pressure tappings (ref. BS 1042: Part 2A: 1973, paragraph 4.2). Depression measurements made by means of a piezometer ring or a single point tapping, as used by Caterpillar appraisal engineers, meet these requirements.

A manometer, if used, should be capable of reading up to 750 mm (30 in) water. In order to eliminate possible errors in measurement introduced by the length/volume of the manometer tubing, a “damping” volume should be included in the run of manometer tubing, as illustrated above.

A tapping should be made into the induction system as shown in the diagram, i.e. in a straight pipe section as close as possible to the induction manifold or turbocharger inlet.

Where measurement on a bend is unavoidable, the tapping should be perpendicular to the plane of the bend, as illustrated below.

NOTE: For a given system restriction, the restriction reading is dependent on the cross-sectional area of the pipe section in which the measurement is made. In order to register the restriction as “seen” by the engine, the pipe section into which the manometer tapping is made must therefore have the same internal diameter/cross-sectional area as that of the induction manifold or turbocharger inlet.

This is particularly important for turbocharged engines, due to the high air velocities involved. For the purpose of a preliminary check, or where it is not possible to measure adjacent to the turbocharger air intake, approximate valves of inlet depression can be determined as follows:

(a) Use of straight parallel pipe

The tapping point should be positioned in a straight parallel pipe, as illustrated below.

The main features of this arrangement are:

1. The bore of the pipe should be the same as the internal diameter of the turbocharger air intake. For simplicity of connection, the pipe should preferably also be of the same outside diameter as that of the air intake.

2. There should be a smooth transition between the induction trunking and the pipe. Sudden changes of section should be avoided.

3. Inlet depression should be measured in the pipe at a point P, positioned:

   — not less than 0.5D nor more than 4D from the intake.
   — not less than 1D from the commencement of change of pipe section (where D = internal diameter of intake).

(b) General case

In situations where a straight parallel pipe is not available, a tapping may be used in the induction pipework as shown.
The following points should be noted:

1. Depression measurement should be made at a point P positioned not less than 0.5D nor more than 4D from the intake (where D = internal diameter of intake).

2. The measurement point should preferably be situated in a straight section of pipe. Where measurement on a bend is unavoidable, the tapping should be perpendicular to the plane of the bend, as previously illustrated.

3. Where the induction pipe diameter at the measurement point is larger than the turbocharger air intake diameter, the allowable inlet depression will be less than that allowed directly at the air intake to compensate for the lower air velocity. Approximate maximum inlet depression levels allowable under these circumstances are detailed in SECTION 16, TECHNICAL DATA.

Restriction should be measured at maximum governed speed in the case of naturally aspirated engines, or, in the case of turbocharged engines, at full engine output at maximum rated speed.

Air filters incorporating a restriction indicator tapping should incorporate a small filter built into the indicator connection, as a precaution against dust ingress in the event of a failure in the indicator or indicator pipework.

When the indicator is connected to a tapping in the induction system pipework, suitable adapters incorporating a safety filter are available from the filter manufacturers.

Air Filter Restriction Indicator

For dry type filters only, it is strongly recommended that a restriction indicator should be fitted. This enables maximum service life to be obtained from the filter element without exceeding the engine restriction limit, and prevents premature renewal of the element.

Details of suitable restriction indicators for the various engine types are included in SECTION 16, TECHNICAL DATA. Alternative indicator types are also available from the air filter manufacturers.

The type of indicator detailed in Section 16 is shown in the illustration below, and consists of a resettable plunger which indicates when restriction has reached the applicable value.
AIR FILTER SERVICING
Air filter servicing should be carried out at the intervals recommended in the engine handbook, or more frequently if operating conditions are particularly adverse.

In the case of dry air filter installations equipped with a restriction indicator, servicing is only necessary when the indicator signals the requirement.

Extreme care should be exercised in all cases to ensure that dust ingress into the induction system does not take place during filter servicing, and all joints and seals should be inspected and renewed if necessary.

Oil bath filters should be cleaned and refilled to the correct level, with the grade of oil indicated in the engine handbook.

It is important that the specified oil level is not exceeded, or oil “carry-over” and possibly dirt ingress into the engine may take place.

Dry Air Filters
Instructions for servicing certain dry air filter types are included in the engine handbooks, and these should be strictly adhered to. In other cases, the filter manufacturer’s servicing instructions should be carefully followed.

INDUCTION SYSTEM LAYOUT
Air Inlet Location
The position of the air filter inlet, or of the inlet to the air filter extension if fitted, should be such that air is drawn from an area:

(a) Of the lowest possible dust concentration.
(b) Well clear of water splash in the case of mobile applications.
(c) At a temperature as close as possible to the prevailing ambient temperature.

Additionally, care should be taken to minimize the possibility of exhaust fumes being drawn into the induction system, since this will result in a reduction in element life in the case of a dry type filter.

Where some exhaust contamination cannot be avoided, extended element life will be obtained by using specially treated elements (see TREATED ELEMENTS).

Induction system layout varies considerably according to the application type and duty, but typically arrangements are shown in the following diagrams.

Automotive Applications
In general, in the case of engine mounted air filters, an extension tube should be fitted to the air filter inlet, as shown, in order to allow air to be drawn from outside the engine compartment. This is because underbonnet air temperature is commonly of the order of 30°C above ambient temperature, and induction of air at this temperature is likely to result in a loss in engine output and/or deterioration in exhaust emission.

For “on-highway” applications operating in dry and dusty territories, and also depending on the duty, for a number of off-highway applications, the high level intake arrangement shown is recommended.

Industrial Applications
In general, in enclosed applications, air should be drawn from outside the engine enclosure, in order to avoid excessive intake temperatures. Exceptions to this are certain applications using pusher-type cooling fans, where, depending on enclosure ventilation arrangements, air temperature in the enclosure may be relatively low close to the ventilation inlets. Care should however be taken to avoid local high temperature areas close to the exhaust system.

Agricultural Applications
A typical tractor induction system arrangement is shown in the preceding diagram. Various arrangements are used however, and where chaff or similar contaminants are likely to be encountered, a pre-screener should be fitted (see PRE-SCREENERS) to prevent ingress into the main filter.

Air Filter Accessibility for Maintenance
The filter must be readily accessible for maintenance, with adequate space provision for removal of the filter oil bowl, or replacement of the element, in the case of dry-type filters.

INDUCTION SYSTEM PIPEWORK
Introduction
Careful attention must be given to the pipework and associated fittings used in the induction system, in order to minimize restriction, and in order to ensure that reliable sealing will be maintained under the operating conditions which will be met in service.

In order to minimize the restriction incurred in the system, pipework length should be as short as possible, and the number of bends in the system should be kept to a minimum.

The cross-sectional area of all pipework must not be less than that of the induction manifold inlet, and in the case of Vee engines using a single air filter and branch pipe arrangement delivering air to both induction manifolds, the cross-sectional area of the branch system must not be less than twice that of a single manifold inlet.

Rigid Tubing
This may be either steel, aluminum, or in some cases molded plastic, but in all cases the internal bore must be smooth and free from defects.

When used in conjunction with hose connections, the ends of the tubing must be truly circular, and have a smooth finish for a minimum length of 50 mm (2 in) at each connection. The wall thickness of the tubing must be adequate to resist deformation under the pressure of the hose clamps.

In order to improve sealing, and security against the hose pulling off, all tubing should preferably incorporate end beading.
**Hosework**

Plain, i.e. unreinforced, hose sections must only be used to connect together items of rigid pipework etc., which are in line and close together, and where there is little relative movement. When a connection must be made between items which are not in line, and where it is not possible to use a molded bend or similar item, or when there is significant relative movement, a short section of reinforced flexible induction hose may be used. It is essential that this type of hose is of adequate quality and durability, and that it conforms to Caterpillar requirements (see FLEXIBLE HOSES/TRUNKING).
Specification Requirement, Plain (Unreinforced) Hoses

Hoses used in the induction system must be of adequate specification to withstand service conditions. The basic requirements are as follows:

1. Naturally aspirated engines
   Hose Material:
   Synthetic Rubber.
   Oil Resistance:
   Resistance to fuel oil and lubricating oil on external surface.
   Maximum Working Temperature:
   105°C
   Working Pressure:
   Up to 1300 mm (≈ 50 in) W.G. depression (negative pressure).

2. Turbocharged engines without charge cooler
   Hose Material:
   Synthetic Rubber.
   Oil Resistance:
   Resistant to fuel oil and lubricating oil on both internal and external surfaces.
   Maximum Working Temperature:
   120°C
   Working Pressure:
   As for Naturally Aspirated specification.
   NOTE: These requirements apply to pipework on the inlet side of the turbocharger only. Only the appropriate connection, supplied as part of the engine build, may be used for the connection from the turbocharger to the induction manifold.

3. Turbocharged engines with charge air cooler inlet side of turbocharger and outlet from charge cooler to induction manifold.
   Hose Material:
   Synthetic Rubber.
   Oil Resistance:
   Resistant to fuel oil and lubricating oil on internal and external surfaces.
Maximum Working Temperature: 105°C

Working Pressure:
- Inlet side of turbocharger: up to 1300 mm (≈ 50 in) W.G. depression (negative PRESSURE).
- Outlet from Charge Cooler to Induction Manifold: 103 KN/m² (15 lbf/in²).

**Turbocharger to charge air cooler**

Hose Material: Silicone Rubber.

Oil Resistance: Resistant to fuel oil and lubricating oil on both internal and external surfaces.

Maximum Working Temperature: 106°C

Working Pressure: 103 KN/m² (15 lbf/in²).

**Flexible Hoses/Trunking**

The use of plain bore hoses with internal coil spring insertions to provide flexibility is not approved, as experience has shown that service problems are likely due to the spring insert moving out of position, with the consequent possibility of local distortion and closure of the pipe.

This type of hose reinforcement also imposes a relatively high restriction to air flow.

Wire reinforced convoluted flexible hose/trunking may be used in the induction system, but it is essential to appreciate that:

1) This type of hose imposes a relatively high restriction to air flow, and the length of hose run should therefore be as short and straight as possible.

2) The hose must be of adequate specification and durability to withstand service conditions. A variety of hose materials is available which will give satisfactory service, but the use of hoses of light canvas construction, as often found in ventilation systems, etc., is not approved, since these do not have adequate durability.

This type of hose is easily damaged by chafing against sharp edges etc., and must be adequately supported to prevent this.

Support clips and brackets must have rubber or soft plastic gripping surfaces, and all bulkhead/canopy apertures through which the hose passes must also be fitted with suitable protective grommets or sleeves.

All hose runs must be pre-formed lengths, incorporating plain end sections (Cuffs) of suitable compressibility length and surface finish, to enable effective and reliable sealing to be achieved. Sections of hose with the wire reinforcement removed at the ends to form a “plain” section are not acceptable.

**Cuff construction** — Cuffs must be seam-free and of a smooth texture on the inner surface. A neoprene-based material of 55° to 75° Shore hardness has been found to give adequate compressibility to effect a seal providing that a wall thickness of approximately (nominal diameter \( \times 1/20 \)) is maintained.

The cuff should preferably be bonded on to the trunking or, if not, be a tight fit with added adhesive, so as to achieve a leak-free connection. The cuff design should be such that it extends to cover the outside of the trunking as well as the inner surface so as to produce a smooth clipping surface at least equal in length to the connection spigot.

It may be necessary to terminate the wire reinforcement just within the cuff area in order to create sufficient flexibility to ensure a leak-free connection.

**Hose Clips/Clamps**

For hose connections used in conjunction with tubing/spigots of up to 80 mm (3.215 in) diameter, hose clips of the worm drive type are satisfactory. Spring type clips without a means of tightening are not approved, since they do not ensure the necessary standard of sealing.

For tubing/spigots exceeding 80 mm (3.215 in) diameter, band clamps as shown must be used, in order that sufficient clamping force may be exerted to ensure satisfactory sealing. The band must have a minimum width of 18 mm (0.7 in).

If there is significant relative movement between the two ends of the hose, due to engine movement on flexible mountings, etc., two hose clips/band clamps should be used at each point.

**Accessibility for Maintenance**

It must be ensured that all induction system pipework and hose connections are readily accessible for periodic inspection and maintenance.

**CHARGE AIR COOLER — T6.3544 VEHICLE APPLICATIONS**

All T6.3544 engines in vehicle applications must be fitted with a charge air cooler which meets Caterpillar requirements with regard to heat dissipation ability and pressure drop.

For further information, see SECTION 7, COOLING SYSTEM.
**BRAKING COMPRESSOR AIR SUPPLY**

Problems can arise if the compressor air supply is taken from a point in the induction pipe close to the turbocharger, due to the high level of depression involved. It is therefore recommended that, if compressors are supplied from the trunking between the air filter and the turbocharger, connections should be made into the largest diameter portion where the depression is minimal.

**INDUCTION SYSTEM NOISE EMISSION**

The induction system can make a significant contribution to overall noise level in some application types.

Certain air filter types are quite effective as induction silencers in addition to their primary filtration function, and an absorption type induction silencer may also be advantageous in suppressing high frequency noise, particularly in the case of turbocharged engines.

For further information, reference should be made to SECTION 13, NOISE CONTROL.
GENERAL CONSIDERATIONS

The exhaust system must be designed to keep the resistance to gas flow (back pressure) of the exhaust system as low as possible and within the limits specified for a particular engine type (see BACK PRESSURE).

The system should also be designed for minimum noise emission, while also being as economical as possible.

Adequate clearance must be provided for the complete exhaust system, to ensure that it does not foul with other components when operating, and especially when starting and stopping. The exhaust must not pass too close to the fuel injection pump, filters, fuel pipe, fuel tank, etc. (See EXHAUST SYSTEM CONFIGURATION.)

BACK PRESSURE

Exhaust Back Pressure

The exhaust system will produce a certain resistance to flow for the exhaust gases. This resistance or back pressure must be kept within specified limits to ensure engines do not invalidate legislation applying in certain countries, for example BS AU 141a: 1971, in U.K.

Maximum permissible back pressure for Caterpillar engines is specified in SECTION 16, TECHNICAL DATA.

Excessive back pressure is usually caused by one or more of the following factors:

— Exhaust pipe diameter too small.
— Excessive number of sharp bends in system.
— Exhaust pipe too long between manifold and silencer.
— Silencer resistance too high.

Effects of Back Pressure

Too high a back pressure leads to:

(a) Loss of power: approx. 1% decrease for each 50 mm (2 in) of mercury above maximum level

(b) Poor fuel economy: fuel consumption increases by approx. 1% for each 50 mm (2 in) of mercury above maximum level.

(c) High combustion temperature: 5% increase in exhaust gas temperature for each 50 mm (2 in) mercury above maximum level.

These conditions produce over-heating and excessive smoke from the installation, and reduce the lives of the valve heads and valve seats.

Measurement of Exhaust Back Pressure

A mercury manometer to read up to 250 mm (10 in) Hg should be used to record the exhaust back pressure. A length of metal tube, Bundy or Similar, 150-220 mm (6-9 in) long is brazed to the exhaust pipe within a distance of three to six times the pipe diameter, downstream from the exhaust manifold outlet flange, at a section free from bends. The metal tube must be flush to the inside of the exhaust pipe.

The back pressure must be recorded after the engine has reached its operating temperature, and at the stage where the engine is developing its maximum power at the rated speed.

EXHAUST NOISE

Nature of Exhaust Noise

On many types of application, the exhaust is one of the principal noise sources.

The noise arises from the intermittent release of high pressure exhaust gas from the engine cylinders, causing strong gas pressure pulsations in the exhaust pipe. These lead not only to discharge noise at the outlet, but also to noise radiation from exhaust pipe and silencer shell surface. The purpose of the exhaust system is to reduce these gas pulsations, and, with the aid of a properly matched silencer, not only can efficient exhaust noise attenuation be achieved, but also sometimes a decrease in the power loss caused by the exhaust system.

Exhaust Silencing Requirements

For exhaust noise not to be significant, its contribution should be at least 10 dB’A’ lower than the target overall noise level of the complete machine or vehicle.
Selection of the most suitable silencing arrangement for a particular application is, to a certain extent, a matter of experience, taking into account the relevant operating factors which include:

- Degree of noise attenuation required
- Exhaust noise frequency characteristics
- Permissible back pressure
- Configuration required
- Space available
- Cost

Silencer manufacturers generally are best qualified to advise on the most suitable designs to meet particular requirements, but the following notes are offered as initial guidelines. (Names of recommended silencer manufacturers can be supplied by Caterpillar on request.)

**SILENCERS**

**Exhaust Silencer Types**

The most commonly used types are:

a) Absorption type — usually of “Straight-through” construction, consisting of a perforated tube passing through a chamber packed with an absorption material such as fiberglass. This type usually has a fairly low back pressure, and is mainly effective in suppressing high frequency noise. It is therefore particularly suitable for turbocharged engines, where the low frequency pulsations are suppressed by the turbocharger.

![“STRAIGHT-THROUGH” ABSORPTION TYPE SILENCER](image)

b) Baffle type — in which the exhaust gas flow is subjected to several reversals of direction within the silencer before being discharged. This type is effective over a wide frequency range, but tends to have a higher back pressure than the absorptive type.

In some circumstances, a combination of both silencer types may be necessary.

![THREE-PASS BAFFLE TYPE SILENCER](image)

c) Expansion chamber — these are used early in the system to dissipate energy quickly, or used as a resonator towards the back of the system to reduce noise of a specific frequency.

![SIMPLE EXPANSION CHAMBER](image)

![DOUBLE EXPANSION CHAMBER](image)

**Silencer Dimensions**

The two principal guidelines are:

- **Volume** — for effective silencing, this should be of the order of 3 to 5 times engine cubic capacity, for both naturally aspirated and turbocharged engine installations.

- **Cross-sectional area** — this should be large, e.g. a silencer of 180 mm (7 in) diameter by 300 mm (12 in) length is preferable to one of 100 mm (4 in) by 900 mm (36 in) length, although both have volumes of approximately 7.5 liters (460 cubic inches). Ideally, the ratio of silencer body diameter to inlet pipe diameter should be of the order of 4 or 5 to 1.

The most elementary silencer in accordance with the above guidelines on dimensions should give 10-15 dB’A’ attenuation of open exhaust noise, while more sophisticated designs (e.g. of more complex internal construction, or having double-skinned or wrapped casings) may give up to 25-35 dB’A’ reduction.

The guidelines on silencer volume and cross-sectional area apply equally to cylindrical and oval section units although, from manufacturing and reliability considerations, the cylindrical form is preferable.

**EXHAUST SYSTEM CONFIGURATION**

**Silencer Position (see diagram)**

There is some divergence of opinion amongst exhaust system specialists as to the ideal position. However, experience has shown that the silencer, or at least an expansion chamber, should be within approximately 1.5 m (4 ft) of the exhaust manifold.
Silencers should not be mounted in the engine compartment, due to the resulting higher under bonnet temperatures and the subsequent loss of cooling performance, particularly if a pusher fan is used.

For recommendations on long exhaust systems, see LONG EXHAUST SYSTEMS.

**Pipework (see diagram)**

**Tail pipe length** is best determined by “tuning”. Where the silencer is very close to the manifold, e.g. within 500 mm (20 in) as on many agricultural tractors and earth moving machines, the tail pipe should be at least equal to this length. However, long tail pipes may create obtrusive exhaust notes under some conditions, necessitating the fitting of an additional volume of “resonator” near the end of the system, tuned to suppress noise at particular frequencies. (Note — when tuning an exhaust system, noise and back pressure must both be considered.)

**Twin down pipes** — where these are used, as on V8 engines, should go straight into the silencer, or join in an expansion chamber/junction box, rather than having the exhaust pipes siamesed together and then going on to a silencer. Twin exhaust systems all the way through often produce more noise than twin down pipes to a junction box.

**Outlet position** — taking into account the noise regulations or requirements to be net (i.e. bystander, operator, etc.), some advantage may be gained by directing the outlet away from microphones or observers. It is most important to select the direction of the tail pipe exit so that the exhaust smoke:

(a) is not drawn back through the radiator by a puller fan installation. This is likely on combines, where exhaust exit and radiator entry are usually both on top of the machine.

(b) is not drawn into any dry element air cleaner, subsequently rapidly clogging the element and reducing service life.

(c) is directed away from the sight lines of the machine operator.

**Exhaust System Construction**

Silencers and exhaust pipes are commonly of 16 gauge steel (1.5 mm thickness). Where larger degrees of noise attenuation are required, radiated noise from body shells and pipes may be reduced by means of silencers having wrapped or sandwich-type constructions, and by use of double-skinned exhaust pipes, obtainable from some manufacturers.

**Exhaust System Installations**

The exhaust pipe run should avoid touching or passing close to the air cleaner, fuel and lubricating oil filters, fuel tank or piping, injection or fuel lift pumps, radiator or sump, and also dynamo, alternator, starter motor and wiring. If this is unavoidable, a suitable heat shield should be used. Batteries, instrument capillaries and rubber parts should not be sited in the vicinity of the exhaust manifold or piping.

Adequate clearance must be provided for the exhaust assembly to ensure that the system does not foul during operation, and especially when starting and stopping the engine.

Many agricultural and construction applications require vertical outlet systems, but care must be taken to ensure that the tail pipe is high enough so that the outlet position does not increase the noise level at the operator’s position. (See also PIPEWORK.)

---

**OPTIMUM DIMENSIONS FOR EXHAUST SYSTEMS**
Mountings

(a) **Horizontal**

The exhaust down pipe must be securely clamped at the flywheel housing or gearbox, to avoid any stress being imposed on the exhaust manifold or flange.

Where the engine is flexibly mounted, the exhaust system should be isolated from the body-work by means of flexible mounts, e.g. shear rubber, to ensure that there is flexibility in the system, and that noise and vibration excitation is not transmitted to body panels. The attachment points should be structurally stiff.

(b) **Vertical**

Silencers can be mounted vertically directly onto the exhaust manifold on the smaller engines, but a vibration check is essential to ensure that the manifold flanges will not fatigue or exhaust manifold cracking occur.

When large silencers are fitted vertically, some additional support brackets will be required independent of the engine (e.g. on the hood) to avoid over stressing the exhaust manifold. This is also very important on all turbocharged engines, to ensure that the turbocharger flange is free from stress.

On machines where “sight lines” are important, an oval design of silencer is usually used and orientated to present the least restriction to visibility.

Connections

Pipe joints and connections should obviously be free from leaks, and must be maintained in good condition.

On machines such as earth moving equipment where the exhaust silencer is fitted outside the engine compartment, some manufacturers use a two piece system to give easier access to the engine compartment for service maintenance.

These two piece type systems sometimes have a joint on the underside of the engine hood, and unless a complete seal is obtained at this point, engine overheating problems can occur due to exhaust gases being pushed into the radiator core by the air flow over the engine. This flow of gases into the radiator core causes a carbon build-up on the radiator tubes and fins, thus restricting the air flow which reduces heat dissipation.

Drainage

The exhaust pipe can accumulate a considerable amount of condensed moisture, especially when the pipe is long. To avoid internal corrosion, a condensate trap and drain can be provided at the lowest point in the system.

With vertical exhaust systems, to prevent entry of rain and snow, it is recommended either that a flap is fitted to the end of the exhaust tail pipe (although this is not always acceptable due to “clatter” at low engine speeds), or alternatively that the tail pipe end is turned through 90° to give a horizontal outlet.

A small drain hole can be incorporated in the lowest part of the exhaust system if the manifold is a downward exit and a curved pipe is required to redirect the exhaust vertically upwards. A drain hole should not be used on applications with a pusher fan however, due to possible contamination of the radiator core from the slight exhaust leak.

Some instances have been found where the life of vertically mounted silencers is greatly reduced because the silencer can trap a pool of water externally.

For this reason types “a” and “b” should be recommended but type “c” avoided because of potential corrosion at the top.
Long Exhaust Systems

The following recommendations are applicable to installations where the exhaust gas must be discharged at some considerable distance from the engine. A standby generator in the basement of a building, with the exhaust outlet on the roof, is a typical example of this arrangement.

In these systems the back pressure is significantly influenced by pipe diameter and the number of bends in the pipe. The accompanying chart relates pipe diameter to engine power, pipe length and number of 90° bends. Certain assumptions have been made relating to exhaust temperature, heat losses from the pipe, resistance through the silencer, and general internal smoothness of the pipe.

Maximum allowable back pressures for the Caterpillar engine range are as quoted in SECTION 16, TECHNICAL DATA. The chart assumes no heat loss from the pipe, but for uninsulated pipes there will be some reduction in actual back pressure due to the cooling of the gas as it passes down the pipe.

Wherever possible, the silencer should be positioned as recommended in SILENCER POSITION, but this may not always be possible, e.g. in a building basement.

If the silencer is placed at the end of the exhaust system (e.g. on the roof of a building), the resistance through it will be reduced due to the lower gas temperature, but the noise from the engine end will be increased.

Conversely, if the silencer is positioned close to the engine the back pressure will be increased due to the high flow of hot gas, but the noise will be reduced.

Consideration must be given to the noise transmitted to the structure of the building. One solution is an expansion chamber near the engine, and a secondary silencer at the end of the pipe.

The chart assumes the silencer to be close to the engine and generally relates to the worst conditions for any power or pipe length.

EXHAUST CONDITIONING

Spark Arresters

Spark arresters enable diesel engines to operate in areas of fire hazard, by reducing the discharge of hot carbon particles through the exhaust pipe.
**Principle of operation of Spark Arrester**

The stainless steel spiral causes the exhaust gases to rotate, throwing the hot carbon particles against the outer casing and cooling them before discharge (see diagram). This type of spark arrester is suitable for fork lift trucks, towing tractors, etc.

When inflammable gases are present in the atmosphere such as in coal mines, special spark arresters or flame traps must be fitted to both induction and exhaust systems to prevent explosion from engine induced sparks.

Information on the approved types for these applications can be obtained from Caterpillar. These types of arrester are liable to rapid choking due to the environment in which they work, so it must be ensured that they are regularly cleaned to prevent the induction and exhaust restriction limits being exceeded.

