Selecting Fuels for Standby Dependability

The types of fuels available for diesel engines vary from highly volatile jet fuels and kerosene to the heavier fuel oils. Most diesel engines are capable of burning a wide range of fuels within these extremes. The following information will assist you in selecting the type of fuel that will afford the best overall performance and reliability of your electric set.

Generally speaking, engines which operate much of the time at low load demand (which is typical or many diesel-electric sets) are better off with a higher-grade fuel such as Diesel No. 1 or kerosene. These lighter fuels also are recommended where minimum exhaust smoke is required. Any money saved on fuel cost with low-grade fuels, such as Diesel No. 2 and furnace oil, will likely be offset by additional maintenance and the required use of high-priced lubricating oils. More important is the peace of mind afforded by high-grade fuels, which aid quick starting and are less apt to burden your engine with deposits, wear, corrosion or sludge.

Types of Fuel Oil

The quality of fuel oil can be a dominant factor in satisfactory engine life and performance. A large variety of fuel oils are marketed for diesel engine use. Their properties depend upon the refining practices employed and the nature of the crude oils from which they are produced. For example, fuel oils may be produced within the boiling range of 300 to 700 °F, having many possible combinations of other properties.

The American Society for Testing and Materials has set up classifications for commercially available fuel oils. Grade 1D fuels range from kerosene to the intermediate distillates. Grade 2D has a higher boiling point and a wider tolerance of contaminants.

The fuels commonly known as high-grade fuels (kerosene and 1D fuels) seldom contribute to the formation of harmful engine deposits and corrosion. On the other hand, while refining improves the fuel, it also lowers the B.T.U. or heat value of the fuel. As a result, the higher-grade fuels develop slightly less power than the same quantity of low-grade fuel. This is usually more than offset by the advantages of high-grade fuels, such as quicker starts and less frequent overhauls. Before using low-grade fuels, therefore, some understanding of the problems and extra costs that may be encountered is necessary.

Fuels with high sulfur content cause corrosion, wear and deposits in the engine. Fuels that are not volatile enough or don't ignite rapidly may leave harmful deposits in the engine and may cause poor starting or running under adverse operating conditions. The use of low-grade fuels may require the use of high-priced, higher-detergent lubricating oils.

The additional contaminants present in low-grade fuels may result in darker exhaust and more pronounced odor. This may be objectionable in hospitals, offices, commercial and urban locations. Thus, location, application and environmental conditions should be considered when selecting fuel.

The electric-set owner may elect to use a low-grade fuel because high-grade fuels are not readily available in his area or because he can realize a net saving with low-grade fuels despite higher engine maintenance costs. In that case, frequent examination of lubrication oil should be made to determine sludge formation and the extent of lube oil contamination.

Aside from the various grades of fuel oil commonly used in diesel engines, aircraft jet fuels also are sometimes used, especially in circumstances where the jet fuels are more readily available than conventional fuels. Jet fuels are lower in B.T.U. content and lubrication quality than conventional fuels. As a result, some diesel fuel systems must undergo major modifications to accommodate this type of fuel. However, Detroit Diesel engines with their unit injector fuel systems do not require a major modification to satisfactorily burn jet fuels.

Reliable operation of a diesel engine may vary from one fuel to another, depending on many factors, including fuel characteristics and engine operating conditions. To understand these factors and their effects, let's see how combustion takes place in a diesel engine.

ASTM Classification of Diesel Fuel Oils

	No. 1-D	No. 2-D
Flash Pt.; °F Min.	100	125
Carbon Residue; %	0.15	0.35
Water and Sediment; (% by Volume) Max.	Trace	0.10
Ash; % by Wt.; Max.	0.01	0.02
Distillation, °F 90% Pt.; Max.	550	640
Min.		540
Viscosity at 100°F; centistokes Min.	1.4	2.0
Max.	2.5	4.3
Sulfur; % Max.	0.5	0.5
Cetane No; Min.	40	40

Compression-Ignition Principle

The diesel engine is a high-compression internal combustion engine. Whether two-cycle or four-cycle, the same events of intake, compression, power and exhaust must take place.

Fresh air enters the cylinder and is compressed by the upward stroke of the piston to 500 to 600 pounds per square inch. The high compression of the air raises its temperature to nearly 1000 °F. As the piston reaches the top of the compression stroke, a finely atomized quantity of fuel is injected into the hot compressed air and ignites, driving the piston downward to produce power. This process is called compression ignition and is the principle of operation of a diesel engine.

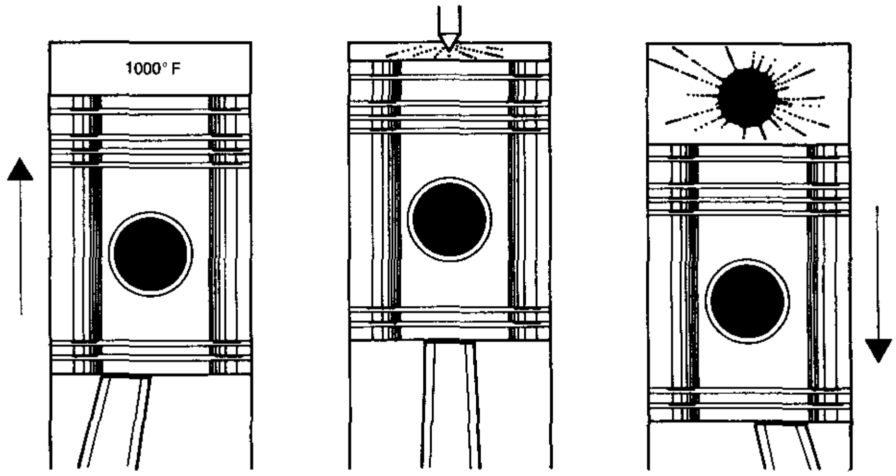


FIG. 6-4 — POWER IS PRODUCED IN A DIESEL ENGINE BY INJECTING FUEL INTO HOT COMPRESSED AIR

Effect of Operating Conditions

Operating conditions (load and ambient air temperature) affect engine temperature. Only in rare instances are engines which power electric sets continuously operated at their rated load capabilities. More commonly, an electric set carries less than 50% of its rated load. Sometimes this is all the load that exists, or it may be the portion of the load that is usually on the line. In either case, variations in load cause variations in the temperature of the engine's combustion chamber. The harder an engine works, the higher the combustion temperatures. Low or moderate load results in lower combustion temperature and thus lower cylinder temperature. A more volatile fuel may be required to assure ignition and efficient combustion when operation is predominantly at low load.

The temperature of the air entering the engine affects compression temperature, which must be high enough to achieve compression ignition. An engine operating with intake air at 20 °F below zero will have lower compression temperatures than one operating in an ambient air temperature of 100 °F, although at low intake temperature, more air is ingested and consequently it is compressed to a higher pressure. Lower compression temperature affects the ability of the engine to achieve compression ignition for starting and running. Therefore, a fuel that is more easily ignited might be necessary when intake air temperatures are apt to be low.

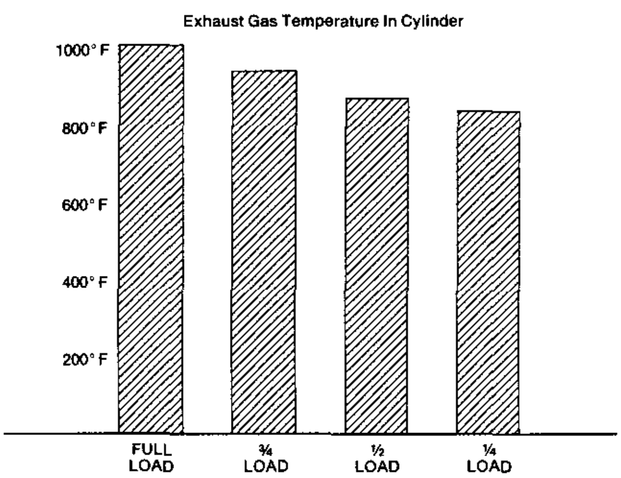


FIG. 6-5 — HOW ENGINE LOAD AFFECTS TEMPERATURE IN CYLINDER

Effect of Engine Design

Although it is sometimes stated that engine design determines the type of fuel to use, most diesel engines can satisfactorily burn a wide range of fuels. Special fuels are not necessarily required by any nationally known diesel engine. The decision to burn a certain grade of fuel is generally up to the individual electric-set owner and any existing ordnances controlling exhaust smoke, odor, and air pollution. The best fuel is the one that suits the operating conditions and is found to give satisfactory operation with minimum maintenance expense.

Fuels with harmful properties have a detrimental effect regardless of the make or type of engine. Some engine manufacturers claim that precombustion chamber design permits engines to use lower grades of fuels. However, a cooperative study made by the petroleum industry and engine manufacturers showed that an increase in sulfur content resulted in an increase in engine deposits and wear in both precombustion chamber engines and open combustion chamber engines. An increase in distillation end-point range had the same effect. Other examples could be cited, but the fact is that low-grade fuels with harmful properties will generate wear and corrosion and cause harmful deposits to form in one engine as well as another.

Basic Fuel Properties

The reason that one fuel may be more satisfactory than another in a particular application is usually related to differences in the three most important properties of diesel engine fuel oil: cetane rating, distillation end-point, and sulfur content.

Cetane Rating: There is a delay between the time that the fuel is injected into the cylinder and the time that ignition by the hot air takes place. This delay characteristic is expressed as a cetane number (usually between 30 and 60). Rapidly ignited fuels have high cetane ratings. Slowly ignited fuels have low cetane ratings.

Engines have cooler compression temperatures when they are starting, idling or under low-load operation,

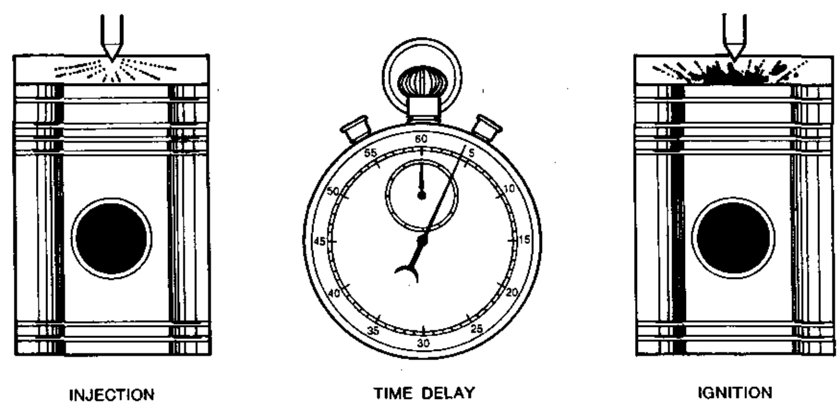


FIG. 6-6 — IGNITION DELAY DEPENDS ON CETANE RATING OF FUEL

particularly in cold weather. A fuel with better ignition quality (e.g., a cetane number of 45) would assist combustion more than a lower cetane fuel when compression temperatures are cooler. This is the reason that ether, with a very high cetane rating of 85-96, is often used for starting in cold weather. The lower the ambient temperature, the greater the need for a fuel that will ignite rapidly.

When the cetane number of the fuel is too low, it may result in difficult starting, engine knock and puffs of white exhaust smoke(unburned fuel), particularly during engine warmup and low-load operation when engine temperatures are very low. If these conditions are allowed to exist, harmful fuel deposits will accumulate within the engine. However, a high cetane number alone will not necessarily insure against deposit formation. Other key fuel properties must be in balance as well.

Distillation End-Point: Fuel can be burned in an engine only in vaporized form. The temperature at which fuel is completely vaporized is called the distillation end-point temperature of the fuel. The distillation end-point of fuel oil should be low enough to permit complete vaporization at the engine temperatures which will be encountered.

Since the combustion chamber temperature depends on the atmospheric temperature and engine speed and load, poor vaporization is particularly apt to occur during cold weather or low-load operation. Thus, for engines operating at reduced speed and loads or in cold weather (low compression temperatures), more volatile fuels (that is, fuels with low distillation end-points) will give more dependable performance.

A fuel whose distillation end-point is too high for the operating conditions may have harmful effects on the engine. For example, fuel that cannot be completely vaporized and burned will accumulate and form sludge and other harmful deposits in the engine. Ring groove deposits increase when heavier, less-volatile fuels are used. Heavy fuels also tend to increase exhaust deposits when engines are operated at low loads.

Sulfur Content: Sulfur content in fuel oil should be as low as possible. Limited amounts can be tolerated, but there is a direct relationship between the amount of sulfur present in fuel and the amount of corrosion and deposit formation within the engine. Impartial tests have shown that increasing sulfur content from 0.25% to 1.25% increased deposits and wear 135%. This action is usually most pronounced on the cylinder liners, pistons and rings.

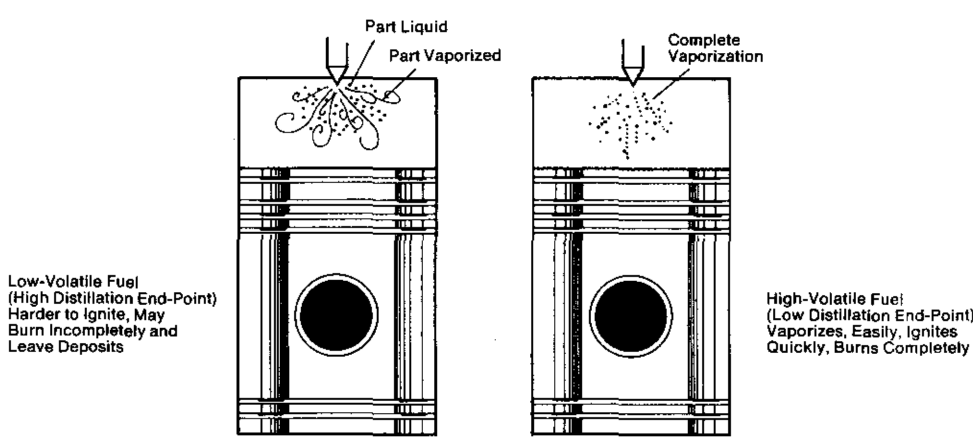


FIG. 6-7 — EFFECT OF DISTILLATION END-POINT ON FUEL VAPORIZATION AND COMBUSTION

Other Fuel Properties

While cetane rating, distillation end-point and sulfur content are the most important properties of fuel oil, there are other properties and contaminants which should be mentioned.

Viscosity measures a fuel oil's internal resistance to flow. Fuel should be able to flow freely at the lowest temperature expected but should not be so thin that it leaks past seals. Multiple-pump fuel systems require a narrower range of viscosity to prevent fuel leakage and consequent loss of power.

Pour Point is the temperature at which fuel stops flowing. For cold weather operation, the pour point should be specified 10 °F. below the ambient temperature at which the engine is to be operated, except where fuel or lube oil heating facilities are provided.

Cloud Point measures the temperature at which wax crystals start to separate from the fuel. This should be below the lowest temperatures encountered to prevent clogging of fuel filters.

Water and the contaminants which accompany it usually result in corrosion and wear of fuel injection systems and harmful ingredients in the lubricant.

The **ash content** of fuel generally consists of such impurities as metallic oxide and sand, which produce an abrasive action on the moving parts of the engine. The amount of ash present in fuel oil should be kept to a minimum.

Carbon Residue should also be kept to a minimum. It is deposited on the surface of the combustion chamber, on the cylinder walls, in the ports and exhaust manifold. When carbon is deposited behind the piston rings, it forms a solid mass causing overheating of the piston with accompanying ring and cylinder liner failure. When deposited on a piston or liner surface in the presence of heat and pressure, it often forms a hard glossy lacquer.

Fuel Selection Guide

Since electric-set engines generally operate lightly loaded, it is recommended that either kerosene or 1-D fuel be used both in winter and summer. Specify fuel properties according to the following chart. These recommendations apply to most Detroit Diesel engine-powered electric sets. For special applications, consult a Detroit Diesel Allison Distributor.

Selecting a fuel that keeps within these specifications will tend to reduce the possibility of harmful deposits and corrosion in the engine, both of which could result in more frequent overhauls and greater maintenance expense. Specify exact fuel properties to your local fuel supplier.

	Final Boiling Point (Max.)	Cetane Number (Min.)	Sulfur Number (Max.)
Winter	550 °F	45	0.30%
Summer	600 °F	40	0.50%

Maintaining Fresh Fuel

Most fuels deteriorate if they stand unused for a period of many months. With standby generators it is preferable to store only enough fuel to support a few days or even a few hours of continuous running of the electric set so that normal engine testing will turn over a tankful within a year and a half. However, if it is necessary to store a large amount of fuel over an extended period of time, kerosene should be used instead of diesel fuel since kerosene will not deteriorate for several years. In such a case, the specifications should state that the engine must be capable of delivering the full KW power on kerosene as well as on diesel fuel.

Other solutions are to add inhibitors to the fuel or to obtain greater turnover by using the fuel for other purposes. A gum inhibitor added to diesel fuel will keep it in good condition up to two years, but kerosene with an inhibitor added will last several times as long. Before using an inhibitor, check with the fuel oil supplier.

If the building furnace has an oil burner, it is possible to burn diesel fuel in the furnace, connecting both the engine and the furnace to the same tank. In this way, a large supply of diesel fuel is available for emergency use by the electric set, and the fuel supply is continuously turned over since it is being burned in the furnace. Thus, there is no long storage problem.

Self-Contained Dependability

In some areas, where natural gas is cheap, natural gas spark-ignition engines are used in electric sets that are intended for continuous service. For standby service, however, this is not recommended. The natural gas supply and regulation system adds substantially to the complexity of the installation, and there is little to be gained in terms of fuel cost over a period of time. More important, it makes the emergency power less dependable. Not only is such an engine less dependable than a diesel, but often the same storm or accident that disrupts the normal electric power also cuts off gas service. Thus, a natural gas engine would be disabled at the very time it is needed. By contrast, a diesel engine, with its fuel in a nearby tank, is a self-contained system that does not depend on outside services. It is more dependable and affords greater standby protection than systems which depend on a public utility for fuel.

Tables and Formulas for Engineering Standby Electric Sets

Table 1. Fuel Consumption Formulas

Fuel Consumption (lb/hr) = Specific Fuel Cons. (lb/BHP/hr) x BHP

$$\text{Fuel Consumption (gal/hr)} = \frac{\text{Spec. Fuel Cons. (lb/BHP/hr) x BHP}}{\text{Fuel Specific Weight (lb/gal)}}$$

Fuel Spec Weight (lb/gal) = Fuel Specific Gravity x 8.34 lb

$$\text{Specific Fuel Consumption (lb/BHP/hr)} = \frac{\text{Fuel Cons. (gal/hr) x Fuel Spec. Wt (lb/gal)}}{\text{BHP}}$$

$$\text{Specific Fuel Consumption (kg/MHP/hr)} = \frac{\text{Spec. Fuel Cons. (lb/BHP/hr)}}{2.24}$$

The specific fuel consumption (lb/BHP/hr) shown in published specification sheets is at Standby Rated Power. If the engine is to be operated at a power output other than the Standby Rated Power Shown in the specification sheet, it is recommended that you consult a Detroit Diesel Allison Distributor for fuel consumption data.

Table 2. Conversions for Units of Power

Unit	Horsepower	Foot-Lb. per Minute	Watts	Kilowatts	Megawatts	Metric Horsepower	Btu. per Minute
1 Horsepower	1	33,000	746	.746	.000746	1.014	42.4
1 Foot-Lb. per Minute	–	1	.0226	–	–	–	.001285
1 Watt	.00134	44.237	1	.001	.000001	.00136	.0568
1 Kilowatt	1.341	44,237	1000	1	.001	1.360	56.8
1 Megawatt	1341	44,237,000	1,000,000	1000	1	1360	56,860
1 Metric Horsepower	.986	32,550	736	.736	.000736	1	41.8
1 Btu. per Minute	.0236	778	17.6	.0176	.0000176	.0239	1

One unit in the lefthand column equals the value of units under the top heading.
Mechanical power and ratings of motors and engines are expressed in horsepower.
Electrical power is commonly expressed in watts or kilowatts.

$$\text{Electric Motor Horsepower} = \frac{\text{KW Input x Motor Efficiency}}{\text{0.746 x Generator Efficiency}}$$

$$\text{Engine Horsepower Required} = \frac{\text{KW Output}}{\text{0.746 x Generator Efficiency}}$$

Piston Travel

Feet per Minute (FPM) = L x N x 2

L = Length of Stroke in Feet

N = Rotational Speed of Crankshaft in RPM

Brake Mean Effective Pressure (BMEP)

2 Cycle: $$\text{BMEP} = \frac{\text{396,000 x BHP}}{\text{Total Displacement x RPM}}$$

4 Cycle: $$\text{BMEP} = \frac{\text{792,000 x BHP}}{\text{Total Displacement x RPM}}$$

Table 3. Conversions of Inches to Millimeters

in.	mm
1/64	0.3969
1/32	0.7937
3/64	1.1906
1/16	1.5875
5/64	1.9844
3/32	2.3812
7/64	2.7781
1/8	3.1750
9/64	3.5719
5/32	3.9687
11/64	4.3656
3/16	4.7625
13/64	5.1594
7/32	5.5562
15/64	5.9531
1/4	6.3500
17/64	6.7469
9/32	7.1437
19/64	7.5406
5/16	7.9375
21/64	8.3344
11/32	8.7312
23/64	9.1281
3/8	9.5250
25/64	9.9219
13/32	10.3187
27/64	10.7156
7/16	11.1125
29/64	11.5094
15/32	11.9062
31/64	12.3031
1/2	12.7000
33/64	13.0969
17/32	13.4937
35/64	13.8906
9/16	14.2875
37/64	14.6844
19/32	15.0812
39/64	15.4781
5/8	15.8750
41/64	16.2719
21/32	16.6687
43/64	17.0656
11/16	17.4625
45/64	17.8594
23/32	18.2562
47/64	18.6531
3/4	19.0500
49/64	19.4469
25/32	19.8437
51/64	20.2406
13/16	20.6375
53/64	21.0344
27/32	21.4312
55/64	21.8281
7/8	22.2250
57/64	22.6219
29/32	23.0187
59/64	23.4156
15/16	23.8125
61/64	24.2094
31/32	24.6062
63/64	25.0031
1	25.4001
1-1/32	26.1938
1-1/16	26.9876
1-3/32	27.7813
1-1/8	28.5751
1-5/32	29.3688
1-3/16	30.1626
1-7/32	30.9563
1-1/4	31.7501
1-9/32	32.5438
1-5/16	33.3376
1-11/32	34.1313
1-3/8	34.9251
1-13/32	35.7188
1-7/16	36.5126
1-15/32	37.3063
1-1/2	38.1001
1-17/32	38.8938
1-9/16	39.6876
1-19/32	40.4813
1-5/8	41.2751
1-21/32	42.0688
1-11/16	42.8626
1-23/32	43.6563
1-3/4	44.4501
1-25/32	45.2438
1-13/16	46.0376

in.	mm
1-27/32	46.8313
1-7/8	47.6251
1-29/32	48.4188
1-15/16	49.2126
1-31/32	50.0063
2	50.8001
2-1/32	51.5939
2-1/16	52.3876
2-3/32	53.1814
2-1/8	53.9751
2-5/32	54.7688
2-3/16	55.5626
2-7/32	56.3564
2-1/4	57.1501
2-9/32	57.9439
2-5/16	58.7376
2-11/32	59.5314
2-3/8	60.3251
2-13/32	61.1189
2-7/16	61.9126
2-15/32	62.7064
2-1/2	63.5001
2-17/32	64.2939
2-9/16	65.0876
2-19/32	65.8814
2-5/8	66.6751
2-21/32	67.4689
2-11/16	68.2626
2-23/32	69.0564
2-3/4	69.8501
2-25/32	70.6439
2-13/16	71.4376
2-27/32	72.2314
2-7/8	73.0251
2-29/32	73.8189
2-15/16	74.6126
2-31/32	75.4064
3	76.2002
3-1/32	76.9939
3-1/16	77.7877
3-3/32	78.5814
3-1/8	79.3752
3-5/32	80.1689
3-3/16	80.9627
3-7/32	81.7564
3-1/4	82.5502
3-9/32	83.3439
3-5/16	84.1377
3-11/32	84.9314
3-3/8	85.7252
3-13/32	86.5189
3-7/16	87.3127
3-15/32	88.1064
3-1/2	88.9002
3-17/32	89.6939
3-9/16	90.4877
3-19/32	91.2814
3-5/8	92.0752
3-21/32	92.8689
3-11/16	93.6627
3-23/32	94.4564
3-3/4	95.2502
3-25/32	96.0439
3-13/16	96.8377
3-27/32	97.6314
3-7/8	98.4252
3-29/32	99.2189
3-15/16	100.013
3-31/32	100.806
4	101.600
4-1/32	102.394
4-1/16	103.188
4-3/32	103.981
4-1/8	104.775
4-5/32	105.569
4-3/16	106.363
4-7/32	107.156
4-1/4	107.950
4-9/32	108.744
4-5/16	109.538
4-11/32	110.331
4-3/8	111.125
4-13/32	111.919
4-7/16	112.713
4-15/32	113.506
4-1/2	114.300
4-17/32	115.094
4-9/16	115.888
4-19/32	116.681
4-5/8	117.475

in.	mm
4-21/32	118.269
4-11/16	119.063
4-23/32	119.856
4-3/4	120.650
4-25/32	121.444
4-13/16	122.238
4-27/32	123.031
4-7/8	123.825
4-29/32	124.619
4-15/16	125.413
4-31/32	126.206
5	127.000
5-1/32	127.794
5-1/16	128.588
5-3/32	129.382
5-1/8	130.175
5-5/32	130.969
5-3/16	131.763
5-7/32	132.557
5-1/4	133.350
5-9/32	134.144
5-5/16	134.938
5-11/32	135.732
5-3/8	136.525
5-13/32	137.319
5-7/16	138.113
5-15/32	138.907
5-1/2	139.700
5-17/32	140.494
5-9/16	141.288
5-19/32	142.082
5-5/8	142.875
5-21/32	143.669
5-11/16	144.463
5-23/32	145.200
5-3/4	146.159
5-25/32	146.841
5-13/16	147.638
5-27/32	148.432
5-7/8	149.225
5-29/32	150.019
5-15/16	150.813
5-31/32	151.607
6	152.400
6-1/16	153.988
6-1/8	155.575
6-3/16	157.163
6-1/4	158.750
6-5/16	160.338
6-3/8	161.925
6-7/16	163.513
6-1/2	165.100
6-9/16	166.688
6-5/8	168.275
6-11/16	169.863
6-3/4	171.450
6-13/16	173.038
6-7/8	174.625
6-15/16	176.213
7	177.800
7-1/16	179.388
7-1/8	180.975
7-3/16	182.563
7-1/4	184.150
7-5/16	185.738
7-3/8	187.325
7-7/16	188.913
7-1/2	190.500
7-9/16	192.088
7-5/8	193.675
7-11/16	195.263
7-3/4	196.850
7-13/16	198.438
7-7/8	200.025
7-15/16	201.613
8	203.200
8-1/16	204.788
8-1/8	206.375
8-3/16	207.963
8-1/4	209.550
8-5/16	211.138
8-3/8	212.725
8-7/16	214.313
8-1/2	215.900
8-9/16	217.488
8-5/8	219.075
8-11/16	220.663
8-3/4	222.250
8-13/16	223.838
8-7/8	225.425