**Exhaust Scrubbers**

Diesel engined vehicles used underground or in a confined space usually require the exhaust gases to be treated to render them cool and harmless. By passing the exhaust through a special container filled with water, the gas is cooled, and the soluble constituents and some odor will be removed.

However, passing the exhaust gas through water will have little effect on the following gases:

- Carbon monoxide \( \text{CO} \)
- Carbon dioxide \( \text{CO}_2 \)
- Nitric oxide \( \text{NO} \)
- Nitrogen dioxide \( \text{NO}_2 \)

The gases leaving the scrubber therefore are still toxic and the operator must be made aware of the dangers of operating the engine in a confined space. Certain operating conditions may be hazardous to health, and contravene local legislation, e.g. Health and Safety at Work Act, in the United Kingdom.

**Exhaust Diluters**

These are designed to mix large quantities of ambient air with the exhaust gas before releasing it to atmosphere.

This cools and dilutes the exhaust gas constituents to levels that can be acceptable to the driver and personnel in the vicinity of the vehicle.

The fine clearance of the nozzle gap may particularly affect back pressure in service, and periodic checks should be made to ensure that back pressure is still within the recommended limits.

Spark arresters, exhaust scrubbers and diluters must all be fitted in accordance with the manufacturers' recommendations and Caterpillar approval should be obtained.

**Exhaust Catalysts (Purifiers)**

Exhaust gas catalysts function by the catalytic oxidation of the carbon monoxide and hydrocarbons in the exhaust gas, as well as aldehydes and ketones.

The purifier element is usually a platinum plated matrix enclosed in a stainless steel cylindrical case which is fitted into the exhaust pipe before any exhaust silencer. As they are normally more efficient at high exhaust temperatures, exhaust catalysts should be fitted as close as possible to the exhaust manifold outlet flange. At exhaust gas temperatures of below 250°C, exhaust catalysts are ineffective, so are not recommended on applications with a duty cycle involving light loads and long idle periods.

Exhaust catalysts can give rise to high exhaust back pressures resulting in unacceptable power loss. A tapping can however be brazed into the inlet side of the purifier to enable up-stream pressure to be monitored, and to indicate when the purifier needs cleaning due to carbon deposits on the catalyst.

**EXHAUST BRAKES**

The simple exhaust brake provides the cheapest form of additional braking on a road vehicle. It is simply a butterfly valve or gate valve situated in the exhaust down pipe between the manifold and silencer.

When the valve is closed, the engine becomes in effect a compressor driven by the road wheels, through the transmission. The pressure built up in the exhaust system retards the engine through the transmission to slow the vehicle, but is not intended to bring it to a halt.

To increase efficiency of the brake, engine speed should be increased by engaging a lower gear.
Control Systems (see diagram)

Main control systems are either pneumatic or by actuation with electric solenoids. A pneumatic system working from the vehicle compressed air supply is generally preferred as being simpler, cheaper and more reliable, operated from a hand or foot control valve.

Alternatively, operation may be electrical from a solenoid with hand control or a micro-switch on the brake pedal.

The system must include means for cutting off the fuel supply (stop control) at the fuel pump during the time the brake is in operation, and the whole system should be used as the engine “stop” control.

On some (Bosch) fuel pumps the stop control lever must be fully returned to the ON position when the brake is OFF, otherwise full fuelling may not be available.

This ensures that the valve is operated frequently and prevents any tendency for carboning up.

EXHAUST BRAKE CIRCUIT

Location of the Brake Valve

Exhaust brake valves have been located in almost all positions from the manifold to the end of the tail pipe up to 6 m (18 ft) away, and test results indicate that the position of the valve makes no difference to performance. Remote located valves are cooler and therefore are kinder to the operating mechanism, but are more prone to “gumming up”. Experience indicates that having the valve close-coupled to, or even built into, the manifold is preferred. With turbocharged engines, the brake valve is located between the manifold and the blower, although this location requires a special valve to accommodate double-entry blowers.

If located down-stream of the blower, the turbine oil seals must be capable of withstanding a pressure of at least 410 kN/m² (60 lbf/in²).

Design Features

The exhaust brake valve must be provided with a relief hole to avoid excessive back pressure. The size of this hole is a compromise between exhaust valve lift or float, and adequate manifold pressure for effective braking. This pressure has proved to be 380 kN/m² (55 lbf/in²) for both naturally aspirated and turbocharged engines.

If this pressure is exceeded, exhaust valve float may cause severe air surging in the induction manifold and air cleaners. This can cause dust migration in paper air cleaners, and ejection of oil from wet type cleaners, particularly if these are mounted directly onto the induction manifold. Noise may also be a problem in certain types of application.

Adequate exhaust manifold to cylinder head face joints must be made to prevent gas leaks when the brake is operated.

Caterpillar should be advised when a customer intends to incorporate an exhaust brake, and all details should be submitted for approval.

EXHAUST LEGISLATION

Many countries have had some measure of smoke legislation in the past, but now there is a new emphasis on vehicle exhaust emissions in the context of environmental control, particularly in Western Europe, U.S.A. and Australia.

For engines to continue to meet the smoke legislation for which they are certified, they must be maintained and serviced by an accredited dealer to Caterpillar recommendations. Faulty maintenance of fuel injection equipment including fuel filters and injection nozzles, together with deterioration of air cleaner performance or incorrect fuel specification, will increase the smoke and emissions levels from the engine.

The type of exhaust system with which the vehicle is certified must not be changed unless prior approval is obtained from the relevant Authorities, e.g. Department of the Environment in the U.K.

The exhaust system must be maintained in good condition, as any leakage could contravene legislation on noise, emissions and the health and safety of the operator.
FUEL SYSTEM
The precise nature of the fuel injection components of diesel engines requires the fuel delivered to them to be clean, free from air and water, and at the correct pressure.

All fuel injection system components must be accessible in the installation for servicing. Choice of tank, filters and other items in the system must be suitable for the duty envisaged and as described in the relevant paragraphs in this section.

Any variation in fuel temperature, specific gravity or viscosity will affect the power and smoke levels, and it is important to arrange the fuel system to minimize these variations.

FUEL TANKS
Bulk Fuel Storage
When planning bulk storage of fuel oil, either above or below ground level, the Local Authority must be consulted concerning applicable by-laws and regulations.

In the installation of tanks with a capacity of 13,500 liters (3000 gallons) and over, the tank should be mounted with a fall of at least 20 mm per meter (¼ inch per foot) towards the sludge valve. In the case of smaller tanks, this fall should be increased to a maximum of 40 mm per meter (½ inch per foot).

A filter should always be fitted in the draw-off pipe. Where a pump is installed, a spring-loaded check valve must be fitted between the filter and the pump, in order to hold back the head of fuel in the tank. Metering pumps and flowmeters should always be mounted on a concrete base.

Draining the sedimented sludge and water from the bulk storage tank before a fuel delivery, and allowing a settling period after delivery, will tend to reduce contamination of the vehicle or machine tank.

Installations subject to low temperatures should comply with the recommended actions outlined in British Standard BS 6380: 1983.

Manufacture
The fuel tank, whether for bulk storage or in the mobile or stationary application, should preferably be manufactured from ferrous metal or suitable reinforced polyester.

Internally, it should be clean and free from all impurities likely to contaminate the fuel. The fuel tank must not be galvanized internally under any circumstances.

Externally it can be galvanized or painted to prevent rusting.

Capacity
It is important that the capacity of the fuel tank is carefully chosen to suit the specific engine installation. To assist in making this decision, a rough guide to the quantity of fuel required by the engine is given below:

Capacity of tank (liters)  
\[ \text{capacity} = \text{liters/h} \times \text{number of hours required} \]
\[ = 0.381 \times \text{gross engine power (kW)} \times \text{number of hours} \]

Capacity of tank (UK gallons)  
\[ \text{capacity} = \text{gallons/h} \times \text{number of hours required} \]
\[ = 0.062 \times \text{gross engine power (BHP)} \times \text{number of hours} \]

NOTE: 1 UK gallon = 1.2 US gallons

Tanks in mobile applications must be designed together with the supply pipe so that adequate fuel is available under all operational gradients.

TYPICAL FUEL TANK AND PIPEWORK
Fuel Tank Pipework
The fuel intake pipe must be above the bottom of the tank so that it is not sealed by frozen water in cold weather, and to ensure that dirt and sediment are not drawn into it.

There should be no gauze filter on the fuel feed pipe in the tank, as it can be difficult to clear when blocked.

A coarse filter may be fitted to the tank filler, and although it will not stop contaminants, it will prevent fuel being siphoned out.

The fuel return pipe is usually connected above the operating level of the fuel in order to permit venting of air and other gases. However, some fuel injection pump types require the return pipe always to be below the operating fuel level.

Position
The positioning of the fuel tank is an important factor in any application.

Wherever possible the fuel tank should be positioned to ensure that:

a) Any difference in height between fuel tank and engine lift pump is kept to a minimum. (See the Fuel System section of SECTION 16, TECHNICAL DATA for limits.)

b) The length of fuel feed pipe is kept to a minimum.

c) It is away from any excessive heat source.

d) The filling point is accessible and easy to use.

Vent and Filler
A suitable air vent should be provided to allow free entry of air as the fuel is used. It is recommended that the words “DIESEL FUEL ONLY” be printed clearly near the filler cap or on the filler cap itself. It is important that the air vent and fuel filler should not allow dust or water to enter the tank from the atmosphere.

LOW PRESSURE FUEL PIPES
Material
The low pressure fuel pipes should be made from good quality seamless copper pipe, steel pipe, or “bundy” tubing, having a wall thickness of 22 S.W.G. (0.71 mm). Plastic or nylon pipe which is specifically manufactured for use with fuel, and is approved by Caterpillar, can also be used between the fuel tank and engine. Plastic piping must not however be used in installations where there is any fire risk, and must always be kept well away from heat sources, e.g. exhaust manifolds etc. It should be checked that insurance or other regulations allow plastic piping before using this material.

Size
The required fuel feed pipe diameter is determined by the size of the connections in the engine components, and the restriction it imposes at the fuel lift pump inlet.

See the Fuel System section of SECTION 16, TECHNICAL DATA for depression limits at the fuel lift pump inlet, and suggested fuel pipe diameters for different engine sizes.

Pipe Position
All pipes should be located in protected areas, free from possible damage, securely clipped in position to prevent vibration, and, when of metal but NOT of plastic, preferably in a position where they receive some engine heat.

The careful selection of pipe runs cannot be over emphasized. It is important for the pipe to avoid excessively long runs and areas subject to cold air blast, i.e., wheel arches, grilles and fan outlet areas.

The pipe should have the minimum number of connections, sharp bends or other features which could lead to air trapping or excessive resistance to flow, and possible waxing in cold conditions.

Examples of bad and good fuel pipe arrangements, and other fuel system features, are illustrated in the accompanying diagrams.

Pipe Connections
Where low pressure fuel pipes are attached to both the engine and the machine frame, sufficient lengths of flexible pipe must be used, preferably reinforced with metal braid.

Fuel injection pump inlet connection
“Straight-in” type connections are normally used (see diagram). This type of connection must however only be used if the fuel filter is mounted higher than the fuel pump, and where there is a continuous slope of piping downwards to the pump from the filter. This enables venting to be done at the filter head.
BAD DESIGN FEATURES

GOOD DESIGN FEATURES

Diagrams by courtesy of the British Technical Council
SPECIAL BANJO-TYPE INLET PIPE CONNECTION,
FOR USE IN RESTRICTED AREAS ONLY.

In this case the venting is done at the banjo bolt in the fuel pump.

Fuel injection pump return outlet connections

The straight-in connections are used in conjunction with rubber olives.

SAE Standard brass olives are non-preferred and should only be used when rubber types are not available.

The pipe end forms illustrated should be applied to all low pressure fuel pipes.

Nylon tube fitting

Nylon tube should be connected to compression fittings by a short length of steel or Bundy tubing, as illustrated.

Standard olives should never be fitted directly on to nylon tube due to the olive collapsing the tube and restricting fuel flow.

The diameter of Bundy tube and nylon pipe required for different sized engines, are tabulated in SECTION 16, TECHNICAL DATA.
Fuel Circuits

Typical fuel circuits, applicable to various engine and fuel pump types, are illustrated in the accompanying diagrams.

SCHEMATIC FUEL SYSTEM WITH "DIRECT FEED" FUELLED STARTING AID, SINGLE FILTER & FUEL PUMP

SCHEMATIC FUEL SYSTEM WITH "DIRECT FEED" INLET FUELLED STARTING AID & TWIN PARALLEL FILTER
Schematic fuel system with "Direct Feed" fuelled starting aid & in-line pump on TV8.540 & V8.540

Schematic fuel system with in-line pump on TV8.640 & V8.640
FILTRATION SYSTEM

The basic components of a fuel filtration system are illustrated. Their individual functions, and the factors to be considered in their selection and installation, are described in the following paragraphs.

FUEL FLOW DIAGRAM OF TYPICAL INSTALLATION
Sedimenter/Water Trap

The sedimenter or water trap, located between tank and lift pump, is designed to remove the larger dirt particles from the fuel and to collect water, which should be regularly drained from the bowl. Although a sedimenter is recommended for all applications, a water trap may be used where the fuel supply is relatively clean.

Diesel engines installed in industrial and construction machines are often called on to operate in adverse conditions, where large quantities of water and dirt are present in the fuel tank due to problems or storage and filling in poor weather conditions, as well as to condensation. To guard against damage to the fuel injection equipment, and also to avoid operational delays caused by water stopping the engine, Caterpillar advocate a heavy-duty fuel filtration system for all engines supplied for these applications. The heavy duty system incorporates a sedimenter of adequate capacity to handle the water and dirt anticipated, and also twin parallel flow filters as shown in the preceding circuit diagrams.

The diagram shows a typical sedimenter which is available with the engine.

Many types of sedimenter and water trap are marketed for use with diesel engines. Those which contain filter elements or fine screens are not recommended for reasons given below. Water traps are considered suitable only for “clean” environments and should not be used where the fuel supply is likely to be contaminated with dirt particles.

The following requirements apply to sedimenters and water traps:

- Adequate flow capacity to handle fuel supply, including that which is returned to the tank.
- Minimal flow restriction to avoid over-loading the lift pump.
- No filter element, as this could become choked with dirt and wax, which tends to be deposited from the fuel in cold operating conditions.
- A glass bowl should be fitted unless legislation or insurance conditions prohibit its use.

- Satisfactory pipe connections, valves, drain plugs, and other sealing surfaces to avoid air leaks, which are difficult to detect on the suction side of the fuel system.
- Should be fitted in an accessible and visible position to facilitate servicing, which should be carried out at regular intervals as determined by site operating conditions. Locate as close as possible to fuel tank to reduce risk of water freezing in fuel feed pipe.
- Special sedimenters, incorporating switches to actuate a warning device when the water capacity is nearly exhausted, can be used. These are not available in the basic engine specification but may be obtained from the Caterpillar Power Centers.
- Spillage deflectors should be provided in all cases where it is possible for fuel to damage an engine component during drainage, (e.g. starter motors and rubber components).

Fuel Lift Pump

In all cases where the engine fuel lift pump is fitted with a hand operated priming facility, the installation must allow access to this to be maintained.

Some installations may require that an extension is fitted to the priming lever to enable it to be operated.

Where the suction pressure required from the fuel lift pump exceeds the limits specified in SECTION 16, TECHNICAL DATA, an additional pump (normally ELECTRIC) should be fitted near the fuel tank. This should not be a positive displacement type.

Fuel Filters

Filter Selection

The choice of the fuel filter arrangement for a particular installation will depend upon the type of application and the operating conditions that the engine will experience. Different types of fuel filters are available, and may be used singly or in pairs. Where a twin system is to be used, the filters should be arranged in parallel.
For installations likely to experience dirty fuel, or large fuel flow rates, twin parallel flow filters should be specified as this arrangement has the advantage of a longer service life.

All filters recommended are of agglomerator flow (see diagram) i.e. the internal circuit is arranged to separate out water from the emulsion of water and fuel which results when water by-passes the “sedimenter”. The diagrams below show the direction of fuel flow through the filters, and details of the filter assembly with paper element.

The original paper elements supplied with the filters, and approved service replacement elements, are to a stringent specification developed by Caterpillar in conjunction with the fuel injection equipment manufacturers.

Only filter elements meeting Caterpillar requirements of filtering ability must be used.

**Filter position**

The filters should preferably be mounted securely to the engine on vibration-free brackets as close as convenient to the fuel injection pump. Element type filters should not be fitted on the suction side of the lift pump, i.e. between the main fuel tank and lift pump, as this can cause restrictions.

To assist venting of the system, the filter vent should be higher than the fuel pump inlet wherever possible. Venting should be applied to the dirty side of the filter only, by means of a permanent 0.5 mm (0.02 in) diameter vent.

Any fuel from the injection pump returned to the filter must enter on the dirty (inlet) side of the filter, to ensure that dirt cannot be continuously circulated through the fuel pump.

It is important that the filters are away from any excessive heat source, and in such a position that easy access for service and periodic draining is obtained.

Spillage deflectors should be provided in all cases where it is possible for fuel to be spilled on to other engine components.

**STARTING AIDS**

Diesel engines require an aid to combustion to start satisfactorily below certain ambient temperatures.

Various types of starting aid can be used with Caterpillar engines, depending on type of engine and conditions.

(See SECTION 16, TECHNICAL DATA for cold starting information, and SECTION 3, COLD START for full cold starting details.)

Two systems, Thermostart and Excess Fuel Device, are connected with the engine fuel system.

**THE FUELED STARTING AID**

The fuelled starting aid is a device for raising the temperature of the air being drawn into the cylinder.

When the heater coil is energized, the valve body is heated and expands to allow the ball valve to open and fuel to flow. The fuel is vaporized and, as the engine is cranked, the fuel/air mixture is ignited, thus raising the temperature of the air entering the cylinder.

The mixture continues to burn as long as the heater coil is energized and fuel is flowing. When the fuelled starting aid
is switched off, the incoming air quickly cools the valve body and the fuel supply valve closes.

The fuel feed is taken from a clean side port or a clean side vent on the filter, via a pipe of suitable size (usually 3.35 mm, 0.132 in inside diameter).

Exhaust smoke and emissions legislation in various countries requires cold starting devices to be designed and constructed to ensure that they cannot be brought into or kept in action when the engine is running normally.

The legal position in respect of these devices should be established by the equipment manufacturer in all cases, and action should be taken to conform to the relevant requirements.

**Excess Fuel Device**

Some fuel injection pumps incorporate an “excess-fuel” device to improve cold starting performance.

The device must be set by the operator before starting from cold, even if another starting aid is also provided. This excess fuel cuts out when the governor operates at a speed determined by the position of the speed control lever.

The excess fuel button or lever must be easily accessible.

As with other fuelled starting aids, the equipment manufacturer should ensure that the excess fuel device, if operated remotely, complies with any legislation prohibiting its operation during normal running. Some engines have an automatic “excess fuel” system incorporated in the pump.

**FUEL INJECTION PUMP**

**Function**

The function of the fuel injection pump is to distribute the clean fuel received from the fuel filters equally, in the correct quantities and at the correct time to the injectors.

The fuel pump injection timing governor setting and fuel delivery levels are accurately set before the engine leaves the manufacturer, and should only be adjusted by a qualified fuel injection engineer.

**Governing**

A governor is an integral part of the fuel injection pump on all Caterpillar engines. This controls the idling speed and maximum speed, and also provides a varying percentage of governing along the operating speed range.

The three categories of governing provided on Caterpillar engines are:

“V” (Vehicle)
Suitable for automotive applications.

“S” (Standard)
general purpose governing suitable for the majority of agricultural and industrial applications.

“T” (Tight)
suitable for applications which require minimum speed variation.

(Refer also to SECTION 2, GOVERNING)

**Special Governing Requirements**

In certain applications very precise speed control is required which is outside the limits obtainable from the standard fuel injection pump governor. For these cases, remote mounted electronic governors are available; further advice on the subject can be obtained from Application Engineering Department, Peterborough.

**Controls**

All fuel pumps have speed controls and fuel shut-off devices fitted. Certain fuel pumps specially developed to suit specific applications often have additional controls. These should be connected in accordance with the manufacturer’s recommendations, as specified in the Workshop Manual or engine handbook.

For further information regarding fuel system controls, see SECTION 14, INSTRUMENTATION & CONTROLS.

**Fuel Pump Feed Pipes**

At all times the fuel feed to the fuel injection pump should be taken from the clean side of the fuel filter, and the return pipe from the pump should be returned to the dirty side of the fuel filter.

**INJECTORS/ATOMIZERS**

The injectors receive high pressure fuel via the high pressure pipes from the fuel injection pump, and inject the fuel into the combustion chamber in the form of a very fine spray.

The injectors are accurately pre-set to a very high pressure, but should be checked periodically by a qualified fuel injection engineer.

There must be sufficient clearance in the installation to allow the injectors to be easily removed for maintenance.

**FUEL LEAK-OFF — RETURN TO TANK**

Surplus fuel delivered to the injectors is carried away by a metal or suitable flexible fuel return line connected to each injector.

This pipe then connects with the fuel filter overflow pipe, which takes the surplus fuel out of the fuel filters (see circuit diagrams, SECTION 10, FUEL CIRCUITS).
The fuel should normally then be drained back into the fuel tank at a point above the operating fuel level. However, fuel systems which have the surplus fuel from the injection pump returned directly to the tank (not through the filter) should have the return pipe below the operating fuel level in the tank to prevent drain-back and reduce the possibility of air getting into the injection pump.

VENTING THE FUEL SYSTEM
Running out of fuel, or a leak in the fuel supply line, particularly on the suction side, can cause air to enter the fuel system, and it may be necessary to “vent” or “bleed” the whole system to remove it.

Venting ports are usually fitted to the fuel injection pump and fuel filter, depending on the type of fuel pump, filter and pipe layout.

Instructions on bleeding the fuel system are given in the Workshop Manual and the Handbook for each engine type.

However, it is most important that the engine and the fuel system are installed in such a way that the venting points are clearly visible and accessible so that the air can be completely and easily removed from the system.

FUEL SPECIFICATION
The fuel oil must have a cloud point below the minimum ambient operating temperature, and a cetane number of not less than 45. If the cetane number is below this value, advice should be obtained from Application Engineering Department, Peterborough.

Other fuel specification details are given in SECTION 16, TECHNICAL DATA.

FUEL HEATERS
Fuel heaters are available as a service kit; further information and advice on these can be obtained from Application Engineering Department, Peterborough.
SECTION 11
Lubricating Oil System

INTRODUCTION .................................................................136
  System Compatibility ..................................................136
  Lubrication Circuit ....................................................136
  Accessibility ..............................................................136

LUBRICATING OIL FILTERS .............................................136
  Full Flow Filters ........................................................136
  By-Pass Filters ..........................................................136
  Remote Filters ..........................................................136

LUBRICATING OIL COOLERS ............................................136
  Oil Temperature .......................................................136
  Types of Cooler .......................................................137

PIPEWORK .................................................................137
  General .................................................................137
  Material ..............................................................137
  Connections and Clamping .........................................137

EXTREMELY DIRTY ENVIRONMENTS ...............................137
  General ..............................................................137
  Filler Cap and Dipstick ............................................137
  Breather System .....................................................138
  Labyrinth Seals .....................................................139

APPROVED OILS ............................................................140
INTRODUCTION

System Compatibility
It is extremely important to ensure that the lubrication system is compatible with the particular application and operating conditions too which the engine will be subjected.

Factors which should be taken into consideration include:

- Lubricating oil specifications
- Lubricating oil temperatures
- Oil sump capacity and gradeability
- Pressure losses in external system
- Protection from dirt contamination

Reference should also be made to SECTION 7 in relation to lubricating oil cooling.

Lubricating Circuit
Most engines store the lubricating oil within the sump, circulating it around the engine by means of a gear driven pump. A relief valve is used to relieve the circuit of excess pressure when cold, and a feed is provided for piston cooling jets on certain engines. Oil levels are indicated by a dipstick. Filtration is provided by a strainer on the suction side of the pump and a paper element filter or filters in the pressure circuit. The appropriate Engine Service Manual includes the circuit diagram and further details of the system applying to the particular engine.

“Dry sump lubrication” is used for special applications where exceptional gradeability requirements or the need for a very shallow sump profile precludes the normal arrangement. In these cases, an additional oil pump scavenges the oil as it is returned from the crankcase, transferring it either to a compartment of the sump, or to a separate oil tank from which the standard oil pressure pump draws its supply for the pressure lubricating system.

Accessibility
To achieve satisfactory engine service life, it is essential to adhere to the oil and filter cartridge change periods recommended in the engine Service Manual. To facilitate oil changes and filter cartridge removal, it is essential for these and the dipstick to be positioned in a readily accessible position and protected from possible damage.

Whenever possible it should not be necessary to remove the engine in order to drop the oil sump.

LUBRICATION OIL FILTERS

Full Flow Filters
Caterpillar engines are supplied with full flow lubricating oil filters as standard equipment. These filters are designed specifically for use on diesel engines to adequately handle the flow, temperature and pressure involved, and provide the required filtration capacity. The use of any filter type other than that supplied with the engine should have the prior approval of Caterpillar.

It should be recognized that large oil coolers can hold significant quantities of oil which may not be drained and changed in the course of routine engine oil changes.

By-Pass Filters
With modern lubricating oils, the use of a by-pass lubricating oil filter is not normally necessary.

However, if unusual conditions of service, or oil grades, are expected in service, then the advice of Caterpillar should be sought. It must be emphasized that a by-pass oil filter does not automatically give an increase in total oil life in the sump, since it is the life of the additive pack which is important in determining oil change periods, as well as the contaminants which are transmitted to the oil during engine operation.