in.	mm
8-15/16	227.013
9	228.600
9-1/16	230.188
9-1/8	231.775
9-3/16	233.363
9-1/4	234.950
9-5/16	236.538
9-3/8	238.125
9-7/16	239.713
9-1/2	241-300
9-9/16	242.888
9-5/8	244.475
9-11/16	246.063
9-3/4	247.650
9-13/16	249.238
9-7/8	250.825
9-15/16	252.413
10	254.001
10-1/16	255.588
10-1/8	257.176
10-3/16	258.763
10-1/4	260.351
10-5/16	261.938
10-3/8	263.526
10-7/16	265.113
10-1/2	266.701
10-9/16	268.288
10-5/8	269.876
10-11/16	271.463
10-3/4	273.051
10-13/16	274.638
10-7/8	276.226
10-15/16	277.813
11	279.401
11-1/16	280.988
11-1/8	282.576
11-3/16	284.163
11-1/4	285.751
11-5/16	287.338
11-3/8	288.926
11-7/16	290.513
11-1/2	292.101
11-9/16	293.688
11-5/8	295.276
11-11/16	296.863
11-3/4	298.451
11-13/16	300.038
11-7/8	301.626
11-15/16	303.213
12	304.801
13	330.201
14	355.601
15	381.001
16	406.401
17	431.801
18	457.201
19	482.601
20	508.001
21	533.401
22	558.801
23	584.201
24	609.601
25	635.001
26	660.401
27	685.801
28	711.201
29	736.601
30	762.002
31	787.002
32	812.802
33	838.202
34	863.602
35	889.002
36	914.402
37	939.802
38	965.202
39	990.602
40	1016.00
41	1041.40
42	1066.80

ft.	in.	mm
3	7	1092.20
3	8	1117.60
3	9	1143.00
3	10	1168.40
3	11	1193.80
4	0	1219.20
4	1	1244.60
4	2	1270.00
4	3	1295.40
4	4	1320.80
4	5	1346.20
4	6	1371.60
4	7	1397.00
4	8	1422.40
4	9	1447.80
4	10	1473.20
4	11	1498.60
5	0	1524.00
5	1	1549.40
5	2	1574.80
5	3	1600.20
5	4	1625.60
5	5	1651.00
5	6	1676.40
5	7	1701.80
5	8	1727.29
5	9	1752.60
5	10	1778.00
5	11	1803.40
6	0	1828.80
6	1	1854.20
6	2	1879.60
6	3	1905.00
6	4	1930.40
6	5	1955.80
6	6	1981.20
6	7	2006.60
6	8	2032.00
6	9	2057.40
6	10	2082.80
6	11	2108.20
7	0	2133.60
7	1	2159.00
7	2	2184.40
7	3	2209.80
7	4	2235.20
7	5	2260.60
7	6	2286.00
7	7	2311.40
7	8	2336.80
7	9	2362.20
7	10	2387.60
7	11	2413.00
8	0	2438.40
8	1	2463.80
8	2	2489.20
8	3	2514.61
8	4	2540.01
8	5	2565.41
8	6	2590.81
8	7	2616.21
8	8	2641.61
8	9	2667.01
8	10	2692.41
8	11	2717.81
9	0	2743.21
9	1	2768.61
9	2	2794.01
9	3	2819.41
9	4	2844.81
9	5	2870.21
9	6	2895.61
9	7	2921.01
9	8	2946.41
9	9	2971.81
9	10	2997.21
9	11	3022.61
10	0	3048.01
11	0	3352.81
12	0	3657.61
13	0	3962.41
14	0	4267.21
15	0	4572.01
16	0	4876.81
17	0	5181.61
18	0	5486.41
19	0	5791.21
20	0	6096.01
21	0	6400.81

ft.	in.	mm
22	0	6705.61
23	0	7010.41
24	0	7315.21
25	0	7620.02
26	0	7924.82
27	0	8229.62
28	0	8534.42
29	0	8839.22
30	0	9144.02
31	0	9448.82
32	0	9753.62
33	0	10,058.4
34	0	10,363.2
35	0	10,668.0
36	0	10,972.8
37	0	11,277.6
38	0	11,582.4
39	0	11,887.2
40	0	12,192.0
41	0	12,496.8
42	0	12,801.6
43	0	13,106.4
44	0	13,411.2
45	0	13,716.0
46	0	14,020.8
47	0	14,325.6
48	0	14,630.4
49	0	14,935.2
50	0	15,240.0
51	0	15,544.8
52	0	15,849.6
53	0	16,154.4
54	0	16,459.2
55	0	16,764.0
56	0	17,068.8
57	0	17,373.6
58	0	17,678.4
59	0	17,983.2
60	0	18,288.0
61	0	18,592.8
62	0	18.897.6
63	0	19,202.4
64	0	19,507.2
65	0	19,812.0
66	0	20,116.8
67	0	20,421.6
68	0	20,726.4
69	0	21,031.2
70	0	21,336.0
71	0	21,640.8
72	0	21,945.6
73	0	22,250.4
74	0	22,555.2
75	0	22,860.0
76	0	23,164.8
77	0	23,469.6
78	0	23,774.4
79	0	24,079.2
80	0	24,384.0
81	0	24,688.8
82	0	24,993.6

Table 4. Conversions for Units of Speed

	Feet per Min.	Meters per Second	Feet per Second	Meters/ Min.	Miles/ Hr.	Kilo-M/ Hr.	Knots per Hour
Feet per Minute	1	.00508	–	–	.01136	–	–
Meters per Second	196.848	1	–	–	–	–	–
Feet per Second	–	–	1	18.288	–	–	–
Meters per Minute	–	–	.05468	1	.03728	–	–
Miles per Hour	88	–	–	26.822	1	1.6093	.8674
Kilometers per Hour	–	–	–	–	.6214	1	–
Knots per Hour	–	–	–	–	1.153	–	1

One unit in the lefthand column equals the value of units under the top heading.

Table 5. Conversions for Measurements of Water

	Cubic Feet	Pounds	Gal. (US)	Gal. (IMP)	Liters	Head (Ft)	Lb/Sq. In.	Ton/Sq. Ft.	Head Min.	Cubic Ft/ (Meters)	Gal. (US) per Hr.
Cubic Feet	1	62.42	–	–	–	–	–	–	–	–	–
Pounds	.01602	1	.12	.10	.4536	–	–	–	–	–	–
Gallons (US)	–	8.34	1	–	–	–	–	–	–	–	–
Gallons (Imperial)	–	10.0	–	1	–	–	–	–	–	–	–
Liters	–	2.2046	–	–	1	–	–	–	–	–	–
Head (Ft).	–	–	–	–	–	1	.4335	–	–	–	–
Pounds per Sq. Inch	–	–	–	–	–	2.3070	1	.02784	.7039	–	–
Tons per Sq. Foot	–	–	–	–	–	35.92	–	1	–	–	–
Head (Meters)	–	–	–	–	–	–	1.4221	–	1	–	–
Cubic Ft. per Min.	–	–	–	–	–	–	–	–	–	1	448.92
Gallons (US) per Hr.	–	–	–	–	–	–	–	–	–	.002227	1

One unit in the lefthand column equals the value of units under the top heading.

Table 6. Barometric Pressures and Boiling Points of Water at Various Altitudes

Altitude	Barometric Pressure: Inches Mercury	Lb. Per Square Inch	Feet Water	Water Boiling Point	
Sea Level	29.92	14.69	33.95	212° F	100° C
1000 Ft.	28.86	14.16	32.60	210.1°F	99° C
2000 Ft.	27.82	13.66	31.42	208.3°F	98° C
3000 Ft.	26.81	13.16	30.28	206.5°F	97° C
4000 Ft.	25.84	12.68	29.20	204.6°F	95.9°C
5000 Ft.	24.89	12.22	28.10	202.8°F	94.9°C
6000 Ft.	23.98	11.77	27.08	201.0°F	94.1°C
7000 Ft.	23.09	11.33	26.08	199.3°F	93° C
8000 Ft.	22.22	10.91	25.10	197.4°F	91.9°C
9000 Ft.	21.38	10.50	24.15	195.7°F	91° C
10000 Ft.	20.58	10.10	23.25	194.0°F	90° C
11000 Ft.	19.75	9.71	22.30	192.0°F	88.9°C
12000 Ft.	19.03	9.34	21.48	190.5°F	88° C
13000 Ft.	18.29	8.97	20.65	188.8°F	87.1°C
14000 Ft.	17.57	8.62	19.84	187.1°F	86.2°C
15000 Ft.	16.88	8.28	18.07	185.4°F	86.2°C

Table 7. Length Equivalents

	Microns	Centimeters	Inches	Feet	Yards	Meters	Kilometers	Miles
1 Micron	1	0.0001	0.00003937	–	–	0.000001	–	–
1 Centimeter	10,000	1	0.3937	0.03281	0.01094	0.01	–	–
1 Inch	25,400	2.540	1	0.08333	0.02778	0.0254	–	–
1 Foot	–	30.48	12	1	0.3333	0.3048	–	–
1 Yard	–	91.44	36	3	1	0.9144	–	–
1 Meter	1,000,000	100	39.37	3.281	1.0936	1	–	–
1 Kilometer	–	100,000	39,370	3281	1093.6	1000	1	0.6214
1 Mile	–	160,935	63,360	5280	1760	1609	1.609	1

One unit in the lefthand column equals the value of units under the top heading.

Table 8. Area Equivalents

Unit	Sq. Cm.	Sq. In.	Sq. M.	Sq. Ft.	Hectare	Acre	Sq. Km.	Sq. Mi.
1 Sq. Cm.	1	0.155	–	–	–	–	–	–
1 Sq. In.	6.4516	1	.00064516	.006944	–	–	–	–
1 Sq. M.	10,000	1550	1	10.764	–	–	–	–
1 Sq. Ft.	929	144	0.0929	1	–	–	–	–
1 Hectare	–	–	10,000	107,639	1	2.4710	0.01	0.003861
1 Acre	–	–	4,047	43,560	0.4047	1	0.004047	0.0015625
1 Sq. Km.	–	–	1,000,000	10,763,867	100	247.1	1	0.3861
1 Sq. Mi.	–	–	2,589,998	27,878,400	258.99	640	2.5899	1

One unit in the lefthand column equals the value of units under the top heading.

Table 9. Weight Equivalents

Unit	Kilograms	Ounces Avoirdupois	Pounds Avoirdupois	Tons		
				Short	Long	Metric
1 Kilogram	1	35.27	2.205	–	–	–
1 Ounce	0.02835	1	0.0625	–	–	–
1 Pound	0.4536	16	1	–	–	–
1 Short Ton	907.2	32000	2000	1	0.8929	0.9072
1 Long Ton	1016	35840	2240	1.12	1	1.016
1 Metric Ton	1000	35274	2205	1.102	0.9842	1

One unit in the lefthand column equals the value of units under the top heading.

Table 10. Volume and Capacity Equivalents

Unit	Cubic Inches	Cubic Feet	Cubic Yards	Cubic Centimeters	Cubic Meters	U.S. Liquid Gallons	Imperial Gallons	Liters
1 Cu. In.	1	.000579	.0000214	16.39	.0000164	.004329	.00359	.0164
1 Cu. Ft.	1728	1	.03704	28317	.0283	7.481	6.23	28.32
1 Cu. Yd.	46656	27	1	764600	.765	202	167.9	764.6
1 Cu. Cm.	.061	.0000353	.00000131	1	.000001	.000264	.00022	.001
1 Cu. M.	61020	35.31	1.308	1,000,000	1	264.2	220.2	1000
1 U.S. Liquid Gal.	231	.1337	.00495	3785	.003785	1	.833	3.785
1 Imperial Gallon	277.42	.16	.00594	4545.6	.004546	1.2	1	4.546
1 Liter	61.02	.03531	.001308	1000	.001	.2642	.22	1

One unit in the lefthand column equals the value of units under the top heading.

Table 11. Conversions of Units of Time

	Second	Minute	Hour	Day	Month	Year
Second	1	.01667	.0002778	.00001157	3.805×10^{-7}	3.17×10^{-8}
Minute	60	1	.01667	.000694	.0000228	1.903×10^{-6}
Hour	3,600	60	1	.0417	.001370	.0001142
Day	86,400	1,440	24	1	.0329	.00274
Month	2,628,000	43,800	730	30.4	1	.0833
Year	31,536,000	525,600	8,760	365	12	1

One unit in the lefthand column equals the value of units under the top heading.

Table 12. Conversions of Units of Flow

	U. S. Gallons Per Minute	Million U. S. Gallons Per Day	Cubic Feet Per Second	Cubic Meters Per Hour	Liters Per Second
1 U. S. Gallon per Minute (U.S.G.P.M.)	1	.001440	.00223	.2270	.0631
1 Million U. S. Gallons per Day (M.G.D.)	694.5	1	1.547	157.73	43.8
1 Cubic Foot per Second	448.8	.646	1	101.9	28.32
1 Cubic Meter per Hour	4.403	.00634	.00981	1	.2778
1 Liter per Second	15.85	.0228	.0353	3.60	1

One unit in the lefthand column equals the value of units under the top heading.

Cubic foot per second, also written second-foot, is the unit of flow in the English system used to express rate of flow in large pumps, ditches and canals. Flow in pipe lines or from pumps and wells is commonly measured in gallons per minute. Rates of water consumption and measurement of municipal water supply are ordinarily made in million gallons per day.

Table 13. Conversions of Centigrade and Fahrenheit

Water boils at .... 100 degrees Centigrade (C. or Cent.) 212 degrees Fahrenheit (F. or Fahr.) Water freezes at .... 0 degrees Centigrade (C. or Cent.) 32 degrees Fahrenheit (F. or Fahr.)

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	32.0								
1	33.8	21	69.8	41	105.8	61	141.8	81	177.8
2	35.6	22	71.6	42	107.6	62	143.6	82	179.6
3	37.4	23	73.4	43	109.4	63	145.4	83	181.4
4	39.2	24	75.2	44	111.2	64	147.2	84	183.2
5	41.0	25	77.0	45	113.0	65	149.0	85	185.0
6	42.8	26	78.8	46	114.8	66	150.8	86	186.8
7	44.6	27	80.6	47	116.6	67	152.6	87	188.6
8	46.4	28	82.4	48	118.4	68	154.4	88	190.4
9	48.2	29	84.2	49	120.2	69	156.2	89	192.2
10	50.0	30	86.0	50	122.0	70	158.0	90	194.0
11	51.8	31	87.8	51	123.8	71	159.8	91	195.8
12	53.6	32	89.6	52	125.6	72	161.6	92	197.6
13	55.4	33	91.4	53	127.4	73	163.4	93	199.4
14	57.2	34	93.2	54	129.2	74	165.2	94	201.2
15	59.0	35	95.0	55	131.0	75	167.0	95	203.0
16	60.8	36	96.8	56	132.8	76	168.8	96	204.8
17	62.6	37	98.6	57	134.6	77	170.6	97	206.6
18	64.4	38	100.4	58	136.4	78	172.4	98	208.4
19	66.2	39	102.2	59	138.2	79	174.2	99	210.2
20	68.0	40	104.0	60	140.0	80	176.0	100	212.0

Table 14. Conversions of Units of Pressure and Head

Unit	Pounds Per Sq. Inch	Feet of Water	Meters of Water	Inches of Mercury	Atmos-pheres	Kilograms per Sq. Cm.
1 Pound per Square Inch	1	2.31	.704	2.04	.0681	.0703
1 Foot of Water*	.433	1	.305	.882	.02947	.0305
1 Meter of Water*	1.421	3.28	1	2.89	.0967	.1
1 Inch of Mercury†	.491	1.134	.3456	1	.0334	.0345
1 Atmosphere (at sea level)	14.70	33.93	10.34	29.92	1	1.033
1 Kilogram per Sq. Cm.	14.22	32.8	10	28.96	.968	1

*Equivalent units are based on density of fresh water at 32° to 62° F.

† Equivalent units are based on density of mercury at 32° to 62° F. Sufficient Accuracy.

Absolute pressure is the sum of the gauge pressure plus the atmospheric pressure, at the location under consideration.

One unit in the lefthand column equals the value of units under the top heading.

For measuring pressure, the common unit is pounds per square inch.

For measuring head and pumping lift, the most common unit is a vertical foot of liquid. It is the pressure exerted by the liquid through a vertical distance of one foot at atmospheric pressure. To convert head of liquid to pounds per square inch, multiply the head in feet by the equivalent pressure for one foot of water (0.433) multiplied by the specific gravity of the liquid.

Table 15. Approximate Weights of Various Liquids

	Pounds per U. S. Gallon	Specific Gravity
Diesel Fuel	6.88 to 7.46	0.825 to 0.895
Ethylene Glycol	9.3 to 9.6	1.12 to 1.15
Furnace Oil	6.7 to 7.9	.80 to .95
Gasoline	5.6 to 6.3	.67 to .75
Kerosene	6.25 to 7.1	.75 to .85
Lubricating Oil (Medium)	7.5 to 7.7	.90 to .92
Water	8.34	1.00

Specific Gravity = Weight of Any Substance/ Weight of Equal Volume of Water

Table 16. Friction of Water in Pipes

*(New Wrought Iron or Steel) from standards of the Hydraulic Institute

Rate of Flow in Gallons Per Minute	Loss of Head in Feet due to Friction per 100 feet of pipe										
	2"	2-1/2"	3"	4"	5"	6"	8"	10"	12"	14"	16"
10	0.25										
15	0.51	0.23									
20	0.87	0.36									
25	1.29	0.56	0.19								
30	1.82	0.75	0.26								
35	2.42	1.00	0.35								
40	3.10	1.28	0.44								
45	3.85	1.60	0.55								
50	4.67	1.94	0.66	0.18							
60	6.59	2.72	0.92	0.25							
75	10.10	4.13	1.39	0.39							
90	14.20	5.82	1.96	0.52	0.17						
100	17.40	7.11	2.39	0.63	0.21	0.09					
125	27.70	11.24	3.77	0.98	0.30	0.12					
150	38.00	15.40	5.14	1.32	0.46	0.19					
175	52.50	21.25	7.07	1.80	0.59	0.24					
200	66.30	26.70	8.90	2.27	0.74	0.30	0.08				
225	83.80	33.70	11.20	2.82	0.92	0.37	0.10				
250	90.70	42.80	14.10	3.60	1.15	0.48	0.12				
300		58.50	19.20	4.89	1.58	0.64	0.16				
350		79.20	26.90	6.72	2.16	0.87	0.22				
400			33.90	8.47	2.72	1.09	0.28	0.09			
450			43.60	10.85	3.47	1.39	0.35	0.11			
500			52.50	13.00	4.16	1.66	0.42	0.14			
550			63.20	15.70	4.98	1.99	0.51	0.16			
600			74.80	18.60	5.88	2.34	0.60	0.19			
650			87.50	21.70	6.87	2.73	0.70	0.22	0.10		
700				25.00	7.93	3.13	0.80	0.26	0.11		
750				28.60	9.05	3.57	0.91	0.29	0.13		
800				32.40	10.22	4.03	1.02	0.33	0.14		
900				40.80	12.90	5.05	1.27	0.41	0.17	0.11	
1000				50.20	15.80	6.17	1.56	0.50	0.21	0.13	
1200				72.00	22.50	8.76	2.20	0.70	0.30	0.19	0.10
1500					34.80	13.50	3.37	1.07	0.45	0.23	0.15

	Flow Restriction of Fittings Expressed as Equivalent Feet of Straight Pipe										
Size of Fitting in Inches	2"	2-1/2"	3"	4"	5"	6"	8"	10"	12"	14"	16"
90° Ell	5.5	6.5	8	11	14	16	21	26	32	37	42
45° Ell	2.5	3	3.8	5	6.3	7.5	10	13	15	17	19
Long Sweep Ell	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Close Return Bend	13	15	18	24	31	37	51	61	74	85	100
Tee—Straight Run	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Tee—Side Inlet or Outlet	12	14	17	22	27	33	43	53	68	78	88
Globe Valve Open	55	67	82	110	140						
Angle Valve Open	27	33	41	53	70						
Gate Valve Fully Open	1.2	1.4	1.7	2.3	2.9	3.5	4.5	5.8	6.8	8	9
Gate Valve Half Open	27	33	41	53	70	100	130	160	200	230	260
Check Valve	19	23	32	43	58						

Obtain head loss per 100 feet of pipe for appropriate flow rate and pipe diameter.

Add total equivalent length of all fittings to actual pipe length. Divide by 100, and multiply quotient by head loss per 100 feet.

*No allowance has been made for age, scale accumulation, differences in diameter, or any abnormal condition of interior surface. Any factor of safety must be estimated from the local conditions and the requirements of each particular installation.

Add total equivalent length for all fittings to actual pipe length. Then compute head loss as for a straight pipe.

Table 17. Contents in Gallons of Square-Section Tanks

	*Depth in Feet and Contents in Gallons									
Dimensions in Feet	*1	4	5	6	7	8	9	10	11	12
4x 4	119.68	479	598	718	838	957	1077	1197	1316	1436
5x 5	187.00	748	935	1202	1309	1516	1683	1870	2057	2244
6x 6	269.28	1077	1346	1616	1885	2154	2424	2693	2968	3231
7x 7	366.52	1466	1833	2199	2566	2922	3299	3665	4032	4398
8x 8	478.72	1915	2394	2872	3351	3830	4308	4787	5266	5745
9x 9	605.88	2424	3029	3635	4241	4847	5453	6059	6665	7272
10x10	748.08	2992	3740	4488	5236	5984	6732	7480	8228	8976
11x11	905.08	3620	4525	5430	6336	7241	8146	9051	9956	10861
12x12	1077.12	4308	5386	6463	7540	8617	9694	10771	11848	12925

*To ascertain the contents of a square tank of depth not given in the above table, multiply the contents of tank one foot deep as in table by the required depth in feet.

Table 18. Contents in Gallons of Cylindrical Vertical Tanks

	†Depth in Feet and Contents in Gallons									
Diameter in Feet	†1	4	5	6	7	8	9	10	11	12
4	94.00	376	470	564	658	752	846	940	1034	1128
5	146.87	588	734	881	1028	1175	1322	1469	1616	1763
6	211.50	847	1058	1269	1481	1692	1904	2115	2327	2538
7	287.86	1152	1439	1727	2015	2303	2591	2879	3167	3455
8	376.00	1504	1880	2256	2632	3008	3384	3760	4136	4512
9	475.85	1904	2379	2855	3331	3806	4283	4759	5235	5711
10	587.47	2350	2938	3525	4113	4700	5288	5875	6462	7050
11	710.90	2844	3554	4265	4976	5687	6398	7109	7819	8531
12	845.97	3384	4230	5076	5922	6768	7614	8460	9306	10152

†To ascertain contents of a round tank of the above diameters, and of depth not given in the above table, multiply the contents of tank one foot deep by the required depth in feet.

Table 19. Head and Lift Definitions

Suction Lift exists when the source of supply is below the center line of the pump.

Static Suction Lift is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped.

Total Dynamic Suction Lift is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped plus all friction losses in the suction pipe and fittings.

Suction Head exists when the source of supply is above the center line of the pump.

Static Suction Head is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped.

Total Dynamic Suction Head is the vertical distance in feet from the center line of the pump to the free level of the liquid to be pumped minus all friction losses in the suction pipe and fittings.

Total Static Head is the vertical distance in feet between the free level of the source of supply and the point of free discharge or to the level of the free surface of the discharge water.

Total Dynamic Head is the vertical distance in feet between the free level of the source of supply and the point of free discharge or to the level of the free surface of the discharge water, plus all friction losses.

Note: It is standard practice to give head in feet, not in pounds per square inch, when referring to centrifugal pumps. This is contrary to the practice in use for reciprocating pumps, where pounds per square inch is always used.

Input Horsepower required for pumping a liquid is obtained from the following formula:

$$HP = \frac{\text{GPM x Head in feet x Specific Gravity}}{\text{3960 x Pump Efficiency (expressed as a decimal)}}$$

Note: The constant 3960 is obtained by dividing the number of foot pounds for one horsepower (33,000) by the weight of one gallon of water (8.34 pounds).

Table 20. Electrical Formulas

Desired Data	Single-Phase	Two-Phase* Four Wire	Three-Phase	Direct Current
Kilowatts (KW)	$\frac{I \times E \times PF}{1000}$	$\frac{I \times E \times 2 \times PF}{1000}$	$\frac{I \times E \times 1.73 \times PF}{1000}$	$\frac{I \times E}{1000}$
Megawatts (MW)	$\frac{I \times E \times PF}{1{,}000{,}000}$	$\frac{I \times E \times 2 \times PF}{1{,}000{,}000}$	$\frac{I \times E \times 1.73 \times PF}{1{,}000{,}000}$	$\frac{I \times E}{1{,}000{,}000}$
Kilovolt-Amperes (KVA)	$\frac{I \times E}{1000}$	$\frac{I \times E \times 2}{1000}$	$\frac{I \times E \times 1.73}{1000}$	
Electric Motor Horsepower Output (HP)	$\frac{I \times E \times \%Eff. \times PF}{746}$	$\frac{I \times E \times 2 \times \%Eff. \times PF}{746}$	$\frac{I \times E \times 1.73 \times \%Eff. \times PF}{746}$	$\frac{I \times E \times \%Eff.}{746}$
Amperes (I) when Horsepower is known	$\frac{HP \times 746}{E \times \%Eff. \times PF}$	$\frac{HP \times 746}{2 \times E \times \%Eff. \times PF}$	$\frac{HP \times 746}{1.73 \times E \times \%Eff. \times PF}$	$\frac{HP \times 746}{E \times \%Eff.}$
Amperes (I) When Kilowatts are known	$\frac{KW \times 1000}{E \times PF}$	$\frac{KW \times 1000}{2 \times E \times PF}$	$\frac{KW \times 1000}{1.73 \times E \times PF}$	$\frac{KW \times 1000}{E}$
Amperes (I) when KVA is known	$\frac{KVA \times 1000}{E}$	$\frac{KVA \times 1000}{2 \times E}$	$\frac{KVA \times 1000}{1.73 \times E}$	

*In three-wire, two-phase circuits the current in the common conductor is 1.41 times that in either other conductor.

E = Volts   I = Amperes   %Eff. = Percent Efficiency of Electric Motor   PF = Power Factor

Table 21. Direct Current Generator Amperes

Generator Rating	Amperes for DC Generators					
KW	115 volts	120 volts	125 volts	230 volts	240 volts	250 volts
15	130	125	120	65	62	60
20	174	167	160	87	83	80
25	217	208	200	108	104	100
30	261	250	240	130	125	120
40	347	333	320	174	167	160
50	434	417	400	217	208	200
60	521	500	480	261	250	240
75	651	625	600	326	312	300
100	869	833	800	434	417	400

Table 22. Alternator Amperes

Generator Rating	Amperes for 3-Phase Alternators													
KVA	KW@ 0.8 P.F.	120 Volts	208 Volts	220 Volts	240 Volts	440 Volts	480 Volts	600 Volts	2400 Volts	3300 Volts	4160 Volts	6900 Volts	11500 Volts	13800 Volts
18.7	15	90	52	49	45	25	23	18	–	–	–	–	–	–
25	20	120	69	66	60	33	30	24	6	4	3	–	–	–
31.3	25	151	87	82	75	41	38	30	8	5	4	2	1.5	1
37.5	30	170	104	99	90	49	45	36	9	7	5	3	2	1.5
50	40	240	139	131	120	66	60	48	12	9	7	4	2.5	2
62.5	50	301	173	164	151	82	75	60	15	11	9	5	3	2.5
75	60	361	208	197	181	99	90	72	18	13	10	6	4	3
93.8	75	452	261	246	226	123	113	90	23	16	13	8	5	4
100	80	482	278	263	241	131	120	96	24	17	14	8	5	4
125	100	602	347	328	301	164	151	120	30	22	17	10	6	5
156	125	751	433	410	376	205	188	150	38	27	22	13	8	6
187	150	901	520	491	450	246	225	180	45	33	26	16	9	8
219	175	1055	609	575	527	288	264	211	53	38	30	18	11	9
250	200	1204	695	657	602	328	301	241	60	44	35	21	13	10
312	250	1503	867	820	751	410	376	300	75	55	43	26	16	13
375	300	1806	1042	985	903	493	452	361	90	66	52	31	19	16
438	350	2110	1217	1151	1055	575	527	422	105	77	61	37	22	18
500	400	2408	1389	1314	1204	657	602	482	120	86	69	42	25	21
625	500	3010	1737	1642	1505	821	753	602	150	109	87	52	31	26
750	600	3612	2084	1970	1806	985	903	722	181	131	104	63	38	31
875	700	4215	2431	2299	2107	1149	1054	843	211	153	122	73	44	37
1000	800	4817	2779	2627	2408	1314	1204	963	241	175	139	84	50	42
1125	900	5419	3126	2956	2709	1478	1355	1084	271	197	156	94	57	47
1250	1000	6021	3474	3284	3010	1642	1505	1204	301	219	174	105	63	52
1563	1250	7527	4343	4106	3764	2053	1882	1506	376	274	217	131	79	65
1875	1500	9031	–	–	4516	2463	2258	1806	452	328	260	157	94	78
2188	1750	10539	–	–	–	2874	2635	2108	527	383	304	183	110	92
2500	2000	12042	–	–	–	3284	3010	2408	602	438	347	209	126	105

Generator Rating	Amperes for Single-Phase Alternators				
KVA	KW @ 0.8 PF	115 volts	120 volts	230 volts	240 volts
18.7	15	163	156	81	78
25	20	217	208	109	104
31.3	25	272	261	136	130
37.5	30	326	313	163	156
50	40	434	417	217	208
62.5	50	543	521	272	261
75	60	652	625	326	312
93.8	75	815	782	408	391
100	80	869	833	435	417
125	100	1086	1042	543	521

Detroit Diesel Allison
Division of General Motors Corporation

13400 West Outer Drive Detroit, Michigan, 48228

8SA151 Rev. 3-73

In Canada: Diesel Division, General Motors of Canada Limited London Ontario

Litho in U.S.A.