Remote Filters
When the standard oil filter positions are not accessible in the installation, a remote-mounted filter may be used. In these cases, the filter must be mounted securely to give as short a run of pipes as possible. Recommendations given in this section on pipework should be followed closely to avoid excessive pressure losses, oil drain back and leakage problems. Proximity to a heat source such as the exhaust pipe or turbocharger should be avoided, or heat shields provided.

Caterpillar advice should be obtained before relocating the lubricating oil filter — particularly where a different model to the original one is proposed, and care should be taken with the cylinder block, adapter, and when piping up, to obtain the correct flow direction through the filter head.

LUBRICATION OIL COOLERS

Oil Temperature
The maximum lubricating oil temperatures for Caterpillar Engines depend on operating conditions and other factors specified in SECTION 7, COOLING SYSTEM. Working within the maximum levels given will help to protect bearings, oil seals and all wearing surfaces of the engine, as well as avoiding excessively high oil consumption.
Lubricating oils recommended for use with the engines are capable of higher temperatures without breakdown, but the specified maximum engine oil temperatures should not be exceeded for the reasons given.

In some applications, and dependent on engine speed and load conditions, a lubricating oil cooler may be needed to avoid exceeding the maximum oil temperature.

**Types of Cooler**

Some engines have a build-on lubricating oil cooler, either as an option, or as part of the base engine. Other engines use remote-mounted coolers of “Air-to-oil” or “water-to-oil” type. These are described in SECTION 7, COOLING SYSTEM.

When a remote mounted oil cooler arrangement is used, it is important to ensure that the total restriction across the cooler and pipework does not exceed recommended limits.

As well as avoiding excessively high oil temperatures, it is important not to over cool in cold weather. The type of cooler selection should therefore not be oversize, and preferably be controlled by the coolant temperature.

To avoid damage to coolers caused by high pressure when starting from cold, a by-pass or dump valve is necessary unless the cooler has been designed to withstand this condition.

**PIPEWORK**

**General**

All pipework to be used for carrying the engine oil should be clean internally. Bore size, pipe run and connections should be selected to ensure the oil pressure drop is kept to a minimum. Maximum pressure drop is specified in SECTION 7, COOLING SYSTEM.

**NOTE:** To avoid damage to the pipes, it is important that any components subsequently fitted by the customer do not come into contact with the lubricating oil pipes.

This applies particularly to flexible pipes with external metal braiding. It is recommended that a clearance of 10 mm is maintained under all conditions.

**Material**

The pipes specified for engine lubricating oil should either be metal or, if flexible pipes are used, these must be of oil-resistant armored construction, and able to withstand working conditions with respect to temperature and pressure. Only screw type connections should be used, hose connections and clips not being approved for lubricating oil pipes.

**Connections and Clamping**

Only pressure tight, screw connections should be used for lubricating oil pipes.

When arranging the pipework, enough flexibility should be allowed to accommodate any relative movement of components but it is important that the pipe is positioned so that it cannot be rubbed or damaged during any operating condition.

Additional clamping may be used on all pipes except on the braided part of those pipes with external metal braiding.

**EXTREMELY DIRTY ENVIRONMENT**

**General**

In extremely dirty or dusty conditions, to prevent contamination of the lubricating oil, a “sealed” lubricating oil filler cap, dipstick and closed engine breather system should be used.

**Filler Cap and Dipstick**

The “sealed” dipstick and lubricating oil filler cap are designed to effect air-tight joints when the engine is operating and also to prevent dust, etc., dropping into the engine when service checks are being carried out. The special filler and dipstick are particularly recommended for construction machinery applications.
A coarse filter screen incorporated in the lubricating oil filler is a useful safety measure — particularly for agricultural and construction machinery applications where “top-up” servicing is often carried out under poor conditions.

Breather System

For engines operating in dusty conditions, an expansion chamber fitted to the bottom of the breather pipe helps to minimize dust ingress. This works by sharply reducing the velocity of the dust-laden air which is drawn into the engine as it is cooling down after being stopped. Dust is attracted to the oily internal surfaces of the chamber. Regular cleaning of the expansion chamber is necessary, especially if the engine stopped frequently in a dusty atmosphere.

For Construction Machinery or other applications working in a very muddy, dirty, or dust-laden environment, and also where regulations prohibit the emission of crankcase fumes, a closed breathing system may be required.
A typical system shown below incorporates a valve to control crankcase pressure, and breather pipes connecting the valve to the air induction manifold and cylinder head cover.

**Labyrinth Seals**

The lubricating oil seals on exposed rotary shafts fitted to engines operating in severely dirty conditions, should be protected where they are liable to be damaged. The front end crankshaft seal may be particularly vulnerable, and is therefore protected by a labyrinth formed on the timing case boss and crankshaft pulley hub.
APPROVED OILS
It is important to use only lubricating oil that conforms to an approved specification to suit a particular engine type. SECTION 16, TECHNICAL DATA gives approved oil specifications and brands which meet the specifications. Information is also given on viscosity ranges recommended for operation within ambient temperature ranges.
INTRODUCTION

The primary function of the electrical system in a diesel powered machine is to provide the energy required for starting the engine.

The system must then provide for the energy taken from the battery to be replaced, and must also provide additional power to maintain any auxiliary electrical load e.g., lighting, blowers, wind screen wipers, etc.

A typical system is shown in the circuit diagram below. This is a representative diagram only, and reference should be made to the circuit diagrams appended to this section for wiring details applicable to specific starter motor and alternator types.

SYSTEM VOLTAGE

The system voltage may be either 12 volt or 24 volt, depending primarily on the cold starting requirements that must be met, and on the engine type — see Cold Starting Data in SECTION 16, TECHNICAL DATA.

To a lesser extent, particularly in applications with extensive ancillary electrical equipment, the voltage used for this equipment may also influence the voltage chosen for the engine starting equipment.

STARTER MOTOR SELECTION

AND INSTALLATION

Starter Motor Selection

(Refer also to SECTION 3 — COLD STARTING)

In order to ensure satisfactory starting under the most adverse conditions that will apply in service, it is essential that the correct combination of starter motor, battery and starting aid (if necessary) should be fitted.

Reference should be made to SECTION 16, TECHNICAL DATA for details of the specifications applicable to the various engine types, to meet particular cold starting requirements.

If it is intended to fit any starter motor type not referred to in SECTION 16, reference should be made to Application Engineering Department, Peterborough.

Starter Motor Installation

Where the starter motor installation is engineered by the O.E.M., it is important that care is taken to ensure that correct engagement of the starter pinion with the starter ring is achieved, and that the correct ratio of pinion to ring is used to give a satisfactory cranking speed. Details are shown in SECTION 16, TECHNICAL DATA of the recommended ratios for the starter motor types listed for the various engine types.
Starter motor types with external solenoid actuation, e.g. Lucas M45, M50, should preferably be mounted so that the solenoid is at least 15° above the horizontal, as illustrated, in order to avoid damage by water ingress.

**Starter Motor Wiring — Earth Return and Insulated Return Systems**

**Earth Return System**

For reasons of economy, the majority of installations use the system shown above, in which the frame of the machine is used to provide the “return” path from the starter motor to the battery.

It is essential with this system to ensure that the “earth return” section of the circuit provides a low resistance current path, and that the connection points to the frame are secure and in good electrical contact.

**Starter Motor Earth Connection**

In order to ensure a low resistance current path between the starter motor and the frame, it is essential that an earthing strap or cable should be fitted between the terminal provided on the starter motor, and the machine frame.

**Insulated Return System**

Where increased reliability is required, and where the risk of fire must be minimized, the “insulated return” arrangement shown above may be used. This will entail the use of an increased length of starter motor cable, however, and it is important that the cable is of adequate cross-sectional area, in order that the voltage drop is not excessive — see STARTER MOTOR CABLES.
**Starter Motor Cables**

The total length of cable in the starter motor (i.e., high current) circuit should be kept to a minimum in order to avoid excessive voltage drop.

The resistance of the total circuit, including the earth return, must not exceed the maximum recommended resistance. This value is dependent upon the application, and can be summarized as:

- 0.0034 ohm — 24V systems (exc. V8)
- 0.0017 ohm — 24V systems (V8 only)
- 0.0008 ohm — 12V systems (exc. V8)

The table below shows the maximum length of commonly used starter motor cables which may be used without exceeding these limits.

N.B. The resistance in a cable will be modified by the number of connections made (each connection having a resistance of approx. 0.0002 ohms). If length or cable size is marginal, the next larger cable size should be used.

**Starter Motor Solenoid Circuit**

All starter motor types specified for Caterpillar engines incorporate solenoid actuated engagement of the starter motor pinion with the starter ring gear. The solenoid may be either mounted externally on the motor, as in the case of the Lucas M45 and M50 motors, or may be incorporated internally in the starter motor, as in the CAV CA45.

In order to ensure satisfactory engagement of the pinion, it is essential that the voltage drop in the starter motor solenoid circuit is not excessive.

Maximum acceptable voltage drop, or maximum acceptable circuit resistance, is shown in the applicable wiring diagram (see appended circuit diagrams) for various starting system configurations. The circuit diagrams also include details of solenoid circuit current in each case, together with details of current flow in other sections of the starting circuit. In order to facilitate selection of the cable size necessary to meet the specified maximum voltage drop/circuit resistance requirements, all wiring diagrams also include a table giving details of resistance/meter length of commonly used cable sizes. In the case of cable types other than those listed, cable type in the table with the cross-sectional area closest to that in use.

**Starter Relay**

If the engine is any great distance from the starter switch, it will be an advantage to use a starter relay in the starter motor solenoid circuit. This will shorten the solenoid circuit wiring, and enable low current cables to be used to the starter switch. The applicable wiring arrangement is shown in the appended circuit diagrams.

Suitable relays are the Lucas 28RA for the Lucas M50 starter or similar, and the Lucas 33RA for the CAV S115/S130 starters and for higher solenoid current draw starters such as the Delco 40MT and the Lucas 45T. Equivalent relays may also be used.

### Cable Size Table

<table>
<thead>
<tr>
<th>MAXIMUM TOTAL LENGTH FOR RESISTANCE OF:</th>
<th>CABLE SIZE</th>
<th>NOMINAL CROSS SECT. AREA</th>
<th>NOMINAL RESISTANCE IN OHMS</th>
<th>APPROX. EQUIVALENT SIZES</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0034 OHM*</td>
<td>METERS</td>
<td>FEET</td>
<td>MM²</td>
<td>IN²</td>
</tr>
<tr>
<td>1.8</td>
<td>6.18</td>
<td>0.93</td>
<td>3.1</td>
<td>0.44</td>
</tr>
<tr>
<td>3.1</td>
<td>10.0</td>
<td>1.54</td>
<td>5.0</td>
<td>0.73</td>
</tr>
<tr>
<td>3.4</td>
<td>11.3</td>
<td>1.7</td>
<td>5.6</td>
<td>0.81</td>
</tr>
<tr>
<td>4.46</td>
<td>14.6</td>
<td>2.2</td>
<td>7.3</td>
<td>1.05</td>
</tr>
<tr>
<td>4.78</td>
<td>15.76</td>
<td>2.38</td>
<td>7.8</td>
<td>1.12</td>
</tr>
<tr>
<td>4.57</td>
<td>15.0</td>
<td>2.3</td>
<td>7.5</td>
<td>1.07</td>
</tr>
<tr>
<td>6.6</td>
<td>21.66</td>
<td>3.3</td>
<td>10.8</td>
<td>1.56</td>
</tr>
<tr>
<td>7.36</td>
<td>24.15</td>
<td>3.7</td>
<td>12.0</td>
<td>1.7</td>
</tr>
<tr>
<td>8.97</td>
<td>29.3</td>
<td>4.48</td>
<td>14.65</td>
<td>2.1</td>
</tr>
<tr>
<td>11.6</td>
<td>38.2</td>
<td>5.6</td>
<td>19.0</td>
<td>2.7</td>
</tr>
<tr>
<td>12.98</td>
<td>42.6</td>
<td>6.49</td>
<td>21.3</td>
<td>3.05</td>
</tr>
<tr>
<td>13.1</td>
<td>43.0</td>
<td>6.56</td>
<td>21.5</td>
<td>3.08</td>
</tr>
<tr>
<td>18.0</td>
<td>56.67</td>
<td>9.0</td>
<td>28.3</td>
<td>4.2</td>
</tr>
<tr>
<td>22.67</td>
<td>73.9</td>
<td>11.33</td>
<td>38.95</td>
<td>5.3</td>
</tr>
<tr>
<td>27.87</td>
<td>91.9</td>
<td>13.93</td>
<td>45.9</td>
<td>6.56</td>
</tr>
</tbody>
</table>

Key:
* Max. total circuit resistances:
  - 0.0034 ohm — 24V systems (exc. V8)
  - 0.0017 ohm — 24V systems (V8 only)
  - 0.0008 ohm — 12V systems (exc. V8)

P — Preferred cables
PF — Preferred flexible cables
The relay shall be mounted close to the starter in a position free from vibration and not subject to radiated heat.

The relay shall be mounted with the terminals in the best position to protect them from water spray and road debris.

**NOTE:** The solenoid circuit currents for the CAV S115/CA45 and AC-Delco starters exceed the rating of the four-position switch Lucas 128SA or similar. If this type is used it is therefore essential that a starter relay is fitted.

### BATTERY SELECTION AND INSTALLATION

#### Battery Type

There are two basic types of battery which can be used with diesel powered machinery, namely the alkaline battery, and the lead acid battery.

The **alkaline battery** is physically larger than the lead acid battery of similar power, it is more expensive, and has a tendency to have a more rapid decrease in terminal voltage with heavy current draw.

It is however suitable for applications such as standby generator sets, sprinkler pumping units, etc., as it does not lose its charge over long periods without use.

The **lead acid battery** is cheaper, easier to maintain, and has a better power/weight ratio. However, it can lose some of its charge over long periods without use.

#### Battery Performance

**Lead/Acid Batteries**

Battery capacity in terms of ampere-hour rating is not a reliable guide to suitability for starting purposes.

In order to provide a satisfactory starting performance, the battery must be capable of sustaining a relatively high terminal voltage under the high current discharge conditions that apply during cold starting. This is illustrated in the curves, which compare results obtained on two battery types when subjected to a 300 ampere discharge current, the batteries being “soaked cold” at –18°C.

It can be seen that, in terms of ampere hour capacity, the smaller battery gave a considerably better performance in this test than the larger battery, and would therefore be much more satisfactory from a starting point of view.

Batteries should conform to an internationally recognized specification. Typical examples are given in SECTION 16, TECHNICAL DATA of specifications meeting given starting requirements for various engine and starter motor configurations.

**Alkaline Batteries**

If it is intended to use this type of battery, the maker’s advice should be sought with regard to suitability for the required duty.

**Battery Capacity**

Battery capacity is not itself an important consideration for starting the engine. However, if the auxiliary loads are high when the engine is not running, then the capacity must be taken into account.

In extreme cases, it will be advisable to use a separate battery, having double-separator construction, for the auxiliary loads so that the starting battery cannot be drained.

The auxiliary battery may be charged from the engine starting system. The capacity should also be adequate to allow the installation to keep running safely for a reasonable time after an alternator failure.

Battery capacity is usually expressed as “reserve capacity” which is the number of minutes the battery will survive while discharging at a constant 25 amps.

Some manufacturers still use the Ampere-hour capacity; the relationship between these systems is:

\[
\text{Amp-hrs} = \frac{(\text{Reserve capacity} - 14, 12)}{1,647}
\]

If the installation is for standby emergency operation, with trickle-charging to keep the batteries charged, then only double-separator type batteries should be used.

Providing the battery specification for starting purposes meets the requirements detailed in SECTION 16, TECHNICAL DATA, the battery will normally have adequate capacity for applications in which conditions are such that the engine driven generator is able to maintain the auxiliary-running load for practically the entire duty cycle, while also providing the additional current required to recharge the battery after starting.

— TECHNICAL DATA, the battery will normally have adequate capacity for applications in which conditions are such that the engine driven generator is able to maintain the auxiliary-running load for practically the entire duty cycle, while also providing the additional current required to recharge the battery after starting.

As a general rule, in order to ensure that the battery will be in a satisfactory state of charge for starting purposes, it is
essential not to permit any load that will result in the battery being discharged by more than 25% of its fully charged capacity.

Example
A machine is required to use its lights for one hour after engine shut down. Current drain on the battery is as follows:

- Headlamps: 96 watts × 1 hour = 96 watt-hours
- Rear Lamps: 14 watts × 1 hour = 14 watt-hours
- Spot Lamps: 200 watts × 1 hour = 200 watt-hours
- Marker Lamps: 14 watts × 1 hour = 14 watt-hours

Total = 324 watt-hours

Watt-Hours = Ampere Hours, System Voltage

So in this case (12 volt system)

Ampere Hours = \frac{324}{12} = 27

If this figure of 27 ampere hours represents 25% or more of the battery capacity specified for starting purposes, then in order to avoid possible starting problems, a battery of increased capacity must be specified, or, in extreme cases, a separate battery should be installed for the auxiliaries.

Battery Installation
the battery must be located away from sources of heat, and must be protected from rain, snow, road splash and dirt, must be readily accessible for routine maintenance, and should be located as close as possible to the starter motor, in order to minimize lead length.

Battery carriers must be properly designed and supported away from areas of vibration. Battery cables must be secured to the machine frame, with a small amount of play to prevent strain at the terminals.

alternators have the following important advantages:

1. Useful current output is available at low engine speed, in some cases down to idling speed, depending on drive ratio.
2. Maximum available output is considerably greater than for a dynamo of comparable size.

Determination of Generator Rating Requirement
In order to determine the generator rating requirement for a particular installation, it is necessary to determine the Average Electrical Loading that will apply during a representative duty period. It is necessary to consider each electrical load in the installation, and then to make an estimate of the time for which that particular load will be in demand. Average Electrical Loading is expressed in Watt-Hours, one watt-hour being the work done by one watt acting for one hour. It is advisable to base the calculation on the most unfavorable conditions that will be met in service, in order to provide adequate reserve.

A typical calculation is shown opposite for a commercial vehicle, taken over a total driving period of 10 hours.

Calculation of Average Electrical Loading — Commercial Vehicle — Total Driving Time 10 Hours

<table>
<thead>
<tr>
<th>Load</th>
<th>Power (watts)</th>
<th>Time (hours)</th>
<th>Load (watt-hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headlamps:</td>
<td>85</td>
<td>6</td>
<td>1020</td>
</tr>
<tr>
<td>Side Lamps:</td>
<td>6</td>
<td>7</td>
<td>84</td>
</tr>
<tr>
<td>Rear Lamps:</td>
<td>6</td>
<td>7</td>
<td>84</td>
</tr>
<tr>
<td>Marker Lamps:</td>
<td>6</td>
<td>7</td>
<td>84</td>
</tr>
<tr>
<td>Number Plate Lamp:</td>
<td>6</td>
<td>7</td>
<td>42</td>
</tr>
<tr>
<td>Instrument Panel: Bulbs:</td>
<td>6</td>
<td>7</td>
<td>168</td>
</tr>
<tr>
<td>Instruments:</td>
<td>12</td>
<td>10</td>
<td>120</td>
</tr>
<tr>
<td>Heater Motor:</td>
<td>48</td>
<td>10</td>
<td>480</td>
</tr>
<tr>
<td>Wind Screen Wipers:</td>
<td>2 at 72</td>
<td>10</td>
<td>1440</td>
</tr>
<tr>
<td>Interior Lighting:</td>
<td>2 at 5</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Stop Lamps:</td>
<td>2 at 24</td>
<td>40 minutes</td>
<td>32</td>
</tr>
</tbody>
</table>

Total = 3564 watt-hours
Since generators are rated in terms of current output, it is convenient to convert the Average Electrical Loading to Ampere-Hours, and since

\[
\frac{\text{Watt-Hours}}{\text{System Voltage}} = \text{Ampere Hours,}
\]

Average Electrical Loading (12 Volt System)

\[
= \frac{3564}{12} = 297 \text{ Ampere Hours}
\]

In addition, it is necessary to consider starting current demand, and in this example one “cold” start plus seven starts with the engine warm are considered:

1 “Cold” start — 450 Amps for 20 seconds

\[
= \frac{2.5}{20} = 2.5 \text{ Ampere Hours}
\]

7 “Hot” starts — 300 Amps for 3 seconds each start

\[
= \frac{1.75}{3} = 1.75 \text{ Ampere Hours}
\]

Average Electrical Loading is therefore:

\[
297 + 2.5 + 1.75 = 301.25 \text{ Ampere Hours}
\]

The generator specified must therefore supply 301.25 ampere hours over a period of 10 hours, i.e. a mean current requirement of \( \frac{301.25}{10} = 30.125 \text{ Amperes} \).

In practice, to provide a reasonable degree of surplus capacity, the generator should be selected to have a rating approximately 20% in excess of this, i.e. 36 Amperes approximately, in this case.

It is important to appreciate that the output available from the generator is dependent on generator speed, which in turn is dependent on engine/generator drive ratio, and engine operating speed. Speed/output characteristics for the various generator types are available from Applications Engineering Department, Peterborough.

**Generator Regulation**

The purpose of the regulator is to control the voltage output of the generator. Regulation is achieved by controlling the field current of the generator, to achieve a stable voltage which is monitored either at the battery or at the generator output terminals.

**Dynamors**

Dynamors are increasingly being replaced with alternators in new installations.

Caterpillar recommends the use of alternators, and no details are therefore given for the use of dynamors. Should this information be required, Application Engineering Department, Peterborough should be contacted.

**Alternators**

The alternator design now usually incorporates the regulator as an integral part of the alternator, although separate regulators are still available.

Alternator regulators are normally of the electronic solid state type with no moving parts.

When a separate regulator is supplied, it should be mounted away from heat and vibration, and in the manner recommended by the manufacturer.

**Ignition Warning Light**

The ignition warning light is an integral part of the charging circuit, and allows an initial current flow to the regulator to commence excitation. A resistor may be used to supplement or replace the warning light, and the appropriate wiring diagram shows details of this. The current flow in this circuit will affect the alternator cut-in speed, the speed at which the alternator commences to produce an output. If any doubt exists, the regulator manufacturer must be consulted.

In installations where it is possible for the field windings to remain energized when the engine is not running, it is desirable to have the field supply switched via a relay which is de-energized when engine oil pressure falls, permitting the oil pressure switch contacts to open.

**Radio Suppression**

Alternator charging systems may cause radio interference, due to the rapid switching action of transistors and the abrupt cut-off of reverse current by diodes. The interference generated by alternator and regulator is transmitted to radio receiving equipment by either radiation or condition.

For applications where this is likely to present a problem, screened electrical equipment is available, and information on this is available from Application Engineering Department, Peterborough.

Legislation in some countries requires that all electrical installations are radio suppressed to within certain limits, or that suppression equipment must be specified in applications requiring freedom from radio interference, e.g., where radio communication is in use. The situation in this respect must be ascertained by the manufacturer of the equipment in which the engine is installed.

**GENERAL WIRING PRACTICE**

**Cable Selection**

The majority of cables used in machine wiring are made up of multiple strands, to give the cable flexibility.

The usual sizes, their current rating and unit resistance are shown in the table below.

When selecting cable sizes, the following factors must be considered:

1. The cable must be capable of carrying the required current.
2. The voltage drop in the cable must not be excessive when carrying this current.
3. The insulation must be adequate to meet the conditions that will apply in service, with respect to temperature, and contamination by fuel oil, lubricating oil, etc. Current resistance and voltage drop are related as follows in the direct current circuits under consideration, and these relationships may be used when estimating voltage drop for a given cable size and current flow, etc.:

- **Voltage Drop (volts)**
  \[ = \text{Circuit Resistance (Ohms)} \times \text{Current Flow (Amperes)} \]

  or

- **Circuit Resistance (Ohms)**
  \[ = \frac{\text{Voltage Drop (volts)}}{\text{Current Flow (Amperes)}} \]

  or

- **Current Flow (Amperes)**
  \[ = \frac{\text{Voltage Drop (volts)}}{\text{Circuit Resistance (Ohms)}} \]

### Wiring Looms

The correct cable size for various parts of the circuit having been determined, it is usually found that several cables require to take a similar route, along the same sections of the machine.

In order to achieve a neat installation, and to provide additional protection, the cables may be bound together, to make a loom harness. This permits the leads to emerge from the loom where they are required.

Where there are several similar installations, the loom may be conveniently pre-formed away from the machine, the loom then subsequently being installed much more easily than with individual cables.

- **It should be taken into account however that the close proximity of the cables in the harness reduces heat dissipation from the individual cables, and consequently the continuous current rating must be reduced by approximately 40%.**

- **The cable lengths emerging from the loom must be of adequate length to prevent straining of the cable and the connections.**

- **Once installed, the loom should be supported at about 250 mm (10 inch) intervals, using suitable clips which have no sharp edges to chafe the cable or loom. The cable run must be kept away from the exhaust system, and secured well clear of rotating shafts, couplings, etc.**

  ![Cable Clips](image)

  *CABLE CLIPS*

  Grommets must be used where cables or looms pass through panels or bulkheads.