Sample Specification for Diesel-Electric Generating System

NOTE TO SPECIFYING ENGINEER:

Here is a new form of Specification for a diesel-powered electric set. This form of Specification is easier to use, both for the specification writer and the bidder. It also is a tighter Specification that avoids loopholes. It helps the specifying engineer specify needed performance and quality without excess capacity or unnecessary cost.

The specification writer has only to fill in quantitative information, then make copies and distribute them. Writing of component or system descriptions or "boiler plate" is unnecessary.

Where possible, quantitative information is presented in tabular form. Some systems are presented in block-diagram form so that component functions and relationships are obvious to specifier and bidder alike.

The tabular form makes it easy for the bidder to take off quantities and to evaluate requirements. The ambiguities that can creep into written specifications are avoided. All bidders will make the same interpretations and bid to the same quality and performance requirements. Differences among bidder proposals will be obvious and therefore more easily compared and evaluated by the specifying engineer.

While the Specification is shorter, with fewer words, it includes more details to assure reliability, performance and serviceability in the finished system. The low bidder will include everything essential that every other bidder includes. He won't overlook an "assumed" requirement —then respond, "You didn't specify it."

A Sample Specification is presented that is applicable to electric sets commonly applied to standby emergency service. If a more sophisticated system is desired, optional paragraphs can be inserted or substituted to add the desired functions.

Subsection 2.1 (Capacity and Power Distribution) is presented in two versions, one for 50 hz and one for 60 hz. Select the applicable sheet for the nominal frequency of your application. Subsection 3.2 (Engine Features and Equipment Requirements) is presented in four versions to accommodate different KW ranges. Select the applicable version according to the KW rating of your electric set. Greater KW capacities than the maximum shown for the highest range can be furnished if required. If your required rating exceeds the maximum listed KW, contact your Detroit Diesel Allison Distributor.

A feature of this Specification that pinpoints requirements is the Bill of Material (Section 18). This lists the major systems plus related support items to be furnished by the bidder. Some items or quantities are left blank to be filled in by the bidder. The completed Bill of Material is returned with the bid and forms a basis of direct comparison of bids.

To aid the specifying engineer in designing the installation, the Specification includes Section 17, "Installation Data to Be Furnished by Bidder." The bidder fills in the data and submits it with his bid. The data supplied is necessary for design of the room ventilation system, radiator discharge duct, engine exhaust piping, fuel supply system, and battery rack. In Section 17 and elsewhere in the Specification, quantitative information to be filled in by the specifier or bidder may be in either metric or British units as applicable.

Spec. Ident.______________________

Specification For Diesel Engine-Driven Emergency Power Generating System

1. General Provisions and Definitions

1.1 Purpose of Specification

The purpose of this Specification is to describe and solicit bids for an emergency electric power generating system. The Specification describes the performance, functions and quality standards required in the construction and installation of a diesel-powered electric set and supporting systems.

1.2 Definitions

1.2.01 Emergency Electric Power Generating System: A diesel-powered A.C. generating electric set and the related switchgear, controls and equipment necessary to provide a fully automatic operating and independent electric power supply, capable of producing a continuous source of quality electric power for the duration of any interruption of the normal electric power source.

1.2.02 Quality Electric Power: A.C. electric power having the performance characteristics specified in Section 2 of this Specification.

1.2.03 Qualified Supplier: An authorized manufacturing and warehousing distributor of a national diesel engine manufacturer. Supplier must be regularly engaged in the manufacture and installation of custom designed electric power generating systems. Must have 24-hour service backup plus training facilities for customer personnel.

1.2.04 Bill of Material: Attached to and part of this Specification. List of all material and equipment to be furnished by the electric set supplier. Must be returned with bid, with quantities and descriptions filled in where necessary.

1.2.05 Exclusion: Material and equipment to be furnished and work to be performed by other than the supplier will be so noted and should not be included in the supplier's quotation. However, the supplier's material and equipment must be compatible with that furnished by others. The supplier must furnish drawings and instructions where necessary to install material and equipment furnished by the supplier.

1.3 Contractual Statement

1.3.01 The supplier shall furnish, ready for installation, where indicated on Dwg. No. __________, an emergency standby diesel-powered electric set with ratings and equipment as stated in the following pages.

1.3.02 Each requirement is identified by a paragraph number; and the supplier is to assume that appropriate words such as, "shall be capable of," "shall be equipped with," "shall operate," or "must be in accordance with" precede each paragraph. By responding to this Request for Quotation, the supplier has agreed to read the applicable words into each paragraph.

1.3.03 All material and equipment shall conform to and be installed in accordance with the National Electrical Code and State and local ordinances.

1.3.04 All material and equipment furnished by the supplier shall be designed to protect operating personnel from injury. The degree of protection shall be that considered reasonable and adequate or as required by local codes, and shall follow specific instructions if given.

1.3.05 Application data as specified in Section 17 of this Specification shall be submitted with the bid.

Spec. Ident.________________________________

2 Capacity and Performance Requirements

2.1 Capacity and Power Distribution

2.1.01 Electric set rating ...._______KW

2.1.02 Nameplate KVA ...._______KVA

2.1.03 Power factor 0.8

2.1.04 Steady-state nominal frequency
at rated KW .... 60 hz
Manually adjustable from ......56 to 64 hz
Synchronous operating speed
at nominal frequency ....1800 RPM

2.1.05 Steady-state nominal line-to-line voltage
at rated KW ...._____ volts
Manually adjustable
...............±5% of nominal voltage

2.1.06 Power distribution
Number of Phases ...._______
Wire ...._______
Phase Arrangement ...._______

2.1.07 Ambient conditions

The electric set shall be capable of producing full load KW under the following ambient conditions:

Altitude .... ____ feet/____ metres
Air temperature at
engine intake ....____°F/____°C
(warmest condition encountered with electric set at full load)

Spec. Ident.______________

2 Capacity and Performance Requirements

2.1 Capacity and Power Distribution

2.1.01 Electric set rating ....______KW

2.1.02 Nameplate KVA ....______KVA

2.1.03 Power factor 0.8

2.1.04 Steady-state nominal frequency
at rated KW ....50 hz
Manually adjustable from ......46 to 54 hz
Synchronous operating speed
at nominal frequency ....1500 RPM

2.1.05 Steady-state nominal line-to-line voltage
at rated KW ....____ volts
Manually adjustable
...............±5% of nominal voltage

2.1.06 Power distribution
Number of Phases ....______
Wire ....______
Phase Arrangement ....______

2.1.07 Ambient conditions

The electric set shall be capable of producing full load KW under the following ambient conditions:

Altitude ....____ feet/____ metres
Air temperature at
engine intake ....____°F/____°C
(warmest condition encountered with electric set at full load)

Specification for Automatic-Starting Standby Electric Set______________________

2.2 Performance Requirements

2.2.01 Voltage regulation ......not to exceed ___%
(difference in average voltage between no-load steady state and full-load steady state)

2.2.02 Voltage steady-load
bandwidth not to exceed ....±___%

2.2.03 Voltage transient performance
Dip—with step application of 0.8 P.F.
full load ....not to exceed ___%
Rise—with step removal of 0.8 P.F.
full load ....not to exceed ___%
Recovery time ...not to exceed ___ seconds

2.2.04 Frequency regulation
(difference in average frequency between no-load steady state and full-load steady state)
Adjustable from ......___% to ___%
Adjusted at assembly to ....___%

2.2.05 Frequency steady-load
bandwidth ....not to exceed ±___%

2.2.06 Frequency transient performance
Dip—with step application of 0.8 P.F.
full load ....not to exceed ___%
Rise—with step removal of 0.8 P.F.
full load ....not to exceed ___%
Recovery time ...not to exceed ___ seconds

2.2.07 The electric set shall achieve the specified performance under the ambient conditions of temperature and altitude specified in 2.1.07.

2.2.08 Upon cold start-up, voltage and frequency shall stabilize within their specified bandwidths at approximately the same time (difference not to exceed 2 seconds).

Spec. Ident.____________________

3 Basic Electric Set

3.1 General Description

3.1.01 The electric set shall consist of one diesel engine directly coupled to one A.C. generator, mounted on a rigid base made of cross-braced steel structural members.

3.1.02 Units and components offered under these specifications shall be covered by the electric-set manufacturer's standard warranty.

3.1.03 The engine, generator and other components shall be of the quality, and have the features and functions, as described in the following paragraphs.

Spec. Ident.______________________________

3 **Basic Electric Set (continued)**

3.2 Engine Features and Equipment Requirements

3.2.01 Liquid-cooled diesel engine.

3.2.02 Two-stroke cycle design.

3.2.03 Full diesel compression-ignition operation.

3.2.04 Capable of operating and achieving the specified performance with any of these fuels: Diesel No. 2, Diesel No. 1, kerosene, or jet fuel.

3.2.05 Self-lubricated, positive displacement, gear-driven lube oil pump.

3.2.06 Lube oil pump pressure relief valve.

3.2.07 Bearing lubrication – pressure-lubricated main, connecting rod, piston pin, camshaft and rocker arm bearings.

3.2.08 Lube oil filter–full-flow, engine mounted, lube oil filter of the replaceable-element type, equipped with an automatic bypass valve.

3.2.09 Lube oil cooler–direct engine mounted (no exposed oil lines) full-flow lube oil cooler with an automatic bypass valve.

3.2.10 Spray oil cooling of piston undercrown.

3.2.11 All integrally cast or drilled oil passages.

3.2.12 Engine must not require Series 3 oil.

3.2.13 Positive crankcase ventilation.

3.2.14 Cylinder inspection ports.

3.2.15 Single camshaft.

3.2.16 Geared camshaft timing drive (no chains).

3.2.17 Camshaft oil retention compartments to eliminate dry starts.

3.2.18 Maximum allowable exhaust temperature at engine exhaust manifold outlet–970°F (520°C).

3.2.19 Self-lubricated, positive displacement, gear-driven fuel transfer pump requiring no adjustments.

3.2.20 Fuel transfer pump seal leakage indicator.

3.2.21 Engine must not require a head of fuel on transfer pump.

3.2.22 Fuel filters–primary and secondary fuel filters of the replaceable-element type.

3.2.23 No exposed fuel lines above 80 psi (550 kPa) pressure.

3.2.24 Fuel limited injectors (no load limit adjustments required).

3.2.25 Self-pressurizing, cam-operated unit injection system.

3.2.26 Normal shutdown achieved by operating governor to no-fuel position.

3.2.27 Air shut-off for emergency shutdown.

3.2.28 Self-lubricated, belt-driven centrifugal water pump (driven by two belts, each capable of driving the pump if one belt fails).

3.2.29 Water pump shaft supported by two self-lubricated ball bearing assemblies.

3.2.30 Water pump seal leakage indicator.

3.2.31 All standard SAE nuts, bolts and studs.

3.2.32 All standard NPT or SAE tubing and fittings.

3.2.33 All steel-backed replaceable main and connecting rod bearing inserts.

3.2.34 Replaceable camshaft bearings and camshaft follower bearings.

3.2.35 Replaceable valve seat inserts and valve guides.

3.2.36 Replaceable crankshaft thrust bearings.

3.2.37 Replaceable rocker arm bearings.

3.2.38 Replaceable piston pin bearings in both piston and connecting rod.

3.2.39 Replaceable, slip-fit, cylinder liners (regrindable bore).

3.2.40 Replaceable cam follower guides.

3.2.41 Regrindable valve seats and valve facings.

3.2.42 Regrindable crankshaft journals and fillets.

3.2.43 Regrindable camshaft lobes and bearing journals.

3.2.44 Regrindable cylinder block bores.

3.2.45 Machinable head and block surfaces.

3.2.46 Rebuildable water pump, fuel pump, lube oil pump.

3.2.47 Rebuildable lube oil regulating valve.

3.2.48 Rebuildable lube oil pressure relief valve.

3.2.49 Rebuildable fuel injectors.

3.2.50 Rebuildable positive air scavenging pump.

3.2.51 Rebuildable block and head.

3.2.52 Rebuildable connecting rods.

3 Basic Electric Set (continued)

3.2 Engine Features and Equipment Requirements

3.2.01 Liquid-cooled diesel engine.

3.2.02 Two-stroke cycle design.

3.2.03 Full diesel compression-ignition operation.

3.2.04 Capable of operating and achieving the specified performance with any of these fuels: Diesel No. 2, Diesel No. 1, kerosene, or jet fuel.