### CABLES NOMINAL RESISTANCE

<table>
<thead>
<tr>
<th>Maximum Continuous Current (Amps)</th>
<th>Number and Diameter of Cable Strands</th>
<th>Nominal Cross-Sectional Area</th>
<th>Nominal Resistance in Ohms</th>
<th>Approximate Equivalent Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MM²</td>
<td>IN²</td>
<td>Per Meter</td>
</tr>
<tr>
<td>6.0</td>
<td>14/0.25</td>
<td>0.6872</td>
<td>0.00107</td>
<td>0.002715</td>
</tr>
<tr>
<td>8.5</td>
<td>14/0.3</td>
<td>0.989</td>
<td>0.00153</td>
<td>0.01884</td>
</tr>
<tr>
<td>13.5</td>
<td>21/0.3</td>
<td>1.4844</td>
<td>0.0023</td>
<td>0.01257</td>
</tr>
<tr>
<td>17.5</td>
<td>28/0.3</td>
<td>1.9792</td>
<td>0.00307</td>
<td>0.00942</td>
</tr>
<tr>
<td>22.0</td>
<td>35/0.3</td>
<td>2.474</td>
<td>0.00383</td>
<td>0.00775</td>
</tr>
<tr>
<td>27.5</td>
<td>44/0.3</td>
<td>3.110</td>
<td>0.0048</td>
<td>0.006</td>
</tr>
<tr>
<td>34.0</td>
<td>60/0.3</td>
<td>4.595</td>
<td>0.0071</td>
<td>0.004</td>
</tr>
<tr>
<td>41.0</td>
<td>84/0.3</td>
<td>5.938</td>
<td>0.0092</td>
<td>0.00314</td>
</tr>
<tr>
<td>48.0</td>
<td>97/0.3</td>
<td>6.857</td>
<td>0.0106</td>
<td>0.00272</td>
</tr>
<tr>
<td>58.0</td>
<td>120/0.3</td>
<td>8.482</td>
<td>0.01314</td>
<td>0.0022</td>
</tr>
<tr>
<td>69.0</td>
<td>80/0.4</td>
<td>10.053</td>
<td>0.0156</td>
<td>0.00182</td>
</tr>
<tr>
<td>112.0</td>
<td>37/0.75</td>
<td>16.35</td>
<td>0.0253</td>
<td>0.0011</td>
</tr>
<tr>
<td>125.0</td>
<td>266/0.3</td>
<td>18.80</td>
<td>0.0291</td>
<td>0.00099</td>
</tr>
<tr>
<td>170.0</td>
<td>37/0.9</td>
<td>23.54</td>
<td>0.0365</td>
<td>0.000762</td>
</tr>
</tbody>
</table>
Connections and Terminals

Incorrect connection between cable and electrical components can increase the circuit resistance, causing poor electrical contact with the possibility of short circuits.

For general wiring, the terminal most commonly used is the "spade" type illustrated below. The male terminal is part of the component, and the female terminal is attached to the cable end, with an insulating sleeve covering the bare connector to prevent accidental short-circuiting.

British Standard BS AU 151: 1970 defines the parameters of these connectors and their nominal sizes. The correct size of "Lucar" type terminal to match the electrical component must be used to prevent movement of the terminal resulting in the possibility of disconnection of "shorting-out" on adjacent terminals.

It is particularly recommended that heavier current circuits such as starter solenoid and charging circuits use connectors made from phosphor bronze as this retains its spring, upon which the contact depends, better than the softer brass type. It is also recommended that hand crimped terminals are not used unless the crimping tool is of a type which compresses the terminal and cable into a solid mass with a predetermined pressure. If this method is not used, the cable end must be either welded or soldered.

Eye type terminals are commonly used (see illustration), the larger type being frequently used for the battery cable connection to the starter motor. The connector fits over a stud terminal, and is fastened by a nut. The cables are either crimped or soldered to the terminal.

**WIRING DIAGRAMS**

The wiring diagrams included in this section cover the most commonly used starter motor and generator combinations. For information on other systems, reference should be made to Application Engineering Department, Peterborough.

The systems included, and the drawing number of the applicable circuit diagrams, are shown in the following tables.

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>Starter Motor</th>
<th>Generator</th>
<th>Remarks</th>
<th>Drawing Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Delco Remy 40 MT</td>
<td>CAV AC5R, Lucas 17ACR, 18ACR, 23ACR or 25ACR</td>
<td></td>
<td>31886112</td>
</tr>
<tr>
<td>12</td>
<td>CAV CA45, Lucas M45, M50</td>
<td>Lucas 15ACR, 17ACR or 18ACR</td>
<td></td>
<td>31886411</td>
</tr>
<tr>
<td>12</td>
<td>Lucas M45, M50</td>
<td>Lucas 15ACR, 16ACR, 17ACR, 18ACR, 23ACR or 25ACR</td>
<td></td>
<td>31886414</td>
</tr>
</tbody>
</table>

| 24             | Lucas M127 | CAV AC5R |         | 31887401          |
| 24             | CAV CA45  | CAV AC5R |         | 31887404          |

Details of the wiring for the Electrical Fuel Shut-Off Solenoid (E.S.O.S.) can be found on drawing ref. 3186T001.
### Resistance of Battery Cables A, B, & C Not to Exceed 0.0008 Ohm

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Cable Nos.</th>
<th>Minimum Cable Size for Circuit Current</th>
<th>Maximum Circuit Current (Amps)</th>
<th>Maximum Circuit Resistance (Ohms)</th>
<th>Maximum Circuit Volt Drop</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternator Charging</td>
<td>1, 1A &amp; 2</td>
<td>2 x 66G.3 &amp; 120G.3 (1ACR)</td>
<td>60</td>
<td>0.0083</td>
<td>0.5 Volt</td>
<td>Max. cable size to 375 series connector 66G.3 2 cables required above this size, cable size to suit alternator.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 x 56G.3 &amp; 80G.4 (13ACR)</td>
<td>65</td>
<td>0.0017</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 x 44G.3 &amp; 120G.3 (23ACR)</td>
<td>95</td>
<td>0.0091</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 x 66G.3</td>
<td>46</td>
<td>0.0110</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17ACR</td>
<td>35</td>
<td>0.0143</td>
<td></td>
</tr>
<tr>
<td>Starting Aid</td>
<td>2, 3, 4, 5</td>
<td>See Charging Circuit</td>
<td>32.3</td>
<td>0.0200</td>
<td>0.6 Volt</td>
<td>Cables 2 &amp; 3 carry relay &amp; starting aid current during starting. Volt drop measured at starting aid no. 2.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starter Relay</td>
<td>2, 3, 6, 7</td>
<td>See Charging Circuit</td>
<td>32.3</td>
<td>0.0600</td>
<td>0.5 Volt</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starter Solenoid</td>
<td>8, 9</td>
<td>85G.3</td>
<td>19</td>
<td>0.0097</td>
<td>0.5 Volt</td>
<td>Solenoid pull in current total 92-104 Amp</td>
</tr>
<tr>
<td>Alternator Warning Light</td>
<td>10, 11</td>
<td>14G.3</td>
<td>3 Max</td>
<td>0.1000</td>
<td>0.5 Volt</td>
<td>Warning light &amp; resistor required to produce initial alternator output</td>
</tr>
</tbody>
</table>

All cable runs to be kept as short as possible.

**Important! To Prevent Alternator Damage:**
- Never disconnect any lead without first stopping the engine & turning switches to off position.
- Always identify a lead to its correct terminal when connecting or disconnecting any lead.
- Never flash connections to check for correct current flow.
- Never run alternator with battery disconnected & field energized.

- **Denotes Earth via Cable**
- **Denotes Earth via Fixing**

**Wiring Diagram — 12V Systems — Negative Earth — V8 Engines**
RESISTANCE OF BATTERY CABLES A, B, & C NOT TO EXCEED 0.0017 OHM

BATTERY 12V
STARTER MOTOR
STARTER RELAY
AMMETER
SWITCH
ALTERNATOR WARNING LIGHT
12V 2W MIN. WITH 27-40 OHM RESISTOR
ALTERNATOR
FUELLED STARTING AIDS
OIL PRESSURE WARNING LIGHT
OIL PRESSURE SWITCH
TEMPERATURE GAUGE
TEMPERATURE SENDER
TACHOMETER
TACHOMETER GENERATOR
OIL PRESSURE GAUGE
OIL PRESSURE SENDER
LIGHT Switch
V.D.O. INSTRUMENT
WIRING DIAGRAM
NO. 2 SWITCH TERMINAL
NO. 1 SWITCH TERMINAL

WIRING DIAGRAM — 12V SYSTEMS — NEGATIVE EARTH

31886411

151
RESISTANCE OF BATTERY CABLES A, B, & C NOT TO EXCEED 0.0017 OHM

<table>
<thead>
<tr>
<th>CIRCUIT</th>
<th>CABLE NOS.</th>
<th>MINIMUM CABLE SIZE</th>
<th>CIRCUIT CURRENT (AMPS)</th>
<th>MAXIMUM CIRCUIT RESISTANCE (OHMS)</th>
<th>MAXIMUM CIRCUIT VOLT DROP</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTERNATOR CHARGING 1 2</td>
<td>440.3 15ACR</td>
<td>28</td>
<td>0.0180</td>
<td>SIZE OF CABLE TO BE INCREASED IF CIRCUIT VOLT DROP EXCEEDS 0.5 VOLT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>440.3 17ACR (DERATED)</td>
<td>28</td>
<td>0.0180</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>650.3 16ACR</td>
<td>32</td>
<td>0.0160</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>650.3 17ACR</td>
<td>36</td>
<td>0.0138</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 x 440.3 18ACR</td>
<td>45</td>
<td>0.0110</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 x 930.3 23ACR</td>
<td>55</td>
<td>0.0091</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 x 1200.3 25ACR</td>
<td>60</td>
<td>0.0083</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALTERNATOR WARNING LIGHT 12V 2W MIN. WITH 27-40 OHM RESISTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLOW PLUG RELAY 2 3</td>
<td>SEE CHARGING CIRCUIT 210.3 25ACR</td>
<td>5.3</td>
<td>0.0077</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>830.3 25ACRH</td>
<td>55</td>
<td>0.0091</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STARTER MOTOR 2 3</td>
<td>SEE CHARGING CIRCUIT 350.3 28ACR</td>
<td>21.05</td>
<td>0.033 VOLT</td>
<td>IMPORTANT — IF LESS THAN 0.63 VOLT DROP CANNOT BE ACHIEVED, A STARTER RELAY WILL BE REQUIRED.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>260.3</td>
<td>15.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALTERNATOR WARNING LIGHT 7 8</td>
<td>SEE CHARGING CIRCUIT 140.3</td>
<td>1</td>
<td>0.1000</td>
<td>WARNING LAMP OR RESISTOR IS REQUIRED FOR INITIAL ALTERNATOR OUTPUT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLOW PLUGS (VIA RELAY) 9 10</td>
<td>650.3</td>
<td>40</td>
<td>0.0125</td>
<td>0.5 VOLT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11 12 13</td>
<td>LINKS SUPPLIED WITH ENGINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All cable runs to be kept as short as possible.

**IMPORTANT! TO PREVENT ALTERNATOR DAMAGE:**

NEVER DISCONNECT ANY LEAD WITHOUT FIRST STOPPING THE ENGINE & TURNING SWITCHES TO OFF POSITION.

ALWAYS IDENTIFY A LEAD TO ITS CORRECT TERMINAL WHEN CONNECTING OR DISCONNECTING ANY LEAD.

NEVER FLASH CONNECTIONS TO CHECK FOR CORRECT CURRENT FLOW.

NEVER CONNECT A BATTERY INTO THE SYSTEM WITHOUT FIRST CHECKING FOR CORRECT POLARITY & VOLTAGE.

NEVER ARC WELD ON INSTALLATION WITHOUT FIRST REMOVING ALTERNATOR CONNECTIONS.

NEVER RUN ALTERNATOR WITH BATTERY DISCONNECTED & FIELD ENERGIZED.

**DENOTES EARTH VIA CABLE**  **DENOTES EARTH VIA FIXING**

WIRING DIAGRAM — 12V SYSTEMS — NEGATIVE EARTH — WITH GLOW PLUGS

31886414
**RESISTANCE OF BATTERY CABLES A, B, C, & D NOT TO EXCEED 0.0034 OHM**

<table>
<thead>
<tr>
<th>CIRCUIT</th>
<th>CABE NOS.</th>
<th>MINIMUM CABLE SIZE FOR CIRCUIT CURRENT</th>
<th>CIRCUIT CURRENT (AMPS)</th>
<th>MAXIMUM CIRCUIT RESISTANCE (OHMS)</th>
<th>MAXIMUM CIRCUIT VOLT DROP</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTERNATOR CHARGING</td>
<td>1, 2 &amp; 3</td>
<td>65/0.3</td>
<td>36</td>
<td>0.027</td>
<td>1.0 VOLT</td>
<td>MAX CABLE SIZE FOR 375 SERIES “LUCAR” TERMINALS — 65/0.3</td>
</tr>
<tr>
<td>FUELED STARTING AID</td>
<td>3 4 5 &amp; 6</td>
<td>SEE ALTERNATOR CIRCUIT 44/0.3 21/0.3</td>
<td>28.3 13.5</td>
<td>0.6 VOLT NOT INCL VOLT DROP IN RESISTOR</td>
<td>CABLES 4 &amp; 6 CARRY BOTH STARTING AIDS &amp; STARTER SOLENOID CURRENTS.</td>
<td></td>
</tr>
<tr>
<td>STARTER MOTOR SOLENOID</td>
<td>3 4 7</td>
<td>SEE ALTERNATOR CIRCUIT 28/0.3</td>
<td>28.3 14.8</td>
<td>1.0 VOLT</td>
<td></td>
<td>WARNING LIGHT &amp; RESISTOR ESSENTIAL FOR INITIAL ALTERNATOR OUTPUT</td>
</tr>
<tr>
<td>ALTERNATOR WARNING LIGHT</td>
<td>8 9</td>
<td>14/0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**WIRING DIAGRAM — 24V SYSTEMS — NEGATIVE EARTH**

- BATTERIES 2 x 12V or 4 x 6V
- STARTER MOTOR
- AMMETER
- SWITCH 5 TERMINAL/4 POSITION
- SWITCH 4 TERMINAL/4 POSITION
- ALTERNATOR WARNING LIGHT
- 24V/2W WITH 300 OHM 6W RESISTOR
- ALTERNATOR
- STARTING AID RESISTOR
- FUELED STARTING AID
- SEE WIRING DIAGRAM 31807001

**Notes:**
- All cable runs to be kept as short as possible.
- Important! To prevent alternator damage: Never disconnect any lead without first stopping the engine & turning switches to off position. Always identify a lead to its correct terminal when connecting or disconnecting any lead. Never flash connections to check for correct current flow. Never connect a battery into the system without first checking for correct polarity & voltage. Never arc weld on installation without first removing alternator connections. Never run alternator with battery disconnected & field energized.
- **DENOTES EARTH VIA CABLE  **  **DENOTES EARTH VIA FIXING**

31887401
RESISTANCE OF BATTERY CABLES A, B, C, & D NOT TO EXCEED 0.0034 OHM

<table>
<thead>
<tr>
<th>CIRCUIT</th>
<th>CABLE NOS.</th>
<th>MINIMUM CABLE SIZE FOR CIRCUIT CURRENT</th>
<th>CIRCUIT CURRENT (AMPS)</th>
<th>MAXIMUM CIRCUIT RESISTANCE (OHMS)</th>
<th>MAXIMUM CIRCUIT VOLT DROP</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>STARTER MOTOR SOLENOID (VIA RELAY)</td>
<td>1, 2</td>
<td>28/0.3 (STANDARD MOTOR) 35/0.3 (OIL SEALED MOTOR)</td>
<td>14</td>
<td>0.0715</td>
<td>0.0510</td>
<td>1.0 VOLT</td>
</tr>
<tr>
<td>ALTERNATOR CHARGING</td>
<td>3, 4, 5</td>
<td>#50/3</td>
<td>36</td>
<td>0.027</td>
<td>1.0 VOLT</td>
<td>MAX. CABLE SIZE FOR 375 SERIES &quot;LUCAR&quot; TERMINALS — 650.3</td>
</tr>
<tr>
<td>GLOW PLUG RELAY</td>
<td>5</td>
<td>SEE CHARGING CIRCUIT</td>
<td>28/0.3 140/3</td>
<td>4.2 (21.1) 2.1</td>
<td>1.0 VOLT</td>
<td>CABLE 6 CARRIES 2 x RELAY CURRENTS OR STARTER SOLENOID CURRENT PLUS GLOW PLUG RELAY CURRENT. CABLE 6 MUST BE OF SUFFICIENT SIZE TO CARRY OTHER SWITCHED AUXILIARY LOADS. STARTER RELAY TO BE POSITIONED AS CLOSE TO STARTER AS POSSIBLE.</td>
</tr>
<tr>
<td>GLOW PLUG RELAY</td>
<td>6</td>
<td>SEE CHARGING CIRCUIT</td>
<td>140/3</td>
<td>4.2 2.1</td>
<td>1.0 VOLT</td>
<td></td>
</tr>
<tr>
<td>ALTERNATOR CHARGING</td>
<td>7, 8</td>
<td>#50/3</td>
<td>36</td>
<td>0.027</td>
<td>1.0 VOLT</td>
<td></td>
</tr>
<tr>
<td>STARTER MOTOR SOLENOID (VIA RELAY)</td>
<td>9, 10</td>
<td>SEE CHARGING CIRCUIT</td>
<td>28/0.3 140/3 35/0.3 (STANDARD MOTOR) 35/0.3 (OIL SEALED MOTOR)</td>
<td>16.1 (21.1) 14.0 19.0</td>
<td>0.082 0.047</td>
<td>1.0 VOLT</td>
</tr>
<tr>
<td>ALTERNATOR WARNING LIGHT</td>
<td>11, 12</td>
<td>140/3</td>
<td>40</td>
<td>0.0125</td>
<td>0.5 VOLT</td>
<td>INITIAL CURRENT DRAW 170 AMP APPROX</td>
</tr>
<tr>
<td>GLOW PLUGS (VIA RELAY)</td>
<td>13, 14, 15, 16, 17 &amp; 18</td>
<td>#50/3</td>
<td>36</td>
<td>0.027</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ALL CABLE RUNS TO BE KEPT AS SHORT AS POSSIBLE.

IMPORTANT! TO PREVENT ALTERNATOR DAMAGE:

NEVER DISCONNECT ANY LEAD WITHOUT FIRST STOPPING THE ENGINE & TURNING SWITCHES TO OFF POSITION.

ALWAYS IDENTIFY A LEAD TO ITS CORRECT TERMINAL WHEN CONNECTING OR DISCONNECTING ANY LEAD.

NEVER FLASH CONNECTIONS TO CHECK FOR CORRECT CURRENT FLOW.

NEVER CONNECT A BATTERY INTO THE SYSTEM WITHOUT FIRST CHECKING FOR CORRECT POLARITY & VOLTAGE.

NEVER ARC WELD ON INSTALLATION WITHOUT FIRST REMOVING ALTERNATOR CONNECTIONS.

NEVER RUN ALTERNATOR WITH BATTERY DISCONNECTED & FIELD ENERGIZED.

DENOTES EARTH VIA CABLE

DENOTES EARTH VIA FIXING

WIRING DIAGRAM — 24V SYSTEMS — NEGATIVE EARTH — 12V GLOW PLUGS

31887404
LUCAS 128 SA AUXILIARY/HEAT/START SWITCH
4 TERMINAL 4 POSITION SWITCH
SWITCH CONTACTS VIEWED FROM REAR OF SWITCH
SWITCH IS ADVANCED IN 30° STEPS WITH SPRING RETURN TO AUXILIARY
TERMINAL NO. 1 – BATTERY FEED
NO. 2 – AUXILIARIES
NO. 3 – HEATER
NO. 4 – START
TERMINAL NO. 1 – OFF
NO. 2 – AUXILIARIES
NO. 3 – HEAT
NO. 4 – HEAT & START

LUCAS 128 SA AUXILIARY/HEAT/START SWITCH
5 TERMINAL 4 POSITION SWITCH
TERMINAL NO. 1 – BATTERY FEED
NO. 2 – AUXILIARY
NO. 3 – START
NO. 4 – ALTERNATOR
NO. 5 – HEATER
TERMINAL NO. 1 – OFF
NO. 2 – AUXILIARIES
NO. 3 – HEAT
NO. 4 – HEAT & START

ELECTRICAL FUEL SHUT-OFF SOLENOID UNIT (E.S.O.S.)
SERIES RESISTOR FOR 24 VOLT INSTALLATIONS WITH 12V E.S.O.S.
9.1 OHM ± 5% 25 WATT RESISTOR FOR CAV E.S.O.S.
7 OHM ± 5% 25 WATT RESISTOR FOR BOSCH E.S.O.S.
NOT REQUIRED FOR 24 VOLT SOLENOID

ALTERNATOR WARNING LIGHT
12 VOLT 2.2 WATT MAXIMUM
24 VOLT 3.0 WATT MAXIMUM
NOTE: LOADS IN EXCESS OF STATED RATING WILL PREVENT E.S.O.S.
DE-ENERGIZING ON SWITCH-OFF UNLESS DIODE IS FITTED

ALTERNATOR WARNING LIGHT WITH OPTIONAL PARALLEL RESISTOR OR OTHER ALTERNATOR ENERGIZED LOADS, REFER TO INSTALLATION WIRING DIAGRAM
TO ALTERNATOR “IND” TERMINAL
12 VOLT SYSTEM AND E.S.O.S.
24 VOLT SYSTEM USING 12/24 VOLT E.S.O.S. (SEE NOTE AND )
BATTERY RETURN
MAXIMUM VOLT DROP IN CIRCUIT IS NOT TO EXCEED 0.5 VOLT AT A CURRENT OF 1.5 AMPS
1 AMP DIODE MUST BE USED FOR 24 VOLT E.S.O.S. WHEN USING COMMON AUXILIARY FEED FOR AND

ELECTRICAL FUEL SHUT-OFF SOLENOID

3186T001
SECTION 13
Noise Control

INTRODUCTION AND BASIC THEORY ........................................... 159
Introduction ................................................................. 159
Definition of Noise ....................................................... 159
Units of Measurement .................................................... 159
Addition and Subtraction of Decibels ............................. 160
Combination and Elimination of Noise Sources ............ 160
Basic Noise Reduction Techniques ............................... 161

MINIMIZATION OF TOTAL INSTALLATION NOISE ..................... 161
Legislative and Marketing Considerations ..................... 161
Noise Reduction Requirements ...................................... 162
Composition of Total Application Noise ....................... 162
Experimental Identification of Noise Sources ............... 164

ENGINE NOISE ................................................................. 164
Nature of Engine Noise ............................................... 164
Sources of Engine Noise ............................................ 164
Methods of Engine Noise Reduction by Attention to the Engine .......................... 164
Methods of Engine Noise Reduction by Attention to Installation and Application .................................... 165

EXHAUST NOISE ............................................................... 166
Nature of Exhaust Noise .............................................. 166
Exhaust Silencer Types ............................................. 166
Exhaust System Selection and Installation .................. 167

INDUCTION NOISE ............................................................. 168
Nature of Induction Noise ............................................ 168
Induction Silencing Requirements ............................. 168
Air Filter Types ........................................................ 168
Induction System Selection and Installation ............... 168
COOLING FAN NOISE ...................................................... 169
  Nature and Causes of Fan Noise ...................................... 169
  Cooling System Design .............................................. 169
  Radiator Selection .................................................... 170
  Fan Selection .......................................................... 170
  Fan Speed ............................................................... 170
  Cooling System Layout and Installation .......................... 170
  Methods of Cooling Air Flow Regulation ....................... 170

OTHER INSTALLATION NOISE SOURCES ............................ 172
  Transmission and Drive Train ...................................... 172
  Hydraulics System ................................................... 172
  Tires ........................................................................ 172

CAB NOISE ................................................................. 172
  Nature and Causes of Cab Noise ..................................... 172
  Cab Noise Reduction Techniques ................................. 173

NOISE REDUCTION CHECK LIST ..................................... 173

SUPPLIERS OF NOISE REDUCTION MATERIALS AND SERVICES .... 174
INTRODUCTION AND BASIC THEORY

Introduction

Pressures are increasing throughout the world for reduction in the noise of everyday life. Noise is a matter which affects not merely the convenience and comfort of the end-user, but the health and welfare of the whole community. Exposure to high noise levels for extended periods of time can cause damage to hearing, and, as the level of noise increases, so the ability of the human ear to withstand injury falls away sharply. In consequence, it is becoming the pattern in legislation to impose on suppliers of products, an obligation, at each point in the chain of manufacture or sale, to ensure that those products will not generate noise levels which induce hearing loss.

For many years, Caterpillar has played a leading part in the field of noise control of both engines and total installations. The aim of this section is to give guidance on ways in which quiet installations may be achieved, based on experience gained on a wide variety of application types.

It is for each manufacturer, who installs an engine in his equipment, to insure that the noise levels produced by that equipment are compatible with the welfare of those who come within the operating environment. This Section is intended to assist equipment manufacturers in discharging that responsibility.

For more detailed information on topics discussed in the following pages, and for specific advice on particular installation problems, O.E.M.s are invited to contact their nearest Caterpillar Area Operations Office. These offices have available to them the full resources of the Application Engineering Department, Peterborough.

Definition of Noise

Noise is generally defined as “unwanted sound.” Sound itself consists of small pressure variations in the air, the source of which may be either a vibrating structure or a pulsating gas flow.

The criteria by which noise is judged are its level (or intensity) and its frequency composition, which determines its subjective characteristics. The human ear in good condition can detect noise over the approximate frequency range 20 to 16,000 Hz (1 Hz = 1 cycle per second), but is particularly sensitive to noise within the frequency range 500 to 4000 Hz.

Units of Measurement

The most widely used unit of sound measurement is the decibel (abbreviated dB) which expresses, on a logarithmic scale, the ratio between the sound being measured, and a reference sound level. This reference level, known as the “Threshold of Hearing,” approximates to the minimum sound audible to a person with very good hearing.

(It should be noted that, as the decibel is a logarithmic unit, an increase of 3 dB actually represents a doubling in sound intensity. However, the response of the average human ear is such that an increase of approximately 10 dB is necessary for a doubling in subjective “loudness” to be perceived.)

The accompanying chart illustrates typical levels of various everyday sounds.

The measurement unit specified in most noise legislation is the “A — weighted decibel” or dB’A’. This approximately simulates the frequency response of the human ear to noise,

<table>
<thead>
<tr>
<th>SOUND PRESSURE LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>“THRESHOLD OF PAIN”</td>
</tr>
<tr>
<td>dB’A</td>
</tr>
<tr>
<td>140</td>
</tr>
<tr>
<td>LOUD AUTOMOBILE HORN AT 1 m.</td>
</tr>
<tr>
<td>PNEUMATIC RIVETTER</td>
</tr>
<tr>
<td>POWER MOWER</td>
</tr>
<tr>
<td>DIESEL ENGINE UNDER FULL LOAD ON TEST BED AT 1 m.</td>
</tr>
<tr>
<td>HEAVY TRUCK ON FULL THROTTLE AT 7.5 m.</td>
</tr>
<tr>
<td>INSIDE SMALL CAR AT 80 km/h (50 mile/h)</td>
</tr>
<tr>
<td>TYPICAL CITY STREET NOISE</td>
</tr>
<tr>
<td>TYPICAL OFFICE</td>
</tr>
<tr>
<td>AVERAGE CONVERSATION</td>
</tr>
<tr>
<td>QUIET RESIDENTIAL NEIGHBORHOOD</td>
</tr>
<tr>
<td>VERY SOFT WHISPER</td>
</tr>
<tr>
<td>BROADCASTING STUDIO</td>
</tr>
<tr>
<td>SOUNDPROOF ROOM</td>
</tr>
<tr>
<td>“THRESHOLD OF HEARING”</td>
</tr>
</tbody>
</table>

TYPICAL LEVELS OF EVERYDAY SOUNDS
by suppression of noise components at very low and very high frequencies, and amplification of those in the middle frequency range.

Most commercially available noise meters incorporate electrical weighing networks which enable dB’A’ levels to be read directly.

**Addition and Subtraction of Decibels**

In noise analysis and reduction work it is often necessary to calculate the effects of combining or eliminating noise sources. However, since the decibel is a logarithmic unit, noise levels cannot be added together arithmetically — in fact, 80 dB + 80 dB = 83 dB, and not 160 dB. (Thus, an increase of 3 dB represents a doubling of sound intensity.)

While addition and subtraction of decibels can be carried out from first principles by use of logarithm theory, in practice this is not necessary since charts are available for the purpose. A simple chart is illustrated, together with instructions for its use.

**To combine decibels:**

Enter the chart with the NUMERICAL DIFFERENCE BETWEEN TWO LEVELS BEING ADDED. Follow the line corresponding to this value to its intersection with the curved line, then left to read the NUMERICAL DIFFERENCE BETWEEN TOTAL AND LARGER LEVEL. Add this value to the larger level to determine the total.

Example: Combine 75 dB and 80 dB. The difference is 5 dB. The 5 dB line intersects the curved line at 1.2 dB on the vertical scale. Thus the total value is 80 + 1.2 or 81.2 dB.

**To subtract decibels:**

Enter the chart with the NUMERICAL DIFFERENCE BETWEEN TOTAL AND LARGER LEVELS if this value is less than 3 dB. Enter the chart with the NUMERICAL DIFFERENCE BETWEEN TOTAL AND SMALLER LEVELS if this value is between 3 and 14 dB. Follow the line corresponding to this value to its intersection with the curved line, then either left or down to read the NUMERICAL DIFFERENCE BETWEEN TOTAL AND LARGER (SMALLER) LEVELS. Subtract this value from the total level to determine the unknown level.

Example: Subtract 81 dB from 90 dB. The difference is 9 dB. The 9 dB vertical line intersects the curved line at 0.6 dB on the vertical scale. Thus, the unknown level is 90 – 0.6 or 89.4 dB.

**Combination and Elimination of Noise Sources**

By reference to the chart, the effects of adding noise sources can be calculated. An example of the cumulative effects of adding a number of equal sources is illustrated below.

**Cumulative effect of addition of identical noise sources.**

From this example it can be seen that the combined effect of four 80 dB noise sources is 86 dB,

i.e. 80 dB + 80 dB + 80 dB + 80 dB = 86 dB

The addition of a fifth 80 dB noise source increases the total to 87 dB,

i.e. 80 dB + 80 dB + 80 dB + 80 dB + 80 dB = 87 dB,

or 86 dB + 80 dB = 87 dB

Conversely, the removal of one of five equal noise sources reduces the total noise level by only 1 dB,

i.e. 87 dB – 80 dB = 86 dB
This demonstrates that suppression of a minor noise source, or just one of a number of equal noise sources, will have only a limited effect on total noise.

On the other hand, the removal of four out of five equal 80 dB noise sources (i.e. effectively removing one source of 86 dB) reduces the total noise level by 7 dB.

i.e. $87 \, \text{dB} - 86 \, \text{dB} = 80 \, \text{dB}$.

This demonstrates the fundamental principle that, where one noise source is predominant, this must be tackled first if any significant reduction in total noise is to be achieved.

**Basic Noise Reduction Techniques**

Listed below are six basic techniques, each of which performs a basic noise reduction function. These techniques may be used simply or in combination, depending on the characteristics of the noise (for example, whether airborne and/or structure-borne, frequency content, amount of reduction required).

a) **Insulation**

This enables a large reduction in noise to be achieved by imposing a substantial barrier or shield between the noise source and the observer. The degree of noise reduction achieved is a function of the mass of the barrier material used — hence, such materials as steel plate, lead sheet and heavy rubber sheet are particularly effective. Complete sealing of all gaps and aperture is absolutely essential if the full potential benefit of insulation is to be achieved.

b) **Absorption**

In contrast to insulation, the material used for acoustic absorption is porous (for example, polythane foam, fiber-glass blanket, etc), and is usually placed inside the area where the noise source is situated, in order to prevent internal reflection and “build-up” (or reverberation) of noise.

c) **Damping**

This technique is used to reduce the vibration of noise radiating surfaces, for example, flat unsupported panels. Damping can be provided either by the application of a surface treatment, or by making the panel from a material which is inherently well-damped. Damping constrains the flexural bending of the panel and absorbs energy as the material is alternately put into tension and compression. Where the mass of the damping layer is significantly in relation to the mass of the panel, the vibration frequently response characteristics of the panel may be modified with beneficial effect.

d) **Stiffness**

Vibration amplitudes can sometimes be reduced by stiffening (for example, by swaging of sheet metal body panels), usually as a design feature. However, the effect on complex structures, such as engine crankcases, is less predictable, as the effects on the vibration amplitude/frequency characteristics of the increased mass may outweigh the benefits of the increased stiffness.

e) **Isolation**

The principle is to isolate sources of vibration from any surfaces which could generate sound waves. All anti-vibration mountings come into this category, an obvious example being engine mountings which are covered in Section 6 of this manual.

It is also possible acoustically to de-couple one surface from another using a rubber compound so that the vibration of the de-coupled surface is out of phase, and of much lower frequency than that of the exciting force.

f) **Separation**

The total noise from a large complicated source such as a truck or a mechanical excavator can sometimes be reduced by re-positioning the separate sources. For example, the exhaust outlet on a long wheelbase truck can be positioned well away from the engine and gearbox. This often leads to the overall noise level being reduced compared with a tanker or short-wheelbase version of the same vehicle where the separate sources are close together.

**MINIMIZATION OF TOTAL INSTALLATION NOISE**

**Legislative and Marketing Considerations**

These are usually the main factors influencing noise reduction requirements. Sometimes legislation sets specific limits upon maximum noise levels which may not be exceeded. Sometimes it is framed in general terms so as to leave the manufacturer responsible for establishing and implementing noise safety levels in respect of his product. Such legislation tends to be supported or supplemented by marketing considerations which grow increasingly important as operators become noise-conscious.

Noise limits fall into two main categories, concerning:

a) external or third party noise

b) internal or driver/operator noise

In both cases many different test procedures and noise limits may be specified by interested parties, including national, state and local authorities, as well as end users.
Noise Reduction Requirements

In setting noise targets for their products, manufacturers would obviously be wise to identify all legislative and marketing requirements to which the vehicle or machine may be subject. Caterpillar is able to give advice on legislation, which is continuously monitored by Product Legislation staff. O.E.M.s themselves are however probably best able to judge marketing requirements.

Note: A margin should be allowed for “scatter” of noise levels between nominally identical vehicles or machines.

It may be found expedient to offer noise-reduced versions of basic products for operation only in noise-conscious territories. In some cases it may also be possible to “trade off” cooling performance against noise reduction for operation in temperate climates.

Composition of Total Application Noise

The total noise of a complete application is due to the combined contributions of various noise sources. This is illustrated for two typical applications. These noise sources fall into two main categories, (a) engine-related, and (b) application-related.

**Engine-related** noise sources include:
- Exhaust
- Inductions
- Cooling Fan

**Application-related** sources include:
- Transmission
- Hydraulics
- Air brake systems
- Tires

The relative magnitudes of the various noise sources can vary greatly, being dependent upon application type and configuration, and operating conditions.

---

Existing legislation is too extensive and too liable to change to list in this manual, but examples of test specifications and applications are indicated below.

a) **External or third-party noise**

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration test (moving vehicle)</td>
<td>Road vehicles and mobile equipment on public roads.</td>
</tr>
<tr>
<td>Engine acceleration (stationary vehicle)</td>
<td>- Road vehicles, industrial and construction machines, stationary equipment.</td>
</tr>
<tr>
<td>Steady speed test (moving vehicle)</td>
<td>Industrial, construction and agricultural machines.</td>
</tr>
<tr>
<td>Steady engine speed test (stationary vehicle or machine)</td>
<td></td>
</tr>
<tr>
<td>Specified working cycles</td>
<td></td>
</tr>
</tbody>
</table>

b) **Internal or driver/operator noise**

<table>
<thead>
<tr>
<th>Limits applied to:</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum noise level (dB‘A’)</td>
<td>Conditions may or may not be specified.</td>
</tr>
<tr>
<td>Equivalent continuous noise level (Leq)</td>
<td>Specified working cycle.</td>
</tr>
<tr>
<td>Time duration of exposure at specified noise levels</td>
<td>Specified working cycle.</td>
</tr>
<tr>
<td>Noise levels at specific frequencies</td>
<td>Specified conditions.</td>
</tr>
</tbody>
</table>
To illustrate this point, the accompanying diagrams show the noise composition (depicted as proportions of total radiated sound energy) of the total noise emitted by two typical application types. It can be seen that the significance of the various noise sources is completely different for the two cases.

**Sources of Vehicle Noise**

**Sources of Excavator Noise**
Experimental Identification of Noise Sources

In order to be able to carry out noise reduction of an existing application methodically and effectively, it is obviously most important to know which of the various constituent noise sources are actually significant.

Some indication can be obtained experimentally by suppressing individual sources in turn, thus:

- Cooling fan: can be temporarily removed.
- Exhaust system: exhaust note can be suppressed by piping away exhaust or by fitting an additional silencer in series.
- Noise radiated by the silencer shell and exhaust pipes can be suppressed by lagging with asbestos tape.
- Induction system: intake can be piped to a remote position.
- Engine and transmission: noise from these units may be reduced by improvising shielding.

The causes, characteristics and methods of reduction of noise from the above sources are described in the following sections.

ENGINE NOISE

Nature of Engine Noise

Engine noise is considered as being that radiated directly from the basic engine structure alone, with noise from other engine-related systems (exhaust, induction and fan) and accessories completely eliminated. It is, however, possible for engine noise to be transmitted to, and radiated from, interconnected systems (for example, transmission units).

Sources of Engine Noise

Engine structural noise is excited by both combustion and mechanical sources. The areas of the engine which are most responsible to this excitation are typically the sump, cylinder block and crankcase, cylinder head covers, timing case cover and crankshaft pulley.

Methods of Engine Noise Reduction by Attention to the Engine

Apart from fundamental re-design of the engine structure, direct methods of reducing engine noise radiation include speed reduction, combustion system modifications, component modifications, acoustic treatment of engine surfaces, and the use of close-fitting engine shields.

Since engine noise increases rapidly with speed, speed reduction is a most effective technique, and has the advantage of also reducing the effects of other engine-related noise sources (fan, exhaust and induction). In consultation with the engine manufacturer, the lowest possible rated speed compatible with performance requirements should therefore be chosen.

Direct engine treatment is however the responsibility of the engine manufacturer alone, and where required is incorporated in the original engine specification. Engine noise reduction methods available to vehicle and machine manufacturers are therefore applicable only to the installation and complete application.

It is important to bear in mind that any noise reduction achieved by direct treatment of the engine alone will usually have a lesser effect on the total vehicle or machine noise, assuming that other sources remain constant. The reduced effect will vary with the type of application, but as a rough guide an engine noise reduction of 2 dB ‘A’ could be...
expected to give a reduction of about 1 dB'A' on a road vehicle. In the case of industrial and construction machines the effect would probably be considered less.

**Methods of Engine Noise Reduction by Attention to Installation and Application**

The obvious area for attention is the engine compartment, which should be designed from the outset to provide as much shielding of the engine as possible.

Various degrees of noise reduction can be achieved by different combinations of basic acoustic treatments, namely:

**Insulation**
- the use of machine mounted shields to prevent airborne transmission of noise to the observer, both by direct radiation and by reflection from the road surface.

**Absorption**
- acoustic absorbent material (approximately 25 mm 1" thick) applied to inner surfaces of the engine compartment to reduce build-up of noise. The material may be held in place by means of wire mesh or thin metal straps. Absorbent material can also usefully be applied to the surfaces of noise shields. (NOTE: care must be taken to ensure that linings do not become a fire hazard due to absorption of fuel oil. Some suppliers offer absorbent material complete with protective surface treatment.)

**Damping**
- treatment applied to resonant panels to reduce their vibration response and noise radiation capacity.

An example of a typical compound barrier/absorbent material is illustrated.

In the extreme case, for an ultra-low noise machine, treatment should comprise a completely enclosed engine compartment, with cooling air inlet and outlet by means of either a silencing duct, or acoustic louvered lined with absorbent foam or similar material, as illustrated. Apart from the cooling air inlet and outlet the compartment should be as nearly airtight as possible, with acoustic absorbent linings to the sides and top. Sealing strip should be fitted around the edges of detachable panels.

The choice of suitable **resilient engine mounts** is very important in minimizing transmission of vibration and excitation to the machine frame and body work. The subject is covered in detail in Section 6 of this manual.

The avoidance of **fouls** between engine and the machine frame and body work is obviously essential.
EXHAUST NOISE

Nature of Exhaust Noise

On many types of application, this is one of the principal noise sources.

The noise arises from the intermittent release of high pressure exhaust gas from the engine cylinders, causing strong gas oscillations in the exhaust pipe. These lead not only to discharge noise at the outlet, but also to noise radiation from exhaust pipe and silencer shell surfaces. The purpose of the exhaust system is to reduce these gas oscillations and, with the aid of a properly matched silencer, not only can efficient exhaust noise attenuation be achieved, but also sometimes a decrease in the power loss of the exhaust system.

Exhaust Silencing Requirements

For exhaust noise not to be significant, its contribution should be at least 10 dB'A' lower than the target overall noise level of the complete machine or vehicle.

Selection of the most suitable silencing arrangement for a particular application is, to a certain extent, a matter of experience, taking into account the relevant operating factors which include:

— Degree of noise attenuation required
— Exhaust noise frequency characteristics
— Permissible back pressure
— Configuration required
— Space available
— Cost

Silencer manufacturers generally are best qualified to advise on the most suitable designs to meet particular requirements, but the following notes are offered as initial guidelines.

**Exhaust Silencer Types**

The most commonly used types are:

(a) Absorption type — usually of “straight-through” construction, consisting of a perforated tube passing through a chamber packed with an absorption material such as fiberglass. This type usually has a fairly low back pressure, and is mainly effective in suppressing high frequency noise. It is therefore particularly suitable for turbocharged engines where the low frequency pulsations are suppressed by the turbocharger.

(b) Baffle type — in which the exhaust gas flow is subjected to several reversals of direction within the silencer before being discharged. This type is effective over a wide frequency range, but tends to have a higher back pressure than the absorptive type.

In some circumstances, a combination of both silencer types may be necessary.
Expansion chamber — these are used early in the system to dissipate energy quickly or used as a resonator towards the back of the system to reduce noise of a specific frequency.

SIMPLE EXPANSION CHAMBER

DOUBLE CHAMBER EXPANSION

Exhaust System Selection and Installation
(Refer also to section 9.3)

(a) Silencer Dimensions

The two principal guidelines are:

- **Volume** — for effective silencing, this should be of the order of 3 to 5 times engine cubic capacity, for both naturally aspirated and turbocharged engine installations.

- **Cross-sectional area** — this should be large, e.g. a silencer of 180 mm (7 in) diameter by 300 mm (12 in) length is preferable to one of 100 mm (4 in) by 900 mm (36 in) length, although both have volumes of approximately 7.5 liters (460 cubic in). Ideally, the ratio of silencer body diameter to inlet pipe diameter should be of the order of 4 or 5 to 1.

The most elementary silencer in accordance with the above guidelines on dimensions should give 10-15 dB'A' attenuation of open exhaust noise, while more sophisticated designs (e.g. of more complex internal construction, or having double-skinned or wrapped casings) may give up to 25-35 dB'A' reduction.

The guidelines on silencer volume and cross-sectional area apply equally to cylindrical and oval section units although, from manufacturing and reliability considerations of cylindrical form is preferable.

(b) Exhaust System Configuration

**Silencer position** (see diagram opposite)

There is some divergence of opinion amongst exhaust system specialists as to the ideal position. However, experience has shown that the silencer, or at least an expansion chamber should be within approximately 1.5 m (4 ft) of the exhaust manifold.

Silencers should not be mounted in the engine compartment, due to the resulting higher under bonnet temperatures and the subsequent loss of cooling performance, particularly if a pusher fan is used.

**Pipework** (see diagram)

**Tail pipe length** is best determined by “tuning”. Where the silencer is very close to the manifold, e.g. within 500 mm (20 in) as on many agricultural tractors and earth moving machines, the tail pipe should be at least equal to this length. However, long tail pipes may create obtrusive exhaust notes under some conditions, necessitating the fitting of an additional volume of “resonator” near the end of the system, tuned to suppress noise at particular frequencies. (Note: when tuning an exhaust system, noise and back pressure must both be considered.)

**Twin down pipes** — where these are used, as on V8 engines, they should go straight into the silencer, or join in an expansion chamber/junction box, rather than having the exhaust pipes siamesed together and then going on to a silencer. Twin exhaust systems all the way through often produce more noise than twin down pipes to a junction box.

**Outlet position** — taking into account the noise regulations or requirements to be met (i.e. bystander, operator, etc.) some advantage may be gained by directing the outlet away from microphones or observers. It is most important to select the direction of the tail pipe exit so that the exhaust smoke:

- is not drawn into any dry element air cleaner subsequently rapidly clogging the element and reducing service life.

- is not drawn back through the radiator by a puller fan installation. This is likely on combines where exhaust exit and radiator entry are usually both on top of the machine.

- is directed away from the sight lines of the machine operator.

(c) Exhaust System Construction

Silencers and exhaust pipes are commonly of 16 gauge steel (1.5 mm thickness). Where larger degrees of noise attenuation are required radiated noise from body shells and pipes may be reduced by means of silencers having wrapped or sandwich-type constructions, and by use of double-skinned exhaust pipes, obtainable from some manufacturers.
(d) Exhaust System Installation

The exhaust pipe run should avoid touching or passing close to the air cleaner, fuel and lubricating oil filters, fuel tank or piping, injection or fuel lift pumps, radiator or sump, and also dynamo, alternator, starter motor and wiring. If this is unavoidable, a suitable heat shield should be used. Batteries, instrument capillaries and rubber parts should not be sited in the vicinity of the exhaust manifold or piping.

Where the engine is flexibly mounted, the exhaust system should be isolated from body work by means of flexible mounts (e.g., shear rubber) to ensure that noise and vibration excitation is not transmitted to body panels. The attachment points should be structurally stiff.

For minimum noise, pipe joints and connections should obviously be free from leaks, and should be maintained in good condition.

INDUCTION NOISE

Nature of Induction Noise

The induction system can make a significant contribution to overall bystander or operator noise on some application types.

Intake noise is caused by the pulsating flow of air through the system. The fundamental frequency of the sound waves thus created is equal to the engine firing frequency, but harmonics at higher frequencies also occur. The noise characteristics will be influenced by manifold and inlet port arrangements, valve timing, ducting arrangement, and type of aspiration, i.e. natural or turbocharged.

Induction Silencing Requirements

For this source not to be significant, its contribution should be at least 10 dB’A’ lower than the target overall noise level of the complete machine.

Air filter manufacturers are well qualified to advise on the best choice of silencer to meet particular requirements, but the following notes are offered as initial guidelines.

Air Filter Types

The two main types are:

a) Oil bath

b) Dry element

Heavy duty versions of both types, incorporating some form of expansion chamber, are quite effective as silencers, but the two-stage dry element type is considered to be the most efficient. If the degree of silencing obtained is insufficient, then another silencer may be added in series with the cleaner unit.

It is essential that the permitted restriction levels should not be exceeded.

Induction System Selection and Installation

Intake silencer dimensions

In general, air filters having volumes matched to air flow requirements, as described in Section 8 of this manual, will provide adequate silencing, although the ratio of body diameter : intake should be large. Ratios of 3 or 4:1 should give reductions in induction noise ranging from 10 dB’A’ in the case of simple units, up to 20-25 dB’A’ for more elaborate units.
Intake system configuration

The air filter should be located as close as practicable to the engine, while the intake should be directed or positioned away from the observer or microphone. Intake stacks may be helpful for this purpose.

The use of an additional absorption type silencer unit at the intake may also be found beneficial in suppressing high frequency noise, particularly in the case of turbocharged engines. Various proprietary units are marketed.

Installation

Pipes should be of round section, and of heavy wall construction to ensure good acoustic barrier properties. It is very important to ensure that the system is airtight at all times.

COOLING FAN NOISE
Nature and Causes of Fan Noise

The term “fan noise” is commonly used to describe noise created by the interaction between the fan and the cooling system air flow. It is now widely recognized that on heavy vehicles and machines this noise source can make a significant contribution to total noise of the installation.

Fan noise may comprise discrete frequency components (characteristic of obstructions in the air flow path) or cover a wide frequency range, due to eddies and turbulence in the airstream. In either case the noise is greatly influenced by the design and configuration of the whole cooling system.

Cooling System Design

For a given power unit heat rejection, there is a large number of combinations of fan type, fan speed and radiator type which will provide the required cooling. The choice of a cooling system package giving the optimum combination of components for low noise is therefore important.

There are also considered benefits to be obtained in respect of cooling efficiency, low noise and low fan power absorption, by ensuring that the system layout provides for a smooth cooling air flow path free from obstructions and deviations. The use of an efficient fan cowl with low blade tip clearances is strongly recommended.

In view of the possible variations in installation size, configuration, accessory cooling requirements and target noise levels, it is not possible in this manual to specify complete cooling systems to meet particular application/engine requirements. The notes given below are therefore intended only as guidelines in the choice of suitable components for “typical” installations.

O.E.M.’s wishing to select cooling system components for particular installations are invited to consult Caterpillar Application Engineering Department for specific recommendations based on the latest available data.

(a) Typical standard-efficiency radiator fin form. Uses — non-clog applications, where high mechanical strength is essential, e.g. construction machines.

(b) Typical continuous louvered fin construction for medium and high-efficiency radiators (depending upon core density). Moderate mechanical strength. Uses — agricultural, industrial and construction machines and commercial road vehicles.

(c) Typical folded fin construction for medium and high-efficiency radiators (depending upon core density. Uses — mainly automotive applications, where high mechanical strength is not required.

EXAMPLES OF RADIATOR CORE FIN TYPES
Radiator Selection
As a general rule the largest possible core area which can be accommodated should be specified. This enables both air flow volume and system pressure drop to be kept to a minimum, with consequent minimization also of fan noise.

For the same reasons the use of high-efficiency radiators is recommended. Examples of radiator fore fin constructions of various efficiency levels are illustrated.

For a given core type area and heat dissipation, the air flow requirement and system pressure loss will vary with core thickness, and there will be an optimum thickness for minimum noise and power absorption. (As an approximate guide, it has been found that on applications having low cooling system noise levels, the air velocity through the radiator core is usually less than 8 m/sec 25 ft/sec).

By careful consideration of the above factors, the air flow requirement and system pressure loss can be reduced so that a lower output is required from the fan, giving lower noise levels and power consumption.

From details of particular installation configuration and operational requirements, Caterpillar can offer specific recommendations on radiator selection.

Note:
— Final choice of radiator will take into account:
— Heat dissipation requirements
— Permissible fin and tube densities in relation to working environment.
— Mechanical robustness in relation to likely dynamic loads during operation.

Fan Selection
Where possible a puller type of fan should be used (i.e. fan situated downstream of the radiator) in preference to a pusher type (fan situated up-stream of the radiator). The engine and ancillary components situated on the inlet side of a pusher fan severely affect its noise level and performance, whereas a puller fan will have the engine on its outlet side, where it has less effect.

In general the largest diameter, lowest speed fan should be used, with the lowest possible tip clearance (ideally less than 1% of fan diameter). If a large tip clearance must be used (say, greater than 2% of fan diameter), care must be taken to ensure that the fan is not running in the stall condition (ref. fan manufacturers’ performance data).

For each fan diameter, a choice will be available of puller and pusher types, number and spacing of blades, blade widths and pitch angles, and possibly fan drive ratio. For particular installations Caterpillar can make recommendations for fan specifications to give the optimum combination of air flow, pressure and speed characteristics for operation in the low noise, high efficiency zone just below the stall region.

Fan Speed
Where a choice of fan drive ratios is available, the ratio should be selected which gives the lowest practicable fan speed, taking into account air flow volume and pressure characteristics.

On some applications there may be considerable advantages to be gained in terms of noise, efficiency and power saving by the use of viscous or clutch fan drives. (See also METHODS OF COOLING AIR FLOW REGULATION.)

Cooling System Layout and Installation
Fan noise is greatly increased by distortion of the air flow passing through it, but this can be minimized by attention to the following:

(a) The fan should lie on the same flow axis as the radiator, and should not overlap the edges of the radiator core.