3.2.05 Self-lubricated, positive displacement, gear-driven lube oil pump.

3.2.06 Lube oil pump pressure relief valve.

3.2.07 Bearing lubrication – pressure-lubricated main, connecting rod, piston pin, camshaft and rocker arm bearings.

3.2.08 Lube oil filter–full-flow, engine mounted, lube oil filter of the replaceable-element type, equipped with an automatic bypass valve.

3.2.09 Lube oil cooler–direct engine mounted (no exposed oil lines) full-flow lube oil cooler with an automatic bypass valve.

3.2.10 Spray oil cooling of piston undercrown.

3.2.11 All integrally cast or drilled oil passages.

3.2.12 Engine must not require Series 3 oil.

3.2.13 Positive crankcase ventilation.

3.2.14 Cylinder inspection ports.

3.2.15 Single camshaft.

3.2.16 Geared camshaft timing drive (no chains).

3.2.17 Camshaft oil retention compartments to eliminate dry starts.

3.2.18 Maximum allowable exhaust temperature at engine exhaust manifold outlet–970°F (520°C).

3.2.19 Self-lubricated, positive displacement, gear-driven fuel transfer pump requiring no adjustments.

3.2.20 Fuel transfer pump seal leakage indicator.

3.2.21 Engine must not require a head of fuel on transfer pump.

3.2.22 Fuel filters–primary and secondary fuel filters of the replaceable-element type.

3.2.23 No exposed fuel lines above 80 psi (550 kPa) pressure.

3.2.24 Fuel limited injectors (no load limit adjustments required).

3.2.25 Self-pressurizing, cam-operated unit injection system.

3.2.26 Normal shutdown achieved by operating governor to no-fuel position.

3.2.27 Air shut-off for emergency shutdown.

3.2.28 Self-lubricated, gear-driven centrifugal water pump.

3.2.29 Water pump shaft supported by two self-lubricated ball bearing assemblies.

3.2.30 Water pump seal leakage indicator.

3.2.31 All standard SAE nuts, bolts and studs.

3.2.32 All standard NPT or SAE tubing and fittings.

3.2.33 All steel-backed replaceable main and connecting rod bearing inserts.

3.2.34 Replaceable camshaft bearings and camshaft follower bearings.

3.2.35 Replaceable valve seat inserts and valve guides.

3.2.36 Replaceable crankshaft thrust bearings.

3.2.37 Replaceable rocker arm bearings.

3.2.38 Replaceable piston pin bearings in both piston and connecting rod.

3.2.39 Replaceable, slip-fit, cylinder liners (regrindable bore).

3.2.40 Replaceable cam follower guides.

3.2.41 Regrindable valve seats and valve facings.

3.2.42 Regrindable crankshaft journals and fillets.

3.2.43 Regrindable camshaft lobes and bearing journals.

3.2.44 Regrindable cylinder block bores.

3.2.45 Machinable head and block surfaces.

3.2.46 Rebuildable water pump, fuel pump, lube oil pump.

3.2.47 Rebuildable lube oil regulating valve.

3.2.48 Rebuildable lube oil pressure relief valve.

3.2.49 Rebuildable fuel injectors.

3.2.50 Rebuildable positive air scavenging pump.

3.2.51 Rebuildable block and head.

3.2.52 Rebuildable connecting rods.

Spec. Ident.________________________

3 Basic Electric Set (continued)

3.2 Engine Features and Equipment Requirements

3.2.01 Liquid-cooled diesel engine.

3.2.02 Two-stroke cycle design.

3.2.03 Full diesel compression-ignition operation.

3.2.04 Capable of operating and achieving the specified performance with any of these fuels: Diesel No. 2, Diesel No. 1, kerosene, or jet fuel.

3.2.05 Self-lubricated, positive displacement, gear-driven lube oil pump.

3.2.06 Lube oil pump pressure relief valve.

3.2.07 Bearing lubrication – pressure-lubricated main, connecting rod, piston pin, camshaft and rocker arm bearings.

3.2.08 Lube oil filter–full-flow, engine mounted, lube oil filter of the replaceable-element type, equipped with an automatic bypass valve.

3.2.09 Lube oil cooler – direct engine mounted (no exposed oil lines) full-flow lube oil cooler with an automatic bypass valve.

3.2.10 Spray oil cooling of piston undercrown.

3.2.11 All integrally cast or drilled oil passages.

3.2.12 Engine must not require Series 3 oil.

3.2.13 Positive crankcase ventilation.

3.2.14 Cylinder inspection ports.

3.2.15 Single camshaft per bank.

3.2.16 Geared camshaft timing drive (no chains).

3.2.17 Camshaft oil retention compartments to eliminate dry starts.

3.2.18 Maximum allowable exhaust temperature at engine exhaust manifold outlet–970°F (520°C).

3.2.19 Self-lubricated, positive displacement, gear-driven fuel transfer pump requiring no adjustments.

3.2.20 Fuel transfer pump seal leakage indicator.

3.2.21 Engine must not require a head of fuel on transfer pump.

3.2.22 Fuel filters–primary and secondary fuel filters of the replaceable-element type.

3.2.23 No exposed fuel lines above 80 psi (550 kPa) pressure.

3.2.24 Fuel limited injectors (no load limit adjustments required).

3.2.25 Self-pressurizing, cam-operated unit injection system.

3.2.26 Normal shutdown achieved by operating governor to no-fuel position.

3.2.27 Air shut-off for emergency shutdown.

3.2.28 Self-lubricated, gear-driven centrifugal water pump.

3.2.29 Water pump shaft supported by two self-lubricated ball bearing assemblies.

3.2.30 Water pump seal leakage indicator.

3.2.31 All standard SAE nuts, bolts and studs.

3.2.32 All standard NPT or SAE tubing and fittings.

3.2.33 All steel-backed replaceable main and connecting rod bearing inserts.

3.2.34 Replaceable camshaft bearings and camshaft follower bearings.

3.2.35 Replaceable valve seat inserts and valve guides.

3.2.36 Replaceable crankshaft thrust bearings.

3.2.37 Replaceable rocker arm bearings.

3.2.38 Replaceable piston pin bearings in both piston and connecting rod.

3.2.39 Replaceable, slip-fit, cylinder liners (regrindable bore).

3.2.40 Replaceable cam follower guides.

3.2.41 Regrindable valve seats and valve facings.

3.2.42 Regrindable crankshaft journals and fillets.

3.2.43 Regrindable camshaft lobes and bearing journals.

3.2.44 Regrindable cylinder block bores.

3.2.45 Machinable head and block surfaces.

3.2.46 Rebuildable water pump, fuel pump, lube oil pump.

3.2.47 Rebuildable lube oil regulating valve.

3.2.48 Rebuildable lube oil pressure relief valve.

3.2.49 Rebuildable fuel injectors.

3.2.50 Rebuildable positive air scavenging pump.

3.2.51 Rebuildable block and head.

3.2.52 Rebuildable connecting rods.

Spec. Ident.________________________________

3 Basic Electric Set (continued)

3.2 Engine Features and Equipment Requirements

3.2.01 Liquid-cooled diesel engine.

3.2.02 Two-stroke cycle design.

3.2.03 Full diesel compression-ignition operation.

3.2.04 Capable of operating and achieving the specified performance with any of these fuels: Diesel No. 2, Diesel No. 1, kerosene, or jet fuel.

3.2.05 Self-lubricated, positive displacement, gear-driven lube oil pump.

3.2.06 Lube oil pump pressure relief valve.

3.2.07 Bearing lubrication -- pressure-lubricated main, connecting rod, piston pin, camshaft and rocker arm bearings.

3.2.08 Lube oil filter—full flow, engine mounted, lube oil filter of the replaceable-element type, equipped with an automatic bypass valve.

3.2.09 Lube oil cooler -- direct engine mounted (no exposed oil lines) full-flow lube oil cooler with an automatic bypass valve.

3.2.10 Spray oil cooling of piston undercrown.

3.2.11 All integrally cast or drilled oil passages.

3.2.12 Engine must not require Series 3 oil.

3.2.13 Positive crankcase ventilation.

3.2.14 Cylinder inspection ports.

3.2.15 Main bearing inspection ports, both sides of crankcase.

3.2.16 Single, two-piece, camshaft per bank.

3.2.17 Geared camshaft timing drive (no chains).

3.2.18 Two-section modular block.

3.2.19 Two-section modular crankshaft.

3.2.20 Individual cylinder head assemblies.

3.2.21 Maximum allowable exhaust temperature at engine exhaust manifold outlet—950°F (510°C).

3.2.22 Self-lubricated, positive displacement, gear-driven fuel transfer pump requiring no adjustments.

3.2.23 Fuel transfer pump seal leakage indicator.

3.2.24 Engine must not require a head of fuel on transfer pump.

3.2.25 Fuel filters—primary and secondary fuel filters of the replaceable-element type.

3.2.26 No exposed fuel lines above 80 psi (550 kPa) pressure.

3.2.27 Fuel limited injectors (no load limit adjustments required).

3.2.28 Self-pressurizing, cam-operated unit injection system.

3.2.29 Normal shutdown achieved by operating governor to no-fuel position.

3.2.30 Air shut-off for emergency shutdown.

3.2.31 Self-lubricated, gear-driven centrifugal water pump.

3.2.32 Water pump shaft supported by two self-lubricated ball bearing assemblies.

3.2.33 Water pump seal leakage indicator.

3.2.34 All standard SAE nuts, bolts and studs.

3.2.35 All standard NPT or SAE tubing and fittings.

3.2.36 All steel-backed replaceable main and connecting rod bearing inserts.

3.2.37 Replaceable camshaft bearings and camshaft follower bearings.

3.2.38 Replaceable valve seat inserts and valve guides.

3.2.39 Replaceable crankshaft thrust bearings.

3.2.40 Replaceable rocker arm bearings.

3.2.41 Replaceable piston pin bearings in both piston and connecting rod.

3.2.42 Replaceable, slip-fit, cylinder liners (regrindable bore).

3.2.43 Replaceable cam follower guides.

3.2.44 Regrindable valve seats and valve facings.

3.2.45 Regrindable crankshaft journals and fillets.

3.2.46 Regrindable camshaft lobes and bearing journals.

3.2.47 Regrindable cylinder block bores.

3.2.48 Machinable head and block surfaces.

3.2.49 Rebuildable water pump, fuel pump, lube oil pump.

3.2.50 Rebuildable lube oil regulating valve.

3.2.51 Rebuildable lube oil pressure relief valve.

3.2.52 Rebuildable fuel injectors.

3.2.53 Rebuildable positive air scavenging pump.

3.2.54 Rebuildable block and heads.

3.2.55 Rebuildable connecting rods.

Spec. Ident.____________________

3 Basic Electric Set (continued)

3.3 Speed Regulating Governor

3.3.01 Gear-driven mechanical-hydraulic governor.

3.3.02 Mechanical set-mounted speed adjustment.

3.3.03 Self-lubricated by engine crankcase oil.

3.4 Generator.

3.4.01 Single-bearing alternator directly connected to engine through flexible coupling.

3.4.02 Rotating field.

3.4.03 Drip-proof, guarded.

3.4.04 Self-ventilated.

3.4.05 Self-lubricated bearing.

3.4.06 Access to shaft at rear of generator for use of hand tachometer.

3.4.07 Generator rotor capable of operating at 15% overspeed.

3.4.08 Engine and generator shall be torsionally compatible.

3.4.09 Insulation conforming to N.E.M.A. standards for standby applications.

3.4.10 Provisions for grounding the neutral.

3.4.11 Positive ground shall exist:

Between generator frame and base through mounting pads.

Between generator and engine.

Between generator frame and the control cabinet.

3.4.12 Generator power connections located in enclosure that is readily accessible for inspection.

3.4.13 N.E.M.A. standard Telephone Influence Factor (TIF).

3.4.14 Waveform deviation factor less than 10% line-to-line.

3.4.15 Full static-type voltage regulator.

3.4.16 Voltage adjusting rheostat.

3.4.17 Static voltage build-up.

3.4.18 Generator circuit protection. (Refer to Circuit Breaker in 7.2.).

Spec. Ident.____________________________

4 Vibration Isolation.

4.1 The electric-set base shall be supported on vibration isolators, and flexible connections shall be incorporated in pipes and ducts connected to the electric set.

4.2 Vibration Isolators.

4.2.01 Number of Isolators: Sufficient number so that floor bearing pressure under each isolator is within floor loading specification and load per isolator is not more than 75% of isolator load rating.

4.2.02 Attachment: Isolators bolted to floor; electric-set base bolted to isolators.

4.2.03 Adjustment: Isolators adjustable for leveling and load distribution.

4.2.04 Vibration Isolation Efficiency: Not less than 98%.

4.2.05 Sound Insulation: Isolators shall be sound-insulating type or shall have sound insulation pad between isolator and floor.

4.2.06 Isolator Location: Equal number on each side of base, spaced for approximately equal load distribution per isolator. Electric-set base shall be drilled for isolator bolts.

4.2.07 Isolators shall be shipped loose with electric set.

4.3 Flexible Connections.

All connections between the electric set and exterior systems (such as fuel lines and exhaust duct) shall be flexible as specified in 9.2 and 10.2.

5 Engine Cooling (Set-Mounted Radiator).

5.1 The engine jacket water shall be cooled by means of a set-mounted water-to-air radiator and engine-driven cooling fan.

5.2 Cooling System Capability.

The cooling system shall be capable of adequately cooling the engine when the electric set is delivering full load at the ambient temperature specified in 2.1.07.

5.3 Radiator.

5.3.01 Vibration-free mounting on the electric-set base.

5.3.02 Filler cap with pressure valve and vacuum valve.

5.3.03 Drain cock in lower tank of radiator.

5.3.04 Drain cock at lowest point in cooling system.

5.3.05 Self air bleed-off.

5.3.06 Core encased in protective shell of attractive appearance, with access to the filler cap.

5.3.07 Duct adapter on outlet side of radiator shell having the same dimensions as the usable radiator area. Bidder must include duct dimensions with bid.

5.4 Fan and Drive.

5.4.01 Capacity: Capable of delivering the air flow specified by the engine manufacturer for adequate cooling at full load at the ambient temperature specified in 2.1.07 against a static head of ____ in. H_2O/____kPa.

5.4.02 Pusher type fan so that air is blown (not sucked) through the radiator.

5.4.03 Belt driven from pulley on engine crankshaft. Poly-V-belt or minimum of two individual V-belts which must be capable of driving fan if one belt fails.

5.4.04 Belt adjusting mechanism.

5.4.05 Sealed fan hub bearings that do not require lubrication until engine overhaul.

5.4.06 Safety guard for fan, belt and pulleys.

Spec. Ident.________________

6 Starting System (Automatic)

6.1 Cranking System

6.1.01 Heavy-duty, long life (6000 hours) D.C. cranking motor or motors . . . . ____ volts.

6.1.02 Engagement mechanism:
Chamfered ring gear and pinion.
Self-lubricated pinion.
Electromechanical engagement.

6.1.03 Enclosed motor and pinion engagement linkage.

6.1.04 Solenoid relay, having contacts capable of carrying the maximum pinion-engagement solenoid current, included in starting circuit between start contacts and the pinion-engagement solenoid.

6.2 Battery Charger

6.2.01 Furnish as separate item (not installed in electric set) a float-type full-static battery charger capable of recharging batteries to full potential within one hour after a cranking cycle.

6.2.02 Adjustable to compensate for battery self-discharge rate during standby periods.

6.2.03 Ammeter included in battery charger housing.

6.2.04 Single-phase 110-volt A.C. input.

6.2.05 Provision for wall mounting.

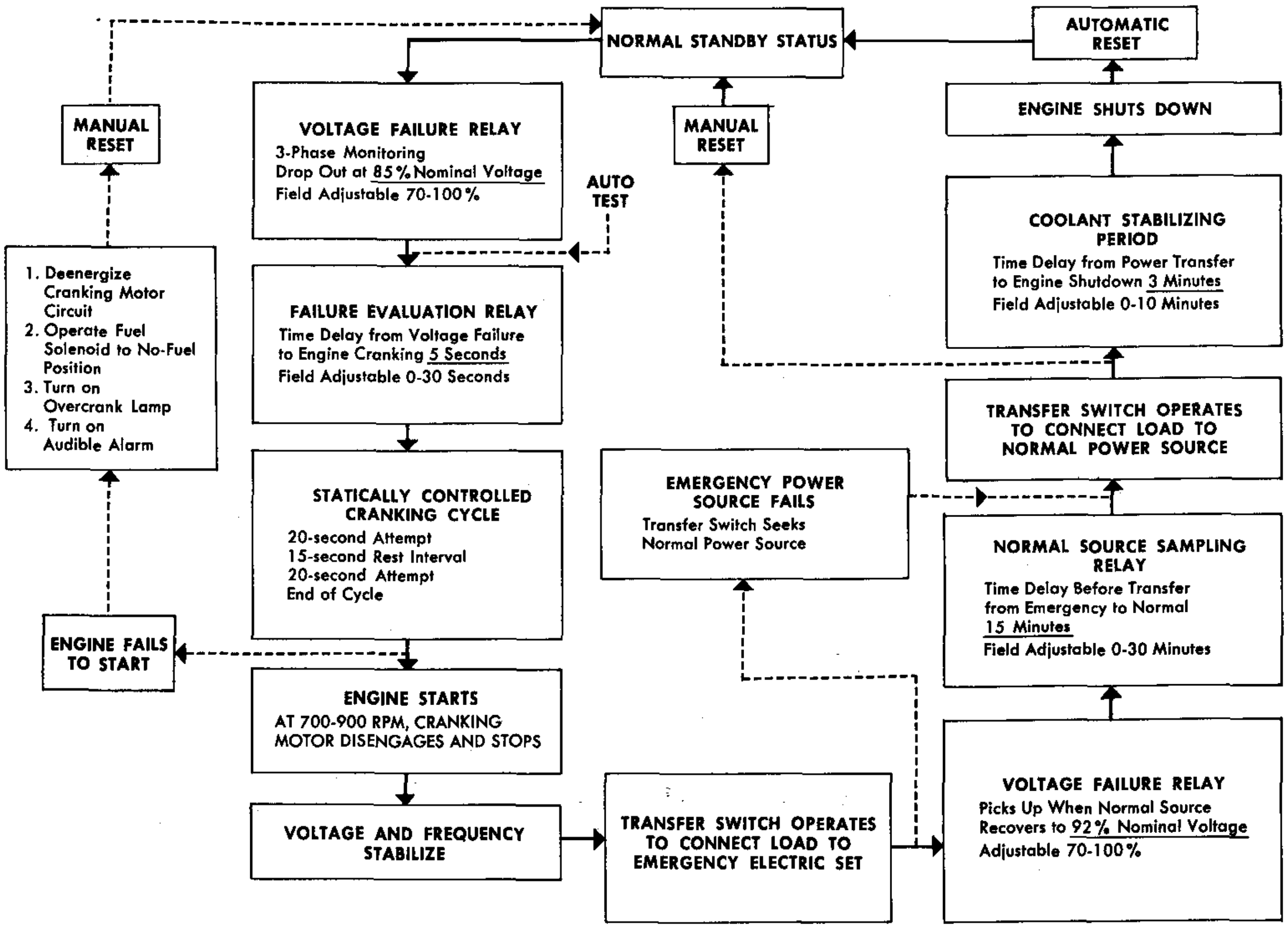
6.2.06 All internal wiring to be terminated at an accessible terminal strip inside the charger enclosure.

6.2.07 Bidder shall furnish wiring diagram of charger internal circuitry.

6.3 Automatic Control

6.3.01 The electric-set supplier shall furnish all the necessary equipment, devices and material necessary to achieve automatic starting, power switching, shutdown, and restore to normal standby condition, according to the sequence depicted on the following Autostart function diagram.

6.3.02 Automatic Starting and Load Switching Sequence



Spec. Ident.________________________________

6 Starting System (Automatic) (continued)

6.3 Automatic Control (continued)

6.3.03 Indicating lamp labeled OVERCRANK CUT-OUT mounted in Autostart Control panel. Labeling to be of type and quality as stated in 7.4.10.

6.3.04 In addition to the automatic starting function, the Autostart Control shall provide for automatic test, manual start, and starting circuit "off" to prevent starting during maintenance. As depicted in 6.3.02, the automatic test function shall permit the system to be tested manually, causing the Autostart Control to react as if a power outage has occurred, starting the engine and transferring the active load to the electric set.

6.4 Starting Performance

6.4.01 The electric set shall be capable of assuming the active load in 10 seconds after a starting signal is applied to cranking motor.

6.4.02 This starting performance time specification shall be measured from the time that the power failure evaluation relay has timed out.

6.4.03 Starting performance shall be achieved without starting aids in an ambient air temperature as stated in 6.5.

6.5 Battery Capacity (Information to be Furnished by Supplier)

Accompanying his bid, the electric-set supplier shall submit recommended battery capacity capable of sustaining engine rated cranking speed through at least three automatic cranking cycles (each cycle as depicted in 6.3.02) at an ambient temperature of 40°F (5°C) without starting aids, and with API-rated 30W oil in the engine crankcase.

Spec. Ident.__________

7 Control Cabinet (Set-Mounted)

7.1 Cabinet

7.1.01 N.E.M.A. enclosure

7.1.02 Vibration-isolation mounting on electric-set base at generator end.

7.2 Circuit Breaker

7.2.01 Line connected.

7.2.02 ____-ampere frame size.

7.2.03 Overcurrent trips at ____% of generator full-load current.

7.2.04 Molded case, air type.

7.2.05 Manually operated switching.

7.3 Neutral Ground Provision

Ground terminals to be provided inside cabinet.

7.4 Instruments

7.4.01 Voltmeter connected through selector switch to read line-to-line voltage, 1-2, 2-3, 3-1. Selector switch to be labeled to indicate meter connection at each position (i.e., 1-2, 2-3, 3-1).

7.4.02 Ammeter connected through phase selector switch to three individual current transformers to read phases 1, 2 and 3. Selector switch to be labeled to indicate meter connection to phases.

7.4.03 Frequency meter.

7.4.04 Running time meter (electric).

7.4.05 Voltage adjusting rheostat. Located on face of control cabinet and labeled VOLTAGE ADJUSTMENT, with arrow labeled RAISE and LOWER.

7.4.06 Engine speed adjuster located on face of control cabinet or on face of control cabinet subbase and labeled ENGINE SPEED CONTROL, with arrow labeled RAISE or LOWER.

7.4.07 Oil pressure gauge in face of control cabinet or in face of control cabinet subbase.

7.4.08 Water temperature gauge adjacent to oil pressure gauge.

7.4.09 Easy-to-read meter scales. Meter accuracy 2% of full scale.

7.4.10 All meters and switches to be labeled to indicate function.

Must be neat, attractive, easy to read and permanent.

Lettering to be applied to panel face or to instrument or to permanently affixed plate.

Lettering to be applied by engraving, etching or other technique that will not rub off or wear off.

Spec. Ident.______________________

8 Room Air Ventilation

8.1 Normally open contacts shall be provided in the engine to operate the relay of the room air supply inlet louvers when the engine reaches self-sustaining firing speed.

8.2 The contacts shall be wired and terminated at a terminal board in the control cabinet. The terminals shall be labeled ILR-1 and ILR-2.

9 Engine Exhaust System

The electric-set supplier shall furnish and install exhaust manifold guard(s) and shall furnish exhaust silencer(s), flexible section(s) and adapters and connecting parts.

9.1 Silencer

9.1.01 One (or more at supplier's option) residential silencing type.

9.1.02 Straight-through type, drain plug at lowest point, one accessible cleanout port. Finished in rust-preventive primer.

9.2 Flexible Exhaust Pipe Section

9.2.01 One (or more at supplier's option) flexible section to be connected between the exhaust pipe and the engine exhaust manifold.

9.2.02 Carbon steel or stainless steel.

9.2.03 Smoke tight.

9.2.04 I.D. same as exhaust pipe.

9.2.05 Flex section(s) shall permit relative motion of engine and exhaust pipe up to 1 in. (2.5 cm) in any direction without strain on engine manifold or exhaust piping.

9.3 Adapters and Connecting Parts

9.3.01 Adapter required to connect silencer inlet to exhaust pipe.

9.3.02 Adapter required to connect silencer outlet to exhaust pipe.

9.3.03 Adapter required to connect flexible section to engine exhaust manifold outlet flange.

9.3.04 Adapter required to connect flexible section to exhaust pipe.

9.3.05 Bolts, nuts, lockwashers and gaskets required for adapters.

9.4 Manifold Guard

9.4.01 Metal guard shall be installed to prevent personnel from contacting the engine exhaust manifold.

9.4.02 Rigid construction of open mesh or expanded metal.

9.5 Information to be Furnished by Supplier

9.5.01 Dimension of engine exhaust manifold outlet flange height from floor when electric set is mounted on isolation pads.

9.5.02 Recommended silencer and recommended exhaust pipe diameter when the exhaust system consists of:

Horizontally mounted pipe ....____feet/____metres
Vertically mounted pipe ....____feet/____metres
Number of elbows ....____

The recommendation shall allow for 30-year scale accumulation.

9.5.03 Engine Exhaust Data

Maximum permissible exhaust back pressure ....____in Hg./____kPa
Exhaust gas flow at full load ....____cfm/____m³/s
Exhaust gas temperature at manifold outlet at full load...____°F/____°C

Spec. Ident.____________________

10 Fuel System

10.1 Engine Fuel System

10.1.01 Engine fuel system completely piped and terminated at a point on the base.

10.1.02 All fuel filters rigidly mounted in an accessible position on the electric set.

10.2 Fuel Supply System

The electric-set supplier shall furnish flexible fuel line sections and adapters.

10.2.01 Flexible fuel inlet line.

10.2.02 Flexible fuel return line.

10.2.03 Adapters for:

Flexible line to engine fuel inlet,
Flexible line to engine fuel return,
Flexible line to fuel supply inlet pipe,
Flexible line to fuel supply return pipe.

10.3 Information to be Furnished by Supplier

10.3.01 Estimated fuel consumption at rated load . . . . ____gal/hr
____litres/hr

10.3.02 Recommended fuel line size
Supply line—
Minimum I.D. . . . . . . ____in./____cm
Return line—
Minimum I.D. . . . . . . ____in./____cm

10.3.03 Recommended class of fuel that will achieve

Long storage capability,
Minimum smoke on transients,
Compatible with MIL-L-2104B or Supplement 1 lube oil in the crankcase.