(b) If fan diameter is well matched to the radiator dimensions, the optimum spacing between fan and radiator is in the range 1/2 to 1 blade width. For poor matching the spacing should be increased.

(c) Obstructions likely to induce air flow distortion should be removed from the fan inlet, particularly with pusher fans. Obstructions downstream of the fan produce less distortion in the fan plane, and if kept one-third of a diameter from the fan should have negligible effect. (Examples of typical obstructions include hoses, pipes, alternators, etc.).

(d) A fan cowl should always be used in the interests of high efficiency as well as low noise. (Note however that the use of a fan cowl does not itself reduce fan noise, but by increasing air flow efficiency may enable fan speed or size to be reduced. Fan power absorption will also be reduced.)

As explained in SECTION 7, COOLING SYSTEM, a tapered cowl form is ideal in order to allow smooth air flow between radiator and fan. Examples of good tapered cowl/fan arrangements are illustrated for:

— puller fan (1/3 of projected blade width protruding from cowl outlet,
— pusher fans (2/3 of projected blade width protruding from cowl outlet.

An example is also shown of a box-type cowl used in conjunction with a pusher fan.

It should be noted that the position of the cooling fan relative to the cowl has a considerable effect on efficiency. The configurations illustrated have been found to give generally satisfactory results, but in particular cases some further improvement may be obtained by adjustment of the fan position, the optimum position being determined by experiment.

(e) Blade tip clearance can be minimized by use of an engine-mounted fan ring. This eliminates relative movement between fan and ring, while relative movement between the engine and radiator can be accommodated by means of a flexible section in the cowl.

(f) Barriers should be fitted where necessary to prevent recirculation of air between downstream and upstream sides of radiator as this creates turbulence, with consequent increase in noise.

For further information on cooling system details and layout, see SECTION 7, COOLING SYSTEM.
IDEAL RADIATOR/COWL/FAN ARRANGEMENT FOR USE WITH PULLER FAN

RADIATOR/COWL/FAN ARRANGEMENT FOR USE WITH PUSHER FAN

ALTERNATIVE RADIATOR/COWL/FAN ARRANGEMENT FOR USE WITH PUSHER FAN AND BOX TYPE COWL
Methods of Cooling Air Flow Regulation

Radiator shutters and blinds
Thermostatically-controlled shutters may be used to maintain optimum working temperatures. In the “open” position they can however create considerable interference to smooth cooling air flow, with consequent increase in fan noise, while in the “closed” position they can also cause a significant increase in noise, since the reduced air flow is likely to cause the fan to go into a “stall” condition. Closed shutters also create additional internal reflecting surfaces which can lead to further build-up of noise within the engine compartment.

Thermostatically-controlled fan drives
As a means of air flow control, thermostatically-controlled fan drives of either the “on-off” or variable-speed type are preferable to shutters in respect not only of noise but also of efficiency and power saving.

The advice of Caterpillar Application Engineering Department should however be sought if the use of such drives is contemplated.

OTHER INSTALLATION NOISE SOURCES

Transmission and Drive Train
Noise under this heading falls into two main categories:

a) noise originating from transmission units and drive train, arising from design, manufacture or assembly, or from excessive wear of components;

b) noise radiated from transmission casings, housings, etc., due to direct excitation from the engine structure.

Some reduction of noise at source may be achieved by the transmission manufacturer and installer, by attention to manufacturing tolerances, etc., and by use of effective isolation techniques.

Further noise reductions will require the use of shielding or enclosure techniques, as described in METHODS OF ENGINE NOISE REDUCTION BY ATTENTION TO INSTALLATION AND APPLICATION. Transmission shields may in fact, most conveniently be combined with engine shields as single units. (Note: care should be taken to ensure that safe working temperatures are not exceeded.)

Hydraulics Systems
In general, hydraulic systems do not add significantly to overall noise levels. They can however, create a nuisance, particularly inside a cab, due to their distinctive frequency characteristics, which may cause them to be clearly audible to the human ear. Noise problems associated with the pump unit itself should be referred back to the pump manufacturer for assistance.

Other hydraulic system noise may be minimized by attention to the following points:

a) Pumps and associated valves, etc. should if possible be flexibly mounted to prevent transmission of vibration.

b) The main hydraulic components should, if necessary, be sited inside an acoustic enclosure (e.g. the engine compartment), or positioned remotely from operators, observers, etc.

c) Flexible pipes should be used in preference to rigid pipes to avoid pipe resonance.

d) Avoid rigid pipe attachments.

e) Avoid sudden changes of section and direction in the hydraulic system.

f) Servo-actuated controls can reduce noise transmission to cabins.

Tires
On some application types, tires can be a major source of noise. This particularly applies to road vehicles operating at speeds above 55-66 km/h (35-40 mph).

Tire noise characteristics are dependent upon a number of factors, including:

— Tire construction and material.

— Tread pattern.

— Degree of tire wear.

— Wheel and tire alignment and balance.

— Road surface.

— Load.

— Inflation pressure.

— Road speed.

As a general guide, it can be stated that radial-ply tires are quieter than cross-ply, and that circumferential rib treads are quieter than cross-bar treads. However, the final choice of tire must be made in consultation with the tire manufacturer in order to achieve the optimum combination of traction, wear and noise characteristics.

CAB NOISE

Nature and Causes of Cab Noise
Cab noise usually comprises a combination of airborne noise entering the cab from various external sources (engine, exhaust, fan, etc), and noise radiated from directly-excited structural parts of the cab itself.

Noise due to both causes may be reinforced by reflection or reverberation within the cab interior.

(Note: radiated and reflected noise can also occur where overhead guards are fitted.)
Cab Noise Reduction Techniques

Substantial noise reductions can often be achieved by judicious application of the basic principles of insulation, damping and absorption, as detailed below:

a) Eliminate the paths by which airborne noise can enter the cab interior. This involves closing and sealing all gaps, apertures and joints by means of sheet metal panels, rubber sheet, sealing strip, etc. Effective gaiters should be used where control levers, etc., pass through holes in body panels. Heater ducts which discharge into the cab can also transmit noise, and should therefore incorporate acoustic lining and/or baffles if possible.

b) Noise transmission through floor panels and engine housing panels should be minimized by use of substantial barrier matting, an example of which is illustrated.

c) Whenever possible the cab should be isolated from the machine frame by means of resilient mounts, in order to minimize excitation of cab body panel vibration.

   (If flexible cab mounting is not possible, individual panels may be decoupled from their surroundings by means of flexible connections, as illustrated.)

d) Panel vibration can further be reduced, either by fabrication from high-damping material or by the application of damping treatment. This is most conveniently achieved by use of proprietary self-adhesive damping pads (which in some cases are available in combination with absorption material.)

e) Reflected noise inside the cab can be reduced by use of acoustic absorbent material, which can be obtained if required with decorative finish for improved appearance.

(Note: as cab noise typically exhibits a substantial low-frequency noise component, the use of at least 25 mm (1 in) thick absorbent material is recommended.)

![Diagram of floor insulation treatment]

NOISE REDUCTION CHECK LIST

1. Which legislative procedures and noise limits are relevant to:
   (a) the application?
   (b) the market territories? (Ref. LEGISLATIVE AND MARKETING CONSIDERATIONS)

2. What degree of noise reduction is necessary to meet the required limits?

3. Which are the most prominent noise sources? (Ref. COMPOSITION OF TOTAL APPLICATION NOISE and EXPERIMENTAL IDENTIFICATION OF NOISE SOURCES).

4. Practical methods of noise reduction:
   (a) Cooling system: (Ref. COOLING FAN NOISE).
      (i) Is the largest possible radiator fitted?
      (ii) Is the fan well matched to the radiator?
      (iii) Could a lower fan speed be used?
      (iv) Is a fan cowl fitted?
      (v) Is the airstream free from obstructions?
   (b) Exhaust system — is the silencer large enough? (Ref. EXHAUST NOISE).
(c) Induction system — is the air cleaner large enough? (Ref. INDUCTION NOISE).

(d) Engine — due to the relatively limited effect which engine modifications and treatment have on total machine noise, the following approaches are worth consideration, depending upon the amount of noise reduction required: (Ref. ENGINE NOISE).

(i) Could the rated speed be reduced?

(ii) Would the application of simple shielding to the machine be beneficial?

(iii) Could the engine compartment be redesigned as a complete enclosure?

(e) Transmission — should shielding be applied to the machine? (Ref. TRANSMISSION AND DRIVE TRAIN).

(f) Hydraulics: (Ref. HYDRAULICS SYSTEMS).

(i) Are the pipes resonating?

(ii) Can any rigid pipe attachments be eliminated?

(iii) Can any sudden restrictions or sharp bends be avoided?

(g) Cab noise: (Ref. CAB NOISE).

(i) Are there holes and gaps through which airborne noise can be transmitted from various sources to the cab interior?

(ii) Are there any paths by which mechanical vibration can be directly transmitted to the cab structure?

(iii) Are cab floor, side and roof panels sufficiently well treated with acoustic material?

SUPPLIERS OF NOISE REDUCTION MATERIALS AND SERVICES
Names and addresses can be supplied by Caterpillar Application Engineering Department on request.
INTRODUCTION .................................................................176

INSTRUMENTATION — ESSENTIAL REQUIREMENTS ...............176

ENGINE OIL PRESSURE AND TEMPERATURE .........................176
  Low Oil Pressure Warning Light ......................................176
  Oil Pressure Gauge ......................................................176
  Engine Oil Pressure Tappings ..........................................176
  Pressure Gauge Pipework ..............................................176
  Electrically Operated Pressure Gauges .............................176
  Lubricating Oil Temperature ..........................................176

ENGINE COOLANT TEMPERATURE .......................................176
  Coolant Temperature Gauge ..........................................176
  Coolant Temperature Tapping Positions ............................177
  High Coolant Temperature Warning Light/Alarm ..................177

ALTERNATOR/DYNAMO WARNING LIGHT AND/OR AMMETER ........177

ENGINE SPEED INDICATORS (TACHOMETERS) AND HOURMETERS ....177
  Engine Speed Indicators (Tachometers) ............................177
  Hourmeters ..............................................................177

ENGINE CONTROLS ........................................................177
  Starting Control .........................................................177
  Excess Fuel Device ....................................................177
  Engine Speed Control ..................................................178
  Engine Stop Control ....................................................178

AUTOMATIC ENGINE PROTECTION EQUIPMENT ........................178
  Introduction ............................................................178
  Fuel Cut-Off Valve .....................................................178
  Electrical Shut-Down Systems .......................................178
  Switch Settings (Engine Coolant Temperature and Oil Pressure)
    for Engine Protection/Alarm Systems ............................178
  Emergency Engine Shut-Down by Inert Gas Induction ............179
INTRODUCTION
The instrumentation covered in this section is that included as part of the installation in order to provide information to the operator, to initiate operation of warning or engine shut-down systems in the event of malfunction arising.

For details of instrumentation requirements for application testing as part of the installation sign-off procedure, see SECTION 15, APPLICATION TESTING.

INSTRUMENTATION — ESSENTIAL REQUIREMENTS
In order to give warning of engine or cooling system malfunction, and so assist in the prevention of possible engine failure, Caterpillar minimum instrumentation requirements are as follows:

1. A warning light to give indication of low engine oil pressure.
2. A temperature gauge, of appropriate range and markings, to indicate engine coolant temperature at the location provided in the cylinder head, or thermostat housing/water outlet body, depending on the engine type.

In the case of Vee engines, two gauges are required, to indicate coolant temperature in both banks.

These basic requirements may be supplemented by additional instrumentation, warning systems, and, particularly in the case of applications required to operate unattended for extended periods, by an automatic engine protection system — see AUTOMATIC ENGINE PROTECTION EQUIPMENT.

ENGINE OIL PRESSURE AND TEMPERATURE
Low Oil Pressure Warning Light
Details of suitable low oil pressure switches are given in the SOS2 catalogs for the various engine types. If switches other than these are used, their operating settings should conform to the limits shown in SWITCH SETTINGS, (ENGINE COOLANT TEMPERATURE AND OIL PRESSURE) FOR ENGINE PROTECTION/ALARM SYSTEMS.

Oil Pressure Gauge
Although, as previously stated, the minimum requirement may be met by a low oil pressure warning light, it is strongly recommended that this should be supplemented by a suitable pressure gauge. This will give an indication of any reduction from nominal operating pressure, and will enable action to be taken when necessary to prevent possible breakdown. Details of suitable low oil pressure gauges are included in the SOS2 catalogs for the various engine types.

Engine Oil Pressure Tappings
Tappings are provided in all engine types, either in the main oil pressure rail in the cylinder block, or in the lubricating oil filter adapter. Reference should be made to the appropriate engine handbook or arrangement drawing.

Pressure Gauge Pipework
In installations where there is little engine movement, steel or copper pipe of 4.76 mm (0.1875 in) outside diameter may be used. The pipe should incorporate two or three axial coils at either the gauge or the engine end, to absorb any relative movement or vibration, and should be suitably secured along its length. In all cases where there is significant engine movement, however, as in many flexibly mounted engine installations, connection should be made by means of steel or copper pipe in conjunction with a flexible pipe at the engine end. The junction of the flexible to the rigid pipework should be anchored, to prevent flexing and possible failure of the rigid pipe.

The flexible pipe section must be of oil-resistant armored construction, and able to withstand working conditions with respect to temperature and pressure. Only screw type end connections should be used.

Plastic or semi-rigid nylon tubing is not suitable for this duty, since it is easily damaged in service due to chafing or crushing, leading to the possibility of loss of oil pressure and engine failure.

Electrically Operated Pressure Gauges
These are widely available, and may be used as an alternative if required.

Lubricating Oil Temperature
It is not usual to provide a lubricating oil temperature gauge as part of the normal installation instrumentation. In the case of engines with integral oil coolers as part of the engine build, oil temperature will be satisfactory providing coolant temperature does not exceed the specified limits (see SECTION 7, COOLING SYSTEM).

In other cases, oil temperature must be checked as part of the application “sign-off” procedure (see SECTION 15, APPRAISAL AND TESTING) in order to establish the maximum permissible operating temperature.

If for some special reason it is required to provide lubricating oil temperature measurement as part of the installation instrumentation, this must be carried out in the main oil pressure rail, lubricating oil filter head or filter adapter, and reference must be made to Application Engineering Department, Peterborough for more detailed information.

Measurement of oil temperature in the sump is not satisfactory, since considerable temperature variations are likely to exist, according to the depth and position of the sensing probe.

ENGINE COOLANT TEMPERATURE
Coolant Temperature Gauge
Details of suitable coolant temperature gauges are given in the SOS2 catalogs for the various engine types. Both capillary and electrical types are available. In the case of the capillary type, care should be taken to route the capillary tubing clear of heat radiated from the exhaust system, otherwise false readings may occur.
It is essential that the thermometer bulb or sender probe should be completely immersed in the coolant in order to ensure accurate readings. In the case of the instruments shown in SOS2 catalogs, correct immersion will be achieved provided that the bulb or sender is screwed directly into the specified tapping point without the use of an intermediate adapter. If instruments other than those detailed in SOS2 catalogs are used, care should be taken in ensure that full immersion is achieved.

Coolant Temperature Tapping Positions
All engine types have tappings provided for measurement of coolant temperature. Depending on the engine type, these may be in the cylinder head, or the thermostat housing/water outlet body, and reference should be made to the appropriate engine handbook or arrangement drawing.

High Coolant Temperature Warning Light/Alarm
In conjunction with a coolant temperature gauge, a temperature-operated switch may be fitted, to operate a warning light or audible alarm in the event of coolant temperature reaching a dangerous level.

For switch setting temperature, see paragraph, SWITCH SETTINGS, (ENGINE COOLANT TEMPERATURE AND OIL PRESSURE) FOR ENGINE PROTECTION/ALARM SYSTEMS.

ALTERNATOR/DYNAMO WARNING LIGHT AND/OR AMMETER
A warning light and/or an ammeter should be fitted, to give warning of any fault resulting in a loss of charging current — see SECTION 12, ELECTRICAL SYSTEMS.

ENGINE SPEED INDICATORS (TACHOMETERS) AND HOURMETERS
Engine Speed Indicators (Tachometers)
All engine types have provision for a tachometer drive. Both electrical and mechanical types are available, and details of these are available from Application Engineering Department, Peterborough.

Hourmeters
Hourmeters are available to fit most engine types, and details of these are available from Application Engineering Department, Peterborough.

ENGINE CONTROLS
Starting Control
The engine starting control must be positive in action, easily understood by the operator, and located for convenient operation.

Where a cold start aid is fitted, a composite switch as illustrated should be used. Approved four-position switches have a positive stop at the “heat” position, which makes it easy to return to this position after starting, if necessary.

If a separate heat or aid button is used, it must be located close to the starting control.

If a cold starting aid is fitted, instructions for its use must be clearly displayed.

The legal position in respect of these devices should be established by the equipment manufacturer in all cases, and action should be taken to conform to the relevant requirements.

Excess Fuel Device
Certain engine types incorporate an excess fuel device in the fuel pump, which must be actuated by the operator prior to starting from cold below a certain ambient temperature, depending on the engine type.

As with electrically heated starting aids, the equipment manufacturer should ensure that excess fuel devices comply with legislation prohibiting their operation during normal engine running.
When a remote actuating arrangement is fitted due to inaccessibility of the device in the installation, care must be taken that this will not result in excessive loads being applied at the fuel pump.

**Engine Speed Control**

In variable speed applications, operation of the speed control lever may be effected through a rod or cable linkage, or through a combination of these, or in certain cases by means of an electrical or other actuator. In all cases, it must be ensured that excessive loadings are not applied at the lever. Where there is a danger of this, as in pedal operated mechanisms (vehicles and other mobile applications, etc), an adjustable stop must be provided, either under the pedal or in the linkage. This must be set to limit pedal travel, so that the load is taken by the pedal/linkage stop rather than by the maximum speed stop at the fuel pump.

The control linkage or cable should incorporate a means of fine adjustment (normally by means of a screw thread), to allow initial setting and adjustment for wear in service.

When necessary, a return spring should be fitted either at the fuel pump or in the control linkage, or both. When a rod type control is fitted to the speed control lever, a swivel type ball joint is recommended, incorporating a threaded end to allow fine adjustment.

**Engine Stop Control**

This may be operated by means of a cable or rod mechanism, or by means of a suitable electrical or other actuator. A spring should be fitted where necessary, to return the linkage to the “run” position when the stop control is released.

For safety reasons, it is essential that the stop control is easily accessible to the operator, and that it should be immediately identifiable for use by other persons in an emergency.

**Automatic Engine Protection Equipment**

**Introduction**

In applications which are required to operate unattended for extended periods, it is recommended that automatic engine protection equipment should be fitted.

Various proprietary systems are available, designed to shut the engine down automatically in the event of coolant temperature, engine oil pressure, engine speed, or other possible parameters falling outside safe limits.

**Fuel Cut-Off Valve**

It should be noted that engine shut-down systems utilizing an electrical or other cut-off valve in the fuel system, and separate from the fuel injection pump, are not recommended by Caterpillar.

This arrangement must not be used in the case of a hydraulically governed engine, since operation of the valve will result in loss of governing and a dangerous engine “run-away” condition.

The valve may be used with mechanically-governed engines, but the following points should be noted:

1. The valve should be used as a means of emergency shut-down only, since experience has shown that, if used as a regular means of shut-down, aeration in the fuel system may result, leading to starting problems.
2. The engine may run on for a considerable period after operation of the valve, depending on load and speed conditions.
3. It must be ensured that fitment of the valve does not result in the introduction of foreign matter into the fuel system.

This is normally achieved by arranging for the actuator of the shut-down control to hold the stop lever in the “run” position, against a return spring.

Engine shut-down should be effected by operation of the stop lever at the fuel pump, either by an electrical, or other type of actuator, or, in the case of some proprietary systems by a spring-operated mechanical linkage. In all cases, the shut-down arrangement should be of the “fail-safe” type. It is the responsibility of the installer to select a system appropriate to the application type and its operating conditions, taking full account of the potential consequences of sudden engine shut-down.

**Electrical Shut-Down Systems**

In order to achieve “fail-safe” operation of solenoids not integral with the fuel injection pump, the solenoids may need to be of either the “energized to run” or “energized to stop” type, depending on the circumstances mentioned above.

Requests for information regarding all shut-down operating devices available from Caterpillar should be addressed to Application Engineering Department, Peterborough.

**Switch Settings, (Engine Coolant Temperature and Oil Pressure) for Engine Protection/Alarm Systems**

Temperature and Pressure operated switches used in conjunction with automatic engine protection systems should have the following settings:

**Coolant temperature**

The switch should be set to operate as a level 3°C below Caterpillar maximum acceptable temperature for the operating altitude and pressure cap setting in use — see SECTION 7, COOLING SYSTEM.

Operating accuracy should be within 3% of the nominal setting.

**Engine oil pressure**

The switch should be set to operate in the range 60 – 90 kN/m² (8.7 – 13 lbf/in²).
If it is required to incorporate engine protection “triggered” by operating parameters other than coolant temperature and oil pressure, Application Engineering Department, Peterborough should be consulted with regard to the applicable limiting values.

**Emergency Engine Shut-Down by Inert Gas Induction**

Emergency shut-down packages are sometimes required to satisfy standards for operation in environments which may become laden with combustible fumes in exceptional circumstances. In such cases specific information and advice should be obtained from Application Engineering Department, Peterborough.

As a general policy, however, Caterpillar recommends the use of combined Carbon Dioxide Injection and Strangler Valve Emergency Engine Shut-Down Systems. Caterpillar does **not** recommend:

— use of Strangler valves alone

— use of gas injection with BCF (bromo-chlorodi-fluoromethane) or other similar fire extinguishing gases, with or without a strangler valve in association.
APPLICATION APPRAISAL

Introduction

This section sets the standards covering the Appraisal Testing and Application Sign-off for guidance and standardization by all Operating Units.

The Appraisal Data Sheets and Sign-off Document have been specifically compiled to form a step-by-step appraisal procedure, terminating with the actual application sign-off. The Data Sheets constitute a “check list” ensuring that all necessary items are examined and recorded, reflecting the recommended standards of the foregoing sections in this manual. It is important to complete all items on the Appraisal Data Sheets.

Installation recommendations for each topic are not incorporated in this section as they are included in previous sections of the manual. Therefore, reference must be made to each section for advice, to ensure that the installation is to a satisfactory standard.

While the preliminary cooling system design is necessarily based on calculations, the suitability of a particular system must be determined by actual tests, which must be representative of the most severe operational conditions likely to be experienced in service.

Optional equipment specified by the O.E.M. must be clearly defined and detailed on the appraisal, and the appraisal and testing must include and cater for such equipment.

Meeting the higher operating ambients involves additional costs to the O.E.M. in respect of some applications, but experience has proved that unless customers can strictly define and control the ultimate territories where equipment will in fact be operating, the recommendations by Caterpillar to cater for the most severe operating conditions are justified.

With increasing emphasis on world-wide standardization, particularly of Industrial, Construction and Farm machinery models, giving manufacturers flexibility to ship machines and parts between different areas of the world, it is strongly recommended that cooling systems are designed so that machines may operate anywhere without changes to the cooling system.

To meet Operating Units’ specific requirements the Appraisal format may be translated, but it is essential to maintain the numbering system adopted.

Copies of all appraisal documents must be forwarded to Application Engineering Department, Peterborough, to enable the information to be tabulated and recorded for future reference and guidance for all Operating Units, and also for reference in respect of information required by Claims and Service Divisions. This request applies equally to applications which are approved or not approved.

World Ambient Operating Temperature

Guidelines for minimum ambient operating clearance temperatures for operation of Caterpillar powered applications have been established. These are based on official meteorological records of world ambient temperatures, and on practical experience accumulated over many years by Caterpillar Application Engineers, both from Peterborough and local Operating Units.

General recommendations for minimum ambient operating clearance temperatures are:

Europe 40°C
Rest of World 46°C

It is recognized that temperatures determined on this broad basis cannot cater for every conceivable operating condition, or for unusual climatic or topographical features of particular geographical locations. Due allowance should therefore be made for such cases.

It is the responsibility of the O.E.M. to ensure that the cooling specification is suitable for all areas where the machine will operate.

More specific guidance on clearance temperature requirements for specific operating conditions and territories can be obtained from Applications Engineering Department, Peterborough, and from local Caterpillar Operating Units.

For customers exporting machines and/or manufacturing in different parts of the world, a standardized cooling system is strongly recommended which is suitable for world-wide use, facilitating spare parts stocking and servicing.

APPLICATION APPRAISAL TESTING

Introduction

The test procedures outlined in this Section have been prepared to provide guidance in conducting the various tests associated with the Installation Appraisal.

One of the main objectives is trying to ensure that temperatures and other data are always recorded at the same point. In the past, engine oil temperature has been recorded at various points by different Operating Units and O.E.M. customers, with significant variations in results obtained. In order to avoid this situation, oil temperature should therefore always be recorded in the main oil pressure gallery or, if this is not possible due to the non-availability of suitable thermocouples, a tapping must be provided in the head of the filter to record the oil temperature entering the oil gallery after the filter.

Some manufacturers offer optional cooling systems. In such cases, prior to conducting any coolant tests, the variations in cooling specifications must be clearly defined and separate tests conducted to clear each specification.

Instrumentation

Recommended minimum requirements — All instruments must be capable of withstanding vibration and general usage on all types of application.

Water manometer to read up to 760 mm (30 ins) for induction system.
Mercury manometers to read up to 250 mm (10 ins) for exhaust system.

Permanently fixed open thermostat(s) (of type used in engine to be tested with opening coinciding with actual temperature setting).

Thermocouples or resistance thermometers for connecting to a read-off dial or recorder suitable for up to 14 stations. (Accuracy required to be within ±1°C.)

Thermometer to record shade ambient temperature. (Accuracy required to be within ±1°C.)

Tachometer to be temporarily installed to record engine rev/min (instrument capacity to read up to 50% above engine governed speed).

Thermometer to record shade ambient temperature. (Accuracy required to be within ±1°C.)

Differential pressure gauge, 0–100 PSI (0–689 kN/m² approx).

The basic instrumentation listed above may be supplemented with other recording data such as air flow meters, water flow meters, vibrograph, etc., depending on whether any special features of the installation are to be checked.

**Recording Points**

In order to obtain the maximum benefit from a cooling test, and so that a full record of relevant data is obtained it is recommended that the following be recorded:

a) Water outlet temperature, i.e. coolant from engine to radiator top tank. This should be measured in the thermostat housing or, if tappings are not provided in this component, in the cylinder head thermometer pocket.

b) Water inlet temperature, i.e. coolant from radiator outlet to engine water pump inlet.

c) Lubricating oil temperature. This is to be recorded in the lubricating oil pressure rail (i.e. oil entering the main gallery).

If an engine oil cooler is fitted, oil temperature into the cooler should also be recorded.

d) Under-bonnet temperature (engine compartment). To be recorded at 2 or 3 different points to provide a general compartment temperature.

e) Air temperature at side of radiator remote from cooling fan (at a distance of approximately 100–150 mm (4–6 in) from radiator core). Two measuring points should be used, i.e., above and below fan center (preferably at ¼ and ¾ × height of radiator core).

f) Air temperature at fan side of radiator core.

g) Air filter intake temperature.

h) Ambient shade temperature, i.e. out of direct sunlight (and out of wind).

i) If hydraulic system coolers are fitted, temperatures in and out of the cooler should be measured.

j) If the application is fitted with a torque converter which incorporates an oil cooler, oil temperatures should be recorded in and out of the cooler.

k) Oil pressure drop across the engine oil cooler circuit, i.e., including interconnecting pipework, must be checked (when the cooler is not an approved Caterpillar part).

l) Air filter restriction (see also SECTION 8, INDUCTION SYSTEM).

m) Exhaust back pressure (see also SECTION 9, EXHAUST SYSTEM).

n) Where possible, exhaust temperature should be measured close to the engine manifold, to enable load factors to be determined.

**Engine Overspeed Testing (Vehicle)**

The object of this test is to define the peak engine speed to which the engine will be subjected during high speed motorway type operating conditions or in areas where long down gradients are prevalent.

In conducting this test it is essential to appreciate the severity of overspeed conditions to which the vehicle may be subjected in different operating territories, both from long down gradient conditions and under conditions where operators change to lower gears at high vehicle speed (a typical example being a driver changing to a lower gear at high vehicle speed when leaving the motorway on to access roads).

The vehicle selected for this test should be fitted with the numerically highest axle ratio, thus providing a lower vehicle road speed but high engine speed, and the test is to be conducted with the vehicle loaded to its maximum G.V.W. During this test the engine oil and water temperatures should be recorded, and also the ambient temperatures.

The maximum permitted engine overspeed in rev/min must be within the values specified by Caterpillar Application Engineering. It is appreciated that areas in which this type of test has to be conducted may not always be ideal, but in view of service experience where engines have sustained major failures as a direct result of overspeeding, this aspect of appraisal testing is considered to be extremely important.

**Noise Tests**

It is strongly advised that noise level measurements should be made in respect of both third party and operator’s ear noise levels, in order to ensure compliance of the vehicle or machine with the relevant legislative requirements. (See also SECTION 13, NOISE CONTROL.)

**Driver Comfort Assessment**

It is recommended that, particularly on agricultural, construction and material handling applications, a subjective assessment should be made of driver comfort characteristics in terms of vibration levels, air velocity through the operator's area, temperature distribution, etc.
COOLING TESTS — GENERAL
(See also SECTION 7, COOLING SYSTEMS)

**Cooling System Terminology**
Several terms are used in defining cooling system capability.

- **Ambient Clearance Temperature** — The maximum ambient temperature in which the machine can be operated without exceeding permissible water and engine oil temperatures.
- **R.O.A.** (Rise Over Ambient) — The difference between the water outlet temperature from engine to radiator top tank and the ambient shade temperature. Also the difference between engine oil temperature and the ambient.
- **T.D.** (Temperature Difference) — Same as R.O.A.
- **Air to Boil** — The ambient temperature at which the water at the radiator inlet (outlet to radiator from engine) reaches 100°C (212°F) (boiling point of water at sea level). This is in respect of a non pressurized coolant system. If a pressure cap or valve is incorporated, this increases the boiling point according to the value of the pressure setting, i.e. 48.3 kN/m² (7 lbf/in²) would give a boiling point of 111°C (232°F), and the Air to Boil would increase accordingly. See also ENGINE WATER OUTLET TEMPERATURE.

Working to the maximum allowable water outlet temperatures as defined in ENGINE WATER OUTLET TEMPERATURE, Air to Boil is also defined as “Air clearance to 103°C”, for example. This expression is used mainly on Farm and Construction Machinery applications where the O.E.M.’s often disregard the effect of the pressure cap and use “Air clearance to 100°C” as the criterion.

**Filling and Capacity Tests**
The following test procedures will define the total coolant capacity of the system and the acceptability in respect of complete system filling:

- With operative thermostats fitted, fill the cooling system slowly with measured quantities of water and note the total capacity.
- Bleed vent points, if approved, for cab heater or any accessory circuits. Note additional water added to top up the system.
- Operate engine to ensure that the cooling system is full; bleed by venting if necessary; record any additional coolant added.
- Drain down the total cooling system and refill at a rate of 10 liters/min (2 gallons/min). This should be done by a continuous flow with no breaks for venting and the time required, to fill, should be recorded. If the established capacity cannot be attained, repeat the test to determine reason for discrepancy, and if this cannot be established, record the difference.
- **N.B.** The filling rate of 10 liters/min (2 gallons/min) is about the minimum acceptable level in service, and should not generally give an unduly long filling time. However, larger industrial, agricultural and construction machines with cooling systems of large capacity may require higher filling rates. The target for these machines is 25 liters/min (5 gallons/min).

**De-aeration and Hot Shut Down**

- **De-aeration** — A critical function of the cooling system is its ability to remove air from the system during the filling process and to further remove entrained air or gases from the system during engine operation.

Aerated coolant can produce localized areas of over heating and result in damage to the engine.

- **Water pump flow** will also be reduced with aerated coolant and could lead to a complete stoppage of coolant flow through the engine.

**Hot shut down** — The cooling system must generally allow for the engine to be stopped at water outlet temperature of up to 95°C (203°F) without discharging from the coolant overflow pipe a total amount in excess of 10% of the nominal system capacity from repeated shut downs. However, for agricultural combines and heavy-duty industrial and construction equipment operating at high load factors and with pressurized cooling systems, the hot shut down temperatures is 100°C (212°F), while for all applications of the V8.640/TV8.640 the temperature is 95°C (203°F). If the amount of discharge is in excess of 10% the design of the system must be checked.

The main cause of high water loss is generally due to the system not de-aering, and this may be caused by inadequate radiator top tank capacity.

**Hot shut down tests** — This test should be carried out with the vehicle or machine coupled to a dynamometer or other similar means of applying full load to the engine. If the facility is not available the fan can be removed to allow the engine to attain the required water outlet temperature.

The radiator overflow pipe should be placed in a container of approximately 5 liters (1 gallon) capacity containing 1 liter (2 pints) of water.

With a standard operative thermostat(s) fitted, the cooling system should be filled as specified in FILLING AND CAPACITY TESTS. Ensure that the system is fitted with a radiator pressure cap or valve to a valve not exceeding 48.3 kN/m² (7 lbf/in²), and that the cap fitted is functioning correctly (preferably by measuring pressure in tank during test). Run engine under load (or without a fan) until the water outlet temperature reaches 82°C (180°F) or the thermostat(s) opening temperature, and note the total loss of coolant from the overflow due to the normal expansion.

Continue to operate the engine until the water outlet temperature reaches the specified temperature, continuing long enough to ensure settled temperatures throughout the system, and then shut the engine down instantly.

The rise in water outlet temperature and the volume of coolant lost should be recorded.

Repeat the hot shut down until either no further coolant is lost after two consecutive cycles, or the total water loss is in excess of 10% of the nominal coolant system capacity. This does not include the water lost due to normal expansion.
up to the thermostat opening temperature. The number of hot shut down tests and the total coolant loss should be recorded. Should the water loss be in excess of 10% of the nominal system capacity, the design of the system must be carefully checked, with particular reference to header tank and tendency to aeration.

With a satisfactory system providing less than 10% water loss, it must be ensured that with the reduced level of water in the system the level of the coolant must be at least 32 mm (1,¼ in) above the radiator core tubes or feed pipe if a separator header tank is fitted.

**Hot starting** — While carrying out the hot shut down tests observe the time taken for engine to start and achieve rated speed, commenting accordingly in the appraisal report.

**De-aeration tests** — If the cooling system fills correctly, and there are no problems with the hot shut downs, then there should **generally** not be any aeration problems.

In the event of any aeration problems, however, de-aeration tests should normally be carried out in conjunction with the hot shut down tests.

To evaluate the level of aeration in the system, reinforced glass tubes (e.g. “Pyrex”) should be fitted between the engine water outlet connection and the inlet to the radiator. If accessible, a better indication of radiator de-aeration function is obtained with tubes fitted to radiator bottom hose.

Ideally there should not be any entrapped air visible through the reinforced glass tubes at any stage of the test, and certainly none by the end of the hot shut downs, or of a similar cycle which simulates the most severe operating conditions likely to be experienced by the engine.

**Engine Oil Coolers**

If the engine oil coolers fitted by the O.E.M. are not a basic Caterpillar fitment, the total oil pressure drop through the oil cooler and interconnecting pipework and fittings must be measured.

Integral oil coolers, where fitted to Caterpillar engines, are adequate for tropical conditions provided that the radiator is capable of keeping the coolant temperature within the specified limits.

For other engine types, the necessity of an oil cooler must be defined based on the appraisal cooling test results and operating areas.

**Cooling Test Preparation**

Prior to preparing the application for cooling tests, it is of the utmost importance to ensure that the general installation is satisfactory, and if any corrective action is to be made following the appraisal which may in particular affect the cooling, these alterations should be carried out at this stage.

Availability of accurate and reliable instrumentation is of the utmost importance, as also are the additional equipment and facilities recommended to carry out the cooling tests.

Instances will occur where all the recommended equipment cannot be made available, but it should be appreciated that the main objective is to ensure that the application is tested under a duty cycle representative of the most severe conditions likely to be experienced in service.

The test should be carried out with the application loaded to its rated capacity (see COOLING TEST — AUTOMOTIVE through COOLING TEST — CRANES).

Recording instruments should be fitted to the applicable points recommended (see RECORDING POINTS).

All tests should be carried out with fixed open thermostat(s).

Coolant system should be drained, flushed and re-filled with water only, the total capacity of the system being checked and recorded.

Install manometers to record air cleaner restriction and exhaust back pressure.

Install tachometer to observe engine rev/min.

A short test run should be carried out to establish that all points to which temperature probes are fitted are functioning correctly. This test will also check that the driver or operator is capable of achieving a satisfactory work rate which will produce typical engine speeds and loadings during the operating cycle.

The test should be carried out under dry weather conditions, with wind speed not in excess of 24 km/h. (15 m/h) and preferably in ambient temperatures above 4°C (40°F).

Water circulation to cab heater should be turned off.

Prior to the cooling test the exhaust back pressure must be determined for both naturally aspirated and turbocharged engines operating at the rated speed under full load conditions (see SECTION 9, EXHAUST SYSTEM).

The air filter restriction must be determined with the engine operating at the rated speed (see SECTION 8, INDUCTION SYSTEM).

Engine oil and water temperatures are generally recorded at 10 minute intervals, but visual checks should be made as frequently as practicable and the peak temperatures recorded.

In respect of maximum speed and overspeed tests with the vehicle applications, the engine peak rev/min should be continuously observed and peaks recorded with duration factor relative to such peaks in engine speed.

**Engine Water Outlet Temperature**

A maximum permissible water outlet temperature is specified in respect of all Caterpillar engines. This varies with pressure cap or valve setting.

From the figures quoted below it can be seen that, with the exception of the V8.640/TV8.640 engines (see note), the maximum allowable temperatures are 8°C (15°F) lower than the true boiling point of water at sea level.
Although pressure caps or valves up to 103 kN/m² (15 lbf/in²) (1 bar) are acceptable for Caterpillar engines, cooling performance is based on a pressure of 48.3 kN/m² (7 lbf/in²) (0.5 bar) (see COOLING SECTION, 7.2.2).

**Lubricating Oil Temperature**

The maximum allowable engine oil temperature varies in respect of certain engines and the type of application.

**Automotive applications**

The normal maximum permissible lubricating oil temperature, measured at the oil filter head or pressure rail, is 121°C (250°F) for most automotive engines. If however, the engine never operates at its maximum speed for more than one hour at a time, for example in a goods or passenger carrying vehicle, operating in a territory which does not have motorways or similar high speed, limited access road, then the maximum oil temperature may be extended to 132°C (270°F).

Integral oil coolers, where fitted as original equipment, are adequate for tropical conditions, provided that the radiator is capable of keeping the coolant temperature within the specified limits.

For other engine types, the installation should be designed so as to allow air to flow freely over the engine lubricating sump and filters. If a cooling test shows an oil cooler to be necessary, Caterpillar Application Engineering Department should be contacted to ensure a satisfactory installation.

**Agricultural and earth moving equipment**

The maximum allowable oil temperature is 121°C (250°F).

**Industrial equipment**

For forklift trucks and similar light duty applications classified as “Intermittent” (but not including rough terrain forklift trucks), the maximum oil temperature is 132°C (270°F), subject to the use of oils to Caterpillar recommendations.

Other industrial applications such as air compressors, generating sets, welding sets, and similar equipment which are classed as “Continuously-rated” applications are limited to 121°C (250°F).

**Engine lubricating oil specifications**

See SECTION 16, TECHNICAL DATA, for recommendations.

**Analysis of Cooling Test Results**

From the stabilized cooling test results obtained during the tests, the maximum allowable operating temperature (i.e. Ambient Clearance Temperature) can be determined. This is illustrated below, using typical results of tests on a typical vehicle operating at sea level. The engine is fitted with an oil cooler and the radiator fitted with an 48.3 kN/m² (7 lbf/in²) 0.5 bar pressure cap.

(a) **Maximum Torque** conditions

<table>
<thead>
<tr>
<th>Item</th>
<th>°C (°F)</th>
<th>°C (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient shade</td>
<td>15 (60)</td>
<td>—</td>
</tr>
<tr>
<td>Water IN</td>
<td>64 (148)</td>
<td>—</td>
</tr>
<tr>
<td>Water OUT</td>
<td>68 (154)</td>
<td>53 (94)</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>78 (172)</td>
<td>63 (112)</td>
</tr>
</tbody>
</table>

(b) **Maximum Speed** conditions

<table>
<thead>
<tr>
<th>Item</th>
<th>°C (°F)</th>
<th>°C (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient shade</td>
<td>14 (58)</td>
<td>—</td>
</tr>
<tr>
<td>Water IN</td>
<td>53 (127)</td>
<td>—</td>
</tr>
<tr>
<td>Water OUT</td>
<td>60 (140)</td>
<td>46 (82)</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>82 (180)</td>
<td>68 (122)</td>
</tr>
</tbody>
</table>

(1) Rise over ambient = Water or oil temperature minus ambient temperature

In this example the following maximum allowable temperatures apply.

- Maximum allowable engine water outlet temperature at sea level is 103°C (217°F).
- Maximum allowable engine oil temperature for automotive applications is 121°C (250°F).
As the Ambient Clearance Temperature = Maximum Allowable Temperature minus Rise Over Ambient, the Rise Over Ambient and Ambient Clearance Temperatures from the example can be summarized as follows:

(a) Maximum Torque conditions

<table>
<thead>
<tr>
<th>Item</th>
<th>Rise over ambient °C (°F)</th>
<th>Ambient clearance temperature °C (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>53 (127)</td>
<td>50 (122)</td>
</tr>
<tr>
<td>Engine oil</td>
<td>63 (146)</td>
<td>58 (136)</td>
</tr>
</tbody>
</table>

(b) Maximum Speed conditions

<table>
<thead>
<tr>
<th>Item</th>
<th>Rise over ambient °C (°F)</th>
<th>Ambient clearance temperature °C (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>46 (115)</td>
<td>57 (134)</td>
</tr>
<tr>
<td>Engine oil</td>
<td>68 (154)</td>
<td>53 (127)</td>
</tr>
</tbody>
</table>

From this summary it can be seen that water temperature under maximum torque conditions is the limiting factor. This application is therefore cleared for operation in ambient temperatures up to 50°C (122°F) at sea level.

Cooling System Test and Approval Conditions

The appraisal testing of cooling systems against the limits outlined in ENGINE WATER OUTLET TEMPERATURE should be carried out under conditions which simulate the most severe type of operation likely to be encountered in service.

In the case of medium and heavy duty applications this should be achieved by operating the machine at wide open throttle setting against the most severe loadings which can be imposed in service.

In the case of certain light duty applications (e.g. passenger cars and their light commercial derivatives) it is possible during the cooling tests to impose high loads (e.g. by means of a towed dynamometer or a "rolling road") which would only be met in service by a very small proportion of the application population, and even then only occasionally, and for short durations. In such cases it is recommended that the normal temperature limits be applied to the true sustainable conditions (e.g. motor way high speed cruise).

Under the exceptional intermittent test conditions above, the maximum water temperature may be allowed to increase to a level more appropriate to the particular cooling system taking into account the pressure cap setting. For example, it is recommended that, with a pressure cap setting of 103 kN/m² (15 lbf/in²) (1 bar), giving a boiling point of 121°C, a maximum water temperature of 113°C, be permitted. The difference between these two temperatures represents the normal Caterpillar allowance for system tolerances and deterioration.

Acceptance of this increased water temperature must however be subject to the following guidelines:

— it applies only where the test procedure used simulates extreme use not representative of normal operation by the majority of the application population.

— an overcheck must be carried out against normal coolant limits at the maximum sustainable operating condition.

— it applies only to mobile applications where overheating can be eliminated by reducing the load.

— a coolant overheating warning device is mandatory.

— the O.E.M. is in agreement with this procedure, and provides a cooling system of adequate mechanical integrity.

— guidance upon the acceptability of the proposed test should be sought from Caterpillar Applications Engineering Department, Peterborough.

COOLING TEST — AUTOMOTIVE

General

Variations in G.V.W. or G.C.W. will affect coolant clearances and the options in final axle ratios. All of these factors must be carefully considered in conjunction with the O.E.M. customer, and what is considered to be the most severe specification in respect of engine cooling requirements must be applicable to the test unit.

The vehicle should be instrumented as detailed in INSTRUMENTATION and RECORDING POINTS.

The induction restriction and exhaust back pressure must be checked and recorded.

Maximum Torque Test

The test vehicle should be loaded to its maximum rated capacity.

Due to high draw bar pull capabilities of the larger trucks a towing dynamometer is recommended. This should be suitable adjusted to control the test vehicle as a road speed of approximately 13–16 km/h (8–10 mph) in an appropriate gear at full throttle opening with the engine operating at the peak torque speed. The test should be continued until stabilized water outlet and inlet temperatures are obtained.

This test should preferably be carried out on a circular track, over a distance of approximately 1.5 km (1 mile), the maximum temperatures being recorded during each lap. The tests should be conducted under dry weather conditions with wind speed not exceeding 24 km/h (15 mph).

In the absence of a circular track the test may be carried out on a level unrestricted highway over a distance of approximately 3–5 km in both directions until stabilized temperatures are obtained.
In the absence of a towing dynamometer a suitable vehicle can be used to provide the required towing load.

**Maximum Speed Test**

Following the maximum torque tests, tests under maximum speed conditions should be carried out.

The vehicle should be loaded to its maximum rated capacity and the test conducted with the vehicle operating in the highest gear at maximum road and engine speed.

It is desirable to conduct this test on a high speed circular track approximately 5 km (3 miles) in length. The maximum temperatures should be recorded during each lap until stabilized engine out temperature are obtained.

Normally the water temperature under this test condition is lower than is obtained under maximum torque, but the oil temperature will generally be higher.

In the event of a high speed test track not being available, the test should be carried out under high speed motorway type conditions over a test distance of 24-32 km (15-20 miles). Under these test conditions it may however be difficult to maintain stabilized conditions due to traffic and gradients, and the maximum recorded temperatures in both directions should therefore be used in determining ambient operating clearance.

**Maximum Power Test**

At the discretion of the appraisal engineer or O.E.M., the following test (as also specified in COOLING TESTS APPLICABLE TO AIR-TO-AIR CHARGE-COOLED VEHICLE ENGINES for charge-cooled vehicle engines) should be carried out when the vehicle is intended to be operated in hilly terrain, especially with long gradients.

If suitable hills are not available, the towing dynamometer procedure specified in MAXIMUM TORQUE TEST should be used with load adjusted so that, in 1st or 2nd gear and a road speed of 13 km/h (8 mph) max with engine at full throttle, the engine achieves full power at rated speed. The test is to be continued until stabilized temperatures are obtained.

**Cooling Tests Applicable to Air-to-Air Charge-Cooled Vehicle Engines**

In addition to the test specified in ENGINE OVERSPEED TESTING (VEHICLE) and MAXIMUM TORQUE TEST, tests must be carried out on air-to-air charge-cooled vehicle applications with the engine developing maximum power at rated speed, while the vehicle is traveling at a low road speed i.e., eliminating any ram air effect.

Temperature and pressure measurements should be at the positions indicated on the diagram.

**Temperature requirements**

Air temperature after the charge cooler (measuring point 4) should not exceed the following values:

<table>
<thead>
<tr>
<th>Ambient temperature</th>
<th>Maximum allowable temperature after charge cooler</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>°F</td>
</tr>
<tr>
<td>20</td>
<td>68</td>
</tr>
<tr>
<td>29</td>
<td>85</td>
</tr>
<tr>
<td>50</td>
<td>132</td>
</tr>
</tbody>
</table>

Intermediate temperatures pro rata.

**Note:** The permissible air inlet temperature is raised at higher ambient temperatures because of the corresponding reduction in power output.

**Instrumentation**

1. Boost pressure before charge cooler, approx. 300 mm (12 in) from the turbocharger.
2. Boost pressure after charge cooler.
3. Air temperature, before cooler approx. 300 mm (12 in) from charge cooler.
4. Air temperature, after charge cooler approx. 300 mm (12 in) from charge cooler.
5. Air temperature, external air six proves evenly distributed approx. 300 mm (12 in) in front of charge cooler.
6. Air inlet to engine, within 75–150 mm (3–6 in) of air cleaner.
7. Air restriction, between air cleaner and turbocharger.
8. Exhaust temperature before turbocharger.

**Pressure drop across air charge cooler**

For information on allowable pressure drop between air charge cooler inlet and outlet, reference should be made to SECTION 16, TECHNICAL DATA.

**Boost pressure**

The boost pressure is to be recorded under the test conditions specified in COOLING TESTS APPLICABLE TO AIR-TO-AIR CHARGE-COOLED VEHICLE ENGINES, a mercury manometer being connected at measuring point 2.

**COOLING TEST — AGRICULTURAL EQUIPMENT**

**General**

The application must be prepared for test and instrumented as detailed in INSTRUMENTATION and RECORDING POINTS.

For accurate and consistent results, cooling tests should preferably be carried out on a dynamometer, where facilities permit. When this is not possible, cooling tests can be
conducted from field trials, but it is essential that machines are subjected to the most arduous conditions which can be achieved. It is therefore most important that the operator should be fully experienced with the machine type concerned.

In addition to cooling tests results, exhaust back pressure and air filter restriction should also be measured and recorded.

**Dynamometer Tests**

**Agricultural tractors**

Load is applied by connecting the tractor P.T.O. shaft to the dynamometer. Performance and cooling characteristics should be determined under full load conditions across the speed range, with special attention to maximum torque and rated speed conditions.

In the event of the tractor manufacturer specifying a “standard” P.T.O. speed at an alternative engine speed performance and cooling should be recorded under the recommended P.T.O. condition.

It should be ensured that the required ambient clearance is achieved throughout the speed range from maximum torque to maximum rated speed.

**Combine harvesters**

With the majority of combine harvesters, the engine can be connected to a dynamometer by removing the engine rear end drive housing and connecting a shaft directly from flywheel to dynamometer.

Prior to commencing cooling tests, it is essential that checks be carried out to ensure the correct rated speed and governor run-out conditions are achieved. Cooling performance should then be recorded at maximum throttle setting with the load adjusted to give rated speed, and also at 75% of rated load on the governor curve. For combines with conventional mechanical transmissions the ambient clearance parameters should be based on:

- coolant — full load, rated speed condition
- lubricating oil — at 75% load on governor curve.

For combines with hydrostatic transmissions, or models equipped with special attachments (e.g. high power
requirement straw choppers etc.) the ambient clearance for both coolant and lubricating oil must be determined under full load rated speed conditions.

NOTE: On applications having hydraulic or transmission oil coolers positioned in the air stream into the radiator, the necessary allowance for heat input must be included in the results.

Other specialized equipment

This covers equipment such as viners, beet harvesters, foragers, etc. With the dynamometer connected at the most convenient position to absorb full engine power, tests should be carried out over the full operating range.

The ambient clearance parameters should be based on the worst cooling condition recorded within the normal operating range of the machine.

Field Tests

A convenient method of determining the highest load condition on the engine is to incorporate an exhaust temperature prove. The machine is then subjected to a variety of duties to determine the highest load that can be maintained to achieve stabilized temperatures. When conducting these trials it is necessary to record the exhaust temperature at full load rated speed as a datum condition.

For agricultural tractors, it is necessary to ensure that excessive wheel slip does not occur. In some cases this problem can be avoided by using P.T.O. driven implements (e.g. Rotavators etc.).