Spec. Ident.________________________________

11 Automatic Electric-Set Protection

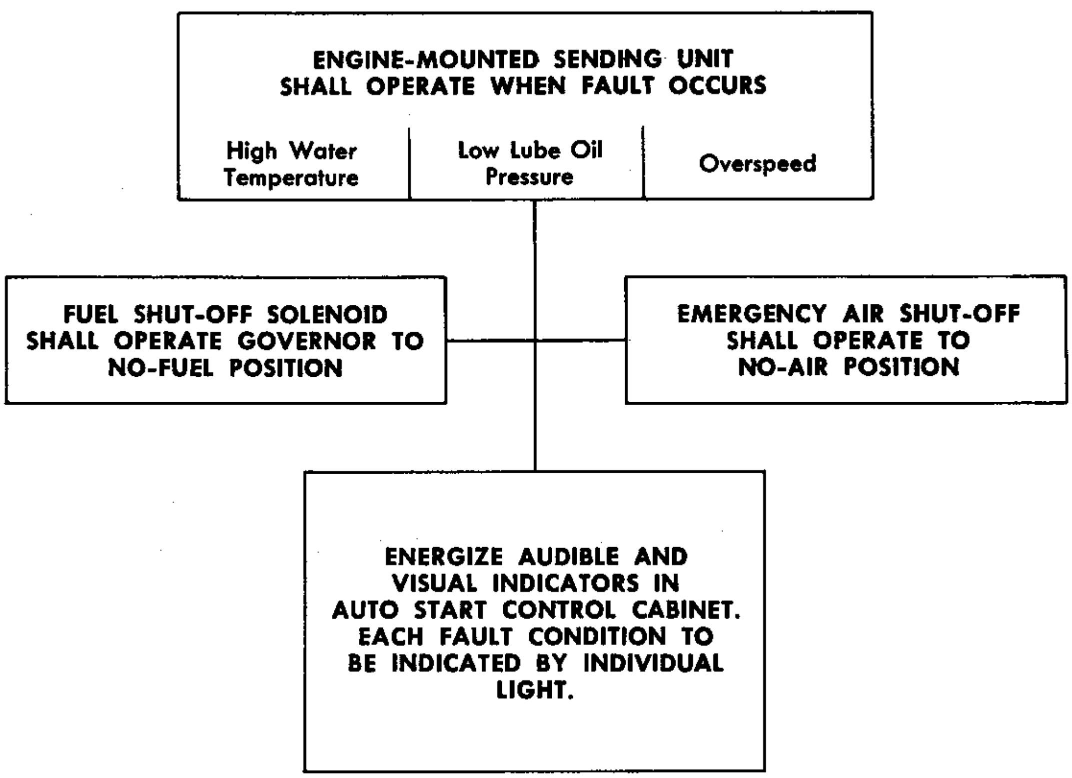
11.1 Protection System

11.1.01 Fault sensors shall be incorporated to cause emergency engine shutdown when any of the faults occur which are depicted in the following Protection Function diagram.

11.1.02 Power for sensors, trips, indicator lights and alarm shall be provided by engine cranking batteries.

11.1.03 Protection System Functions

11.1.03 Protection System Functions



11 Automatic Electric Set Protection (continued)

11.2 Fault sensors

11.2.01 High water temperature sensor set to trip at . . . . .205±3°F/96±2°C

11.2.02 Overspeed sensor set to trip at. . . . 2050 RPM

11.2.03 Low lube oil pressure sensor set to trip at the engine manufacturer's recommendation for lowest permissible oil pressure.

11.3 Fault Indicators

11.3.01 Individual indicator light to be provided in Autostart Control cabinet for each fault condition. Each light to be labeled according to function. The type and quality of labeling to be as stated in 7.4.10.

11.3.02 The lamp that operates when the water temperature sensor trips the safety shutdown shall be labeled HIGH WATER TEMPERATURE.

11.3.03 The lamp that operates when the lube oil pressure sensor trips the safety shutdown shall be labeled LOW OIL PRESSURE.

11.3.04 The lamp that operates when the overspeed sensor trips the safety shutdown shall be labeled OVERSPEED.

11.3.05 Audible alarm (horn or bell) to sound continuously when any fault sensor trips.

11.3.06 All indicators and alarm shall be reset by manual adjustment on Autostart Control panel.

11.4 Engine Shutdown

11.4.01 Both fuel shut-off and air shut-off shall operate when signalled by any fault sensor.

11.4.02 Fuel shut-off solenoid shall operate governor to no-fuel position.

11.4.03 Manual and automatic safety air shut-off. Manual air shut-off to be labeled EMERGENCY SHUT-OFF. The type and quality of labeling to be as stated in 7.4.10.

11.5 Terminal Strip

11.5.01 All engine protection wiring shall be terminated at a terminal strip or block that provides for interconnecting the engine protection system to the Autostart panel.

11.5.02 Terminal strip enclosed in a junction box.

11.5.03 Accessible location on electric set.

11.5.04 Terminals labeled to match corresponding terminal strip in Autostart Control cabinet.

Spec. Ident.________________________________

12 Load Transfer System

12.1 Source sensing and switching functions as shown in 6.3.02.

12.2 Transfer Switch

12.2.01 Current capacity:
Continuous ....______amps
Interrupted ....______amps

12.2.02 Voltage and phase distribution as stated in 2.1.05 and 2.1.06.

12.2.03 Solenoid operated.

12.2.04 Operating current for transfer obtained from source to which load is to be transferred.

12.2.05 Mechanically and electrically interlocked to prevent simultaneous connection to both normal and emergency sources.

12.2.06 Positive mechanical hold-in to either source.

12.2.07 Connections labeled NORMAL, EMERGENCY and LOAD.

12.3 Failure and Evaluation Devices

12.3.01 Normal source voltage failure relay set as stated in 6.3.02.

12.3.02 Normal source failure evaluation relay timing set as stated in 6.3.02.

12.3.03 Normal source sampling relay timing set as stated in 6.3.02.

12.3.04 Coolant stabilizing relay timing set as stated in 6.3.02.

12.3.05 Relays to be labeled according to function.

12.4 Enclosure

12.4.01 Transfer switch and relays housed in a single enclosure.

12.4.02 Provisions for locking enclosure.

12.4.03 Provisions for wall mounting.

12.4.04 All wiring which must be interconnected to the Autostart Control shall be terminated at a terminal board within the enclosure.

12.4.05 Terminals to be labeled to correspond to those in the Autostart Control.

12.5 Information to be Furnished with Bid.

12.5.01 Drawing depicting physical dimensions of enclosure.

12.5.02 Wiring diagram of transfer circuitry and Autostart Control.

Spec. Ident.____________________

13 Engine Labeling

13.1 Option Data Plate

13.1.01 Plate permanently affixed to rocker arm cover.

13.1.02 Lists the following information:
Engine serial number,
Engine model number,
Optional equipment parts type number.

13.1.03 Lettering applied by etching or other permanent techniques.

13.1.04 The electric-set supplier and engine manufacturer shall retain a permanent record of the data contained on this plate.

13.2 Lube Oil Decals

13.2.01 Decal located on lube filler reads:
OIL FILLER

13.2.02 Decal located at lube oil dipstick tube reads:
OIL LEVEL DIPSTICK

14 Electric-Set Finish

14.1 The complete electric set, including the base, shall be spray painted with Alpine Green enamel over a suitable primer.

14.2 One quart of Alpine Green touch-up paint shall be shipped loose with the electric set.

15 F.O.B. Point

15.1 The F.O.B. point shall be the customer's installation site.

15.2 Another contractor will set the electric set and related equipment in place.

16 Service Capability

16.1 The supplier shall be an authorized warehousing and servicing distributor of the engine manufacturer.

16.2 Service Availability

16.2.01 Service to be available 24 hours per day.

16.2.02 Factory-trained technicians.

16.3 The supplier shall maintain facilities for training customer personnel.

16.4 Parts Availability

16.4.01 Complete stock of engine parts.

16.4.02 Computerized parts inventory.

Spec. Ident.______________________________

17 Installation Data to be Furnished by Bidder (Use either metric or British units as applicable.)

17.1 Ventilation Requirements

17.1.01 Heat radiated to room by engine and generator ....____Btu/min or J/sec

17.1.02 Radiator air flow ....____cfm or m^3/s

17.1.03 Combustion air flow.......____cfm or m^3/s

17.1.04 Radiator discharge duct dimensions ....____in. x ____in.
____cm x ____cm

17.2 Engine Exhaust

17.2.01 Exhaust gas temperature at rated power (at manifold outlet)..____°F or °C

17.2.02 Exhaust gas flow at rated power ....____cfm or m^3/s

17.2.03 Maximum allowable exhaust back pressure ....____in. Hg or kPa

17.2.04 Engine exhaust outlet I.D. ....____in. or cm

17.2.05 Height of engine exhaust outlet from floor when electric set is mounted on isolators ......____in. or cm

17.3 Fuel

17.3.01 Estimated fuel consumption at rated power ......____gal/hr or litre/hr

17.3.02 Fuel supply line minimum I.D. ____in. or cm

17.3.03 Fuel return line minimum I.D. ____in. or cm

17.4 Engine Starting

17.4.01 Engine cranking voltage.........____volts

17.4.02 Number of batteries ....____

17.4.03 Battery rating (complete bank)..____amp-hr

17.4.04 Battery dimensions ......____in. x ____in.
____cm x ____cm

17.4.05 Recommended size of battery cables (American Wire Gauge) ....____ga.

Note to Specifying Engineer Regarding Bill of Material

In order to install an electric set, certain related equipment is required to connect the support systems. The Bill of Material is valuable as a device to be sure that all the material required to install the electric set is ordered in advance, and to insure that all the electric set suppliers know precisely what their bid is to include. The Bill of Material lists the electric set but not its individual components such as the generator, governor, base, air cleaners, etc.

The Bill of Material is actually a tabulation of the equipment and material necessary to fulfill the requirements of the Specification, and the writer should check the Bill of Material against the Specification to be sure he has included all the items.

The bidder will return the Bill of Material with his bid. Where the bidder has an option, the specifier leaves quantities blank and the bidder fills in quantities. If the bidder proposes to fulfill a certain requirement by a method that employs material different from that listed by the specifier, it is expected that the bidder will substitute his material on the list, explain the proposed change under "Remarks", and include a sketch of the proposed method.

The Bill of Material will vary when the installation varies and when the specifying engineer elects to have some of the related equipment or material furnished by other contractors. The type of installation and purpose of the electric set will dictate the various types of optional support systems equipment that must be used.

A Bill of Material for a typical automatic-starting standby electric set is provided herewith as Section 18 of the Sample Specification. It has sufficient space to include additional optional equipment that you may want to include in the Specification. Consult the attached optional equipment listing for the suggested description.

Spec. Ident.________________

18 Bill of Material

This is a listing of the material to be furnished by the supplier in order to satisfy the requirements of this solicitation. All of the material must conform to the Specification to which this is attached. The bidder must complete the form by filling in the blank spaces and submit the completed form with bid quotation.

If the bidder proposes to use a method that does not require the material as listed, it should be so noted in the remarks column. The actual material to be used should be listed and a drawing should be included depicting the proposed arrangement.

QTY	ITEM NO.	DESCRIPTIONS	REMARKS
1	.01	Diesel Electric Set	
1	.02	Diesel Engine Cooling Set-Mounted Radiator	
1	.03	Control Cabinet Set-Mounted	
1	.04	Starting, Automatic Wall-Mounted Control Cabinet	
1	.05	Power Distribution Transfer Switch Wall-Mounted	
1	.06	Static Battery Charger	
____	.07		
____	.08		
____	.09		
____	.010	Exhaust Silencer	
____	.011	Adapter—Exhaust Silencer Inlet Flange To Exhaust Pipe	
____	.012	Adapter—Exhaust Silencer Outlet Flange to Exhaust Pipe	
____	.013	Bolts—Exhaust Silencer Adapters	
____	.014	Nuts—Exhaust Silencer Adapters	
____	.015	Lockwasher—Exhaust Silencer Adapters	
____	.016	Gasket—Adapter To Silencer Inlet Flange	
____	.017	Gasket—Adapter To Silencer Outlet Flange	
____	.018	Flexible Exhaust Section	
____	.019	Adapter—Flexible Exhaust Section To Engine Manifold Flange	
____	.020	Adapter—Flexible Exhaust Section to Exhaust Pipe	
____	.021	Bolts	
____	.022	Nuts	
____	.023	Lockwashers	
____	.024	Gaskets—Flexible Exhaust Section Adapters	
____	.025		
____	.026		
____	.027		
____	.028		
____	.029		
1	.030	Flexible Fuel Inlet Line	
1	.031	Flexible Fuel Return Line	
2	.032	Adapter—Flexible Fuel Line To Engine (inlet and return connections)	
2	.033	Adapter—Flexible Fuel Line To Fuel Supply (suction and return pipe)	
____	.034		
____	.035		
____	.036		
____	.037		
____	.038	Vibration Isolators	

Note to Specifying Engineer Regarding Optional Equipment

Items on the following pages may be added to the Bill of Material if it is desired that they be furnished by the electric set supplier.

Spec. Ident.________________

QTY	ITEM NO.	DESCRIPTION	REMARKS

Exhaust System

QTY	ITEM NO.	DESCRIPTION	REMARKS
____		Exhaust Termination Elbow	
____		Exhaust Termination Rain Cap	
____		Exhaust Pipe . . ____Length x ____Dia	
____		Exhaust System Insulating Material	
____		Exhaust System Guards	
____		Exhaust System Hangers	
____		Exhaust System Paint (Qts./Ltrs.)	
____		Exhaust System Expansion Joint	
____		Exhaust System Wall Collar	
____		Exhaust System Flashing	

Fuel System

QTY	ITEM NO.	DESCRIPTION	REMARKS
____		Gate Valve–Fuel Shut-Off (inlet and return)	
____		Fuel Supply Pipe–Suction ____ Length x ____ Dia	
____		Fuel Supply Pipe–Return ____ Length x ____ Dia	
____		Auxiliary Fuel Pump (engine driven)	
____		Auxiliary Fuel Pump (electrically driven)	
____		Fuel Supply Tank Gauge	
____		Fuel Supply Tank Low Level Alarm	
____		Fuel Supply Tank	
____		Fuel Day Tank	
____		Fuel Supply Tank Ventilating Pipe	

Cooling System—Set-Mounted Radiator

QTY	ITEM NO.	DESCRIPTION	REMARKS
____		Radiator Mounted Shutters–Manually Operated	
____		Radiator Mounted Shutters–Automatic (electric)	
____		Radiator Mounted Shutters–Automatic (pneumatic)	
____		Radiator Mounted Shutters–Automatic (hydraulic)	
____		Adapter–Radiator To Air Duct	
____		Flexible Section–Radiator Discharge Air Duct	
____		Duct–Radiator Air Discharge	
____		Louvers–Radiator Air Discharge Duct (fixed)	
____		Louvers–Radiator Air Discharge Duct (automatic electric)	
____		Louvers–Radiator Air Discharge Duct (automatic pneumatic)	
____		Guard–Radiator Air Discharge Duct	

Spec. Ident.________________

QTY	ITEM NO.	DESCRIPTION	REMARKS

Cooling System—Remote-Mounted Radiator

QTY	ITEM