For all applications it is essential that the tests are conducted at maximum throttle, and that an adequate test area is available to enable continuous operation to achieve stabilized temperatures.

The clearance ambient must be determined from the highest coolant and oil temperatures recorded during the test period.

COOLING TEST — EARTH MOVING EQUIPMENT

General

The application must be prepared for test and instrumented as detailed in INSTRUMENTATION and RECORDING POINTS.

For accurate and consistent results cooling tests should preferably be carried out on a dynamometer, where facilities permit. When this is not possible, cooling tests can be conducted from field trials, but it is essential that machines are subjected to the most arduous conditions which can be achieved. It is therefore most important that the operator should be fully experienced with the machine type concerned.

In addition to cooling test results, exhaust back pressure and air filter restriction should also be measured and recorded.

Dynamometer Tests

It is not possible to give specific recommendations regarding the method of connecting machines to a dynamometer, due to the wide variation of machine types, transmissions, etc. The following notes are however included for general guidance, and further information if required can be obtained from Caterpillar Application Engineering Department.

Crawler loaders/dozers: Where machines are fitted with P.T.O. shafts (e.g. winch drives etc), these can be utilized providing it is ensured that the drive is capable of transmitting full engine power, and also that, with torque converter transmissions, the P.T.O. is driven from the torque converter output shaft. If no P.T.O. shaft is incorporated, the dynamometer can be connected (via a step-up gearbox) to any convenient transmission drive shaft, on to the track final drive shaft.

Wheel loaders: In the majority of cases P.T.O. shafts are available, although in some cases, it is necessary to remove the rear transmission housing and connect the dynamometer to the gearbox output shaft.

Excavators: Where necessary the rear drive housing must be removed and the dynamometer connected direct to the engine flywheel.

On hydraulic drive machines, however, stationary tests can be completed without using a dynamometer by utilizing the machine hydraulic pumps to load the engine. This can be achieved by incorporating adjustable valves in the hydraulic oil circuit, but it is necessary to fit an independently hydraulic cooled hydraulic oil cooler to dissipate the increased heat input to the hydraulic circuit.

The loading on the engine can be determined from pressure and flow characteristics, adjustments of flow via the valves enabling the required percentage loading to be achieved as specified below under the heading “Ambient clearance parameters”.

Cooling test procedure

Prior to commencing cooling tests it is necessary to ensure that the maximum no-load engine speed is at the specified setting. Correct governor control and maximum no-load speed is essential for machines incorporating torque converter transmissions, especially where the torque converter speed ratio range is matched to the engine governor curve.

\[
\text{output speed} = \frac{\text{input speed}}{\text{speed ratio}}
\]

All cooling tests with torque converter transmissions should be carried out with the engine under full throttle conditions, the dynamometer loading being adjusted to enable cooling performance to be determined along the torque converter speed ratio curve down to the ratios specified below.

For machines fitted with hydraulic or mechanical drive transmissions the ambient clearance parameters should be determined at the percentage loads at rated speed specified below.

NOTE: Where machines are fitted with hydraulic or transmission coolers, a field test should be completed prior to
dynamometer testing in order to determine the oil temperature rise over ambient which must be simulated during the cooling tests.

**Ambient clearance parameters for dynamometer tests**

For machines fitted with torque converter transmissions the ambient clearance temperature must be based on results obtained over the torque converter speed ratio curve down to a speed ratio appropriate to the machine type, as follows:

- **Crawler loaders and dozers**: 0.3 speed ratio
- **Wheel loaders**: 0.35 speed ratio
- **Industrial tractors, tractor/digger/loaders, etc.**: 0.4 speed ratio

For machines with hydraulic and mechanical drive transmissions, the ambient clearance temperature should be based on the following load factors:

- **Excavators**: 80% load
- **Wheel loaders, industrial tractors, tractor/digger/loaders, etc.**: 85% load at rated speed
- **Crawler loaders/dozers**: 100% load

**Field Tests**

A convenient method of determining the highest load condition on the engine is to incorporate an exhaust temperature probe, and subject the machine to a variety of duty cycles to determine the highest load that can be maintained to achieve stabilized temperatures. When conducting these trials it is necessary to record the temperature at full load rated speed as a datum.

As a check on consistency a minimum of two cooling tests should be carried out at full throttle conditions, using the selected cycle and the ambient clearance parameters based on the highest stabilized coolant, lubricating oil, and hydraulic and transmission oil temperatures recorded during the test.

For guidance the following cycles have been found most effective:

- **Crawler loaders**: The most practical and severe test cycle is to operate the machine by digging an underground ramp as illustrated. This allows the machine to operate for limited periods in still air, and has proved more repeatable than surface testing.

- **Wheel loaders**: The most practical test involves a “dig and dump” cycle, and it is generally found that the period between “dig” and “dump” should be kept to a minimum.

- **Excavators**: It is evident that the most effective test is to excavate a trench. It is however necessary to select a site with rock or heavy clay subsoil in order to submit the machine to a maximum “break-out” loadings and to restrict slewing time to a minimum.

Further guidance in respect of other application types can be obtained on request from Caterpillar Application Engineering Department.

**Oil coolers**

On machines fitted with hydraulic transmission or remote engine oil coolers, the flow rate and pressure drop over the respective coolers should be recorded to ensure that Caterpillar and component manufacturers’ limits are not exceeded.

Full details of the coolers, pipework, hydraulic pumps etc., together with flow and pressure results, must be recorded on the Installation Appraisal Data Sheets.

**Radiator air flow**

Air flow through the radiator should be recorded to ensure uniform distribution, and also that recirculation does not occur throughout the engine speed range.

In order to avoid damage to radiator cores on earth moving equipment, it should be ensured that the average air velocity through the core does not exceed 610 meters/min (2000 ft/min).
COOLING TEST — INDUSTRIAL LIFTING EQUIPMENT

General
This covers the following range of applications:

a) Forklift trucks
b) Side loaders
c) Straddle carriers

With these applications several variants in capacity are normally offered, resulting in major alterations to the basic machine which can cause drastic effects on the efficiency of the coolant system. The same applies also to the fitment of optional transmissions, especially where provision is to be made to cool the transmission oil.

The standard cooling test for the above range of applications is by operating the machine on a duty cycle in which the maximum acceleration is achieved with the shortest distance, attaining maximum engine speed and retardation.

Coolant clearance tests should be carried out with a machine of the range representative of the most demanding in respect of the coolant system. It is also essential to ensure that the operator is proficient and fully conversant with the operation of the machine, and be fully capable of operating the machine to its maximum capacity, thereby ensuring that the test cycle is representative of the most demanding conditions.

In order to load the machine adequately, but also bearing in mind safety in testing, it is recommended that the machine be loaded to 75% of its rated capacity and that the test load is properly secured. Experience confirms that the speed of operation is more critical than the actual load carried and, due to accidents experienced in combining speed of operation with full load, the 75% load factor is recommended.

Test track
Due to the variation in the design of these machines and capacities it is not possible to stipulate the actual length of the test track, the criteria being to meet the duty cycle referred to above. For general guidance however, the following table gives an indication of typical track length requirements for stimulation of typical operation of various capacities of machine.

<table>
<thead>
<tr>
<th>Machine type and rated capacity (Kilograms)</th>
<th>Typical test track length (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forklift trucks:</td>
<td></td>
</tr>
<tr>
<td>1000-2500</td>
<td>15</td>
</tr>
<tr>
<td>2500-4500</td>
<td>25</td>
</tr>
<tr>
<td>5500-7000</td>
<td>40</td>
</tr>
<tr>
<td>7000-30000</td>
<td>50</td>
</tr>
<tr>
<td>Rough terrain trucks:</td>
<td></td>
</tr>
<tr>
<td>2000-3500</td>
<td>35</td>
</tr>
<tr>
<td>Side loaders and straddle carriers:</td>
<td></td>
</tr>
<tr>
<td>1400-2000</td>
<td>30</td>
</tr>
<tr>
<td>2000-2500</td>
<td>60</td>
</tr>
<tr>
<td>2500-5000</td>
<td>80</td>
</tr>
<tr>
<td>5000 upwards</td>
<td>95</td>
</tr>
</tbody>
</table>

Test Procedure
The application must be prepared for tests and instrumented as detailed in paragraphs INSTRUMENTATION, and RECORDING POINTS.

This induction and exhaust back pressure must be checked and recorded with the engine developing its maximum power at the rated speed.

Forklift trucks
The machine should be loaded to 75% of its rated capacity, and the length of test track defined and marked.

The machine with the forks in the lowered position is driven at full engine throttle opening in a forward direction to the end of the test track where a three point turn is executed to face the machine in the opposite direction. The load is then lifted to 75% of full lift at the maximum lifting speed and then lowered. (75% lift is stipulated from a safety aspect). The machine is then driven under full throttle opening back to the starting point where another three-point turning is carried out following by a lift and lower cycle. This cycle is repeated until stabilized water and engine oil temperatures are obtained and maintained for at least 15 minutes.

When the application is fitted with a Torque Converter Transmission the transmission oil temperature must also stabilize. If the converter can be used as an additional braking power this must be used in addition to the standard braking system in bringing the machine to a stop at each end of the test track, thus indicating maximum heat rejection from the transmission.

Side loaders and straddle carriers
The test procedure is basically the same as for forklift trucks, i.e., the load is lifted and lowered at each end of the test track, but the direction of travel is simply reversed without executing a three-point turn.

COOLING TEST — CRANES

Mobile self-propelled cranes
Normally the engine power requirements for the lifting and slewing cycles are low in respect of self-propelled mobile vehicles.

The maximum engine power requirement is generally utilized driving the crane.

The cooling test should therefore be carried out with the machine operating under the most severe load cycle.

Truck mounted cranes
With these applications the engine is generally used to power the operation of the crane in lifting and slewing.

The cooling test should therefore be carried out with the machine operating under the most demanding power requirement until stabilized temperatures are attained.

Test Procedure
The application must be prepared for tests and instrumented as detailed in paragraphs INSTRUMENTATION, and RECORDING POINTS. The induction restriction and exhaust
back pressure must be checked and recorded with the engine developing its maximum power at the rated speed.

**Mobile self-propelled cranes**

The most demanding engine power requirement must be defined. This is generally with the machine travelling on a gradient of sufficient distance to provide stabilized oil and water temperatures.

In defining a suitable gradient for the test it should be appreciated that the maximum road speed of this type of application is only in the region of 8 km/h (5 mph).

**Truck mounted cranes**

With this type of application the engine is generally used to power the crane for lifting and slewing. Prior to the testing the most demanding engine load factor must be established and the cooling test performed at the most severe cycle until water and oil temperatures have stabilized.
Engine Installation

Appraisal Report

Engine Type : ___________________________

Application : ___________________________

Date : ___________________________

Reference : ___________________________

Completed By : ___________________________
The following information is recorded as applicable at the date of visit and installation approval is only to be used as an opinion on the suitability of the engine for the application.

The manufacturer and customer are reminded that it is their responsibility to ensure compliance with the requirements of the Health & Safety at Work Act 1974 and any other applicable legislation, both nationally and internationally, in relation to the engine installation applicable to the equipment concerned.

In giving notice of approval in respect of the installation, the Power Center or Distributor does not assume such responsibilities on behalf of the manufacturer or customer and while engine installation approval and advice is an opinion given in good faith, no liability can be accepted for any error therein and the manufacturer and customer must act and insure accordingly.
APPLICATION CATEGORY: *AUTOMOTIVE/IND/CONSTR. M/c/AGRIC.

Customer_______________________________________________________________________________________________________
Address ________________________________________________________________________________________________________
Engine Type ___________________________________________* Engine No.___________________________________________
Engine Rating __________________________________________ * Parts List No._________________________________________
* Proto./Prod. No. ______________________________________
Machine Model and Type _________________________________________________________________________________________
Machine No. __________________________________________________________________________________________________

ENGINE INSTALLATION APPRAISAL
Carried Out By _________________________________________________ Date ________________________________________
Appraisal Report Reference______________________________________ Date ________________________________________
Operational Limits:
Ambient clearance temperature, water _______°C
Ambient clearance temperature, oil _______°C
Exhaust Back Pressure ___________________________________________________________________________________
Inlet Depression ___________________________________________________________________________________
Known territories for which the machine is destined _________________________________________________________________

ENGINE INSTALLATION APPROVAL
Caterpillar engine installation approval and advice is an opinion offered in good faith, but Caterpillar does not accept any liability whatsoever in relation thereto, for instance in respect of:
1) the customer’s responsibility to ensure compliance with the requirements of the Health and Safety at Work etc. Act 1974.
2) and defect in installation approval or advice given;
and the customer must act and insure accordingly.
* The engine installation is approved.
* The engine installation cannot be approved until the following points have been rectified:

________________________________________________________
________________________________________________________
________________________________________________________
________________________________________________________
________________________________________________________

Signed _____________________________________________ Accepted By _____________________________________________
(Appraisal Engineer) (Application Manager)
Date __________________________________________________ Date __________________________________________________
*Delete as appropriate
SUMMARY OF RECOMMENDATIONS

Engine Mountings/Vibration Level — Section 3.

Induction System — Section 4.

Electrical System — Section 5.
Fuel System — Section 6.

Lubricating Oil System — Section 7.

Exhaust System — Section 8.

Controls and Instrumentation — Section 9.

Belt Drives from Front End — Section 10. Axial Drives from Front End — Section 11.
INSTALLATION APPRAISAL DATA SHEET

Customer: Date:
Address: Report Reference:

Contacts:

1.1 Application:
   Model:

1.2 Duties:

1.3 Territory:

1.4 Ambient Temperature Range:
   Altitude Range:

1.5 Machine Reference No.:

1.6 Engine Type/No.:

1.7 Ratings:

1.8 Curve No.:
   Project No.:

1.9 Prototype/Production P.L. No.:

1.10 SOS Code:

1.11 Low Idle Speed:

1.12 High Idle Speed:
APPLICATION DESCRIPTION/SKETCH ETC.

2.1 Dimensions

Overall length:

Wheel base:

Overall width: Max. allowable frontal area:

Overall height:

2.2 Weights

Normal unladen weight: G.V.W. G.C.W.

2.3 Normal Equipment

No. of drive axles:

Type of drive:

Final axle ratio:

Tire size: Ply rating:

Gearbox make: Type:

Gear ratios:

2.4 Location of engine relative to normal direction of vehicle travel:

2.5 Additional information, including optional gear ratios available:

ENGINE MOUNTINGS — REFER TO THE CATERPILLAR INSTALLATION MANUAL (C.I.M.), SECTION 6.

Manufacturer: Type: Hardness:

3.1 Front:

3.2 Rear:

See next page for mounting positions.

Vibration Level

3.3 Engine: Frame: Operator:

3.4 Additional information and comments:
ENGINE MOUNTINGS — REFER TO C.I.M. SECTION 6.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Inches</th>
<th>mm</th>
<th>Dimension</th>
<th>Inches</th>
<th>mm</th>
<th>Dimension</th>
<th>Inches</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td></td>
<td></td>
<td>D1</td>
<td></td>
<td></td>
<td>G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td></td>
<td></td>
<td>D2</td>
<td></td>
<td></td>
<td>H°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B°</td>
<td></td>
<td></td>
<td>E</td>
<td></td>
<td></td>
<td>J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
INDUCTION SYSTEM — REFER TO C.I.M. SECTION 8.

(Not applicable if air cleaner is S•O•S engine mounted)

4.1 Air cleaner:
Make: Type: Duty:

4.2 Air flow: capacity 2.0 kPa (8 ins H₂O):

4.3 Engine rated air requirement:

4.4 Raincap or precleaner type:

4.5 Air cleaner position:

4.6 Air intake position:

4.7 Is vacuator valve fitted?:

4.8 Restriction indicator:
Setting:
Location of indicator: Tapping position:

4.9 Quality of connections:

4.10* Restriction at engine maximum governed speed:
At air cleaner outlet: X:
At induction manifold thermostat tapping: Y:

4.11 Serviceability of element:

4.12 Comments:

* To be recorded at engine governed speed at maximum power in respect of turbocharged engines.
ELECTRICAL SYSTEM — REFER TO C.I.M. SECTION 12.

5.1 Starter motor type:

5.2 Starter motor position: Earth: Yes ☐ No ☐

5.3 Starter relay fitted and type:

5.4 Starter relay position:

5.5 Starter motor/solenoid circuit cable sizes (length × cross-section):

5.6 Heat/start switch type:

5.7 Alternator type:

5.8 Current rating:

5.9 Regulator type:

5.10 Battery make/type:

5.11 Positive/Negative earth:

5.12 Capacity at 10/20 hour rate:

5.13 Battery cold start performance C.C.A. (cold cranking amps)

   Battery — starter:

   Battery — earth:

   Starter — earth:

5.14 Estimated minimum start temperature:

   Unaided:

   Aided:

5.15 Total electrical load:

5.16 Comments:
FUEL SYSTEM — REFER TO C.I.M. SECTION 10.

6.1 Water trap/sedimenter fitted: Type: 
Position: Visibility: 
6.2 Final/twin fuel filter type: 
6.3 DPA/DPS fuel return: 
6.4 Fuelled starting aid fitted: 
6.5 Ether start fitted: Type: 
6.6 Position of fuel tank base relative to lift pump: 
6.7 Fuel tank capacity: 
6.8 Low pressure fuel pipes satisfactory: 
6.9 Non-return valve fitted in lift pump: 
6.10 Non-return valve fitted in final filter head: 
6.11 Is fuel system to Caterpillar recommendation?: 
6.12 Comments: 

LUBRICATING OIL SYSTEM — REFER TO C.I.M. SECTION 11.

7.1 Oil filter type: Position: 
7.2 Sump type/part no.: 
7.3 Is sump tied to flywheel housing?: 
7.4 Sump gradeability: 
7.5 Application designed maximum gradient: 
7.6 Dipstick position: 
7.7 Oil filler position: 
7.8 Oil drain: 
7.9 Comments:
EXHAUST SYSTEM — REFER TO C.I.M. SECTION 9.

8.1 Minimum exhaust pipe diameter:

8.2 Silencer
   Type: Size:
   Location: Supports:

8.3 Tail pipe exit position:

8.4 Flap or drain fitted if outlet vertical:

8.5 Exhaust back pressure (measured at full power rated speed):

8.6 Maximum boost pressure (measured at full power rated speed):

8.7 Turbocharger position:

8.8 Maximum smoke level:

8.9 Comments:

CONTROL AND INSTRUMENTATION — REFER TO C.I.M. SECTION 14.

9.1 Throttle control: Is maximum speed stop fitted?:

9.2 Stop control: Accessibility to operator:

9.3 Excess fuel button accessibility to operator:

9.4 Tacho fitted:

9.5 Hourmeter fitted: Type: Reading:

9.6 Oil pressure gauge/light fitted:

9.7 Coolant temperature gauge/light fitted:

9.8 Ammeter fitted:

9.9 Visibility of gauges/warning lights: Day: Night:

9.10 Automatic shut down device fitted: Make and type:

9.11 Comments:
BELT DRIVE FROM FRONT OF ENGINE — REFER TO C.I.M. SECTION 5.

10.1 Crankshaft pulley and T.V. damper type: Spline/Key:

10.2 Details of belt(s):
Crankshaft/Water Pump/Alternator:

10.3 Additional belt drives:
Type of belt:
From: To:
Pulley centers:

10.4 Additional belt drives:
Type of belt:
From: To:
Pulley centers:

10.5 Is scheme approved by Caterpillar?:

10.6 Comments:

AXIAL DRIVE FROM FRONT OF CRANKSHAFT — REFER TO C.I.M. SECTION 5.

11.1 Type of driven auxiliary:

11.2 Power absorbed:

11.3 Type of drive:

11.4 Is lay-out approved?:

11.5 Comments:
GEAR DRIVEN AUXILIARIES — TIMING CASE — REFER TO C.I.M. SECTION 5.

<table>
<thead>
<tr>
<th></th>
<th>12.1</th>
<th>12.2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Type of drive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio to engine speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure setting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power requirement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is scheme approved by Caterpillar?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>12.3</th>
<th>12.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Type of drive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio to engine speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure setting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power requirement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is scheme approved by Caterpillar?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12.5 Comments:
BACK END/DRIVE ARRANGEMENT — REFER TO C.I.M. SECTION 4.

13.1 Flywheel housing type/part no:

13.2 Clutch details:

13.3 Torque converter details:

13.4 Gearbox details:

Weight:

Position of C.G.:

13.5 Gearbox ratios:

13.6 Transfer gearbox ratios:

13.7 Belt drives approximate resultant angle:

13.8 Outrigger bearing:

13.9 Axle ratio:

Final drive ratio:

13.10 Driven axle tire size:

13.11 Transmission P.T.O. positions:

13.12 Usage:

13.13 Comments:
14.1 Fan crankshaft ratio:
- Fan blade material:
- Blade width:
- Diameter:
- Number of blades:

14.2 Radiator make:
- Type:
- Mounting:
- Core Area:
- Fins/inch:
- Pitch:
- Pressure cap:
- Number of tubes:

14.3 Lips on all coolant pipes:

14.4 Chaff screen area type:

14.5 Indicate on sketch position and diameter of top and bottom connections and filler

14.6 Position of air cooled/water cooled oil coolers. Indicate size, type etc.
(Not applicable if oil cooler is supplied fitted to engine.)
COOLING SYSTEM (Continued)

14.7 Details and position of air charge cooler:

14.8 Type of coolant system posivent, remote header tank etc. Provide sketch:

14.9 Ancillary cooling — compressor. Cab heater:

Air conditioner: Other:

14.10 Disposition of 14.9 connections:

14.11 Thermostat(s) nominal opening temperature:

14.12 Comments:

COOLANT FILLING TEST — REFER TO C.I.M. SECTION 15.

(Not applicable if S•O•S radiator is fitted)

15.1 Total system capacity:

15.2 Fill rate:

15.3 Aeration:

Draw down:

15.4 Hot shut down:

15.5 Pressure drop through engine oil cooler:

(If not Caterpillar supply)

15.6 Comments:
APPLICATION COOLING TESTS — REFER TO C.I.M. SECTION 15.

16.1 Test procedure:
16.2 Weather conditions:
16.3 Ground conditions:
16.4 Total weight as tested:
16.5 Thermostat(s) fixed open:
16.6 Engine covers:
16.7 Coolant water/antifreeze:
16.8 Comments:

STABILIZED MAXIMUM TEMPERATURES

17.1 Engine water outlet (Both banks — V engines):
17.2 Engine water inlet:
17.3 Water in: out: of:
  Oil cooler if not original equipment fitted to engine:
17.4 Engine oil (gallery):
17.5 Engine oil entering oil cooler if fitted:
17.6 Under bonnet:
17.7 Exhaust:
17.8 Air cleaner intake:
17.9 Ambient:
17.10 Transmission oil temperature: in: out:
17.11 Comments:
COOLANT CLEARANCE

18.1 Water maximum permissible operating ambient temperature:

°F  °C

18.2 Engine oil maximum permissible operating ambient temperature:

°F  °C

18.3 Transmission oil clearance:

Above clearances are based on the following permissible:

Maximum temperature:

Water: °F  °C with pressure cap

Engine oil to:

Transmission oil temperature:

SERVICEABILITY

19.1 Dipstick:

19.2 Oil filter:

19.3 Oil filler:

19.4 Sump drain:

19.5 Radiator filler: Drain:

19.6 Cylinder block drain:

19.7 Battery:

19.8 Water trap/sedimente-r:

19.9 Fuel filters:

19.10 Air cleaner:

19.11 Fan belt adjustment: Replacement:

19.12 Lift pump hand primer:

19.13 Excess fuel control:

19.14 Tappets:

19.15 Injectors:
**Major Assemblies**

19.16 Removal of cylinder head:
19.17 Lubricating oil sump:
19.18 Fuel pump:
19.19 Lift pump:
19.20 Water pump:
19.21 Exhaust manifold(s):
19.22 Induction manifold(s):
19.23 Engine:
19.24 Comments:

**APPROVAL**

20.1 Application cooling system is acceptable/not acceptable

Maximum safe ambient of °F °C at sea level

20.2 Does the application meet the required Caterpillar Engines standard?

20.3 Define limitations:

20.4 Corrective action necessary:

20.5 Application appraisal carried out by:

20.6 Application **ACCEPTED** by:

Application **NOT** accepted by:
**COOLING TEST**

**Test Details**
- **Date:** __________________________
- **Machine under Test:** __________________________  
  **Machine Ref.:** __________________________

- **Test:** Max. Speed/Max. Power/Max. Torque/Variable Cycle/Torque Converter Speed Ratio
- **Test Condition:** Stationary/Moving/Test Cell

**Test Ground Details:**
___________________________________________________________________________________

**Test Load/Cycle:**
___________________________________________________________________________________

**Weather:** __________________________  
**Ground Condition:** __________________________  
**Barometer:** __________________________

**Fuel Pump Type/Setting Code:**
___________________________________________________________________________________

**Installed Idle/Max. Run-out Speed:** __________________________ rev/min.  
____________________________ rev/min.

**Cooling System Pressure:** __________________________  
**Radiator:** __________________________

**Comments:**
___________________________________________________________________________________

___________________________________________________________________________________

**REFER TO C.I.M. SECTION 15 — RECORDING POINTS**

**Probe Positions:**
1 __________________________  2 __________________________  3 __________________________  4 __________________________
5 __________________________  6 __________________________  7 __________________________  8 __________________________
9 __________________________  10 __________________________  11 __________________________  12 __________________________

<table>
<thead>
<tr>
<th>Time (Mins.)</th>
<th>Amb. °C</th>
<th>Probe Position — Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Ambient Clearance Temperatures**

<table>
<thead>
<tr>
<th></th>
<th>Water °C</th>
<th>Lub. Oil °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilized (or Peak) Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rise Over Ambient (R.O.A.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Allowable Temperature (M.A.T.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Clearance (M.A.T. — R.O.A.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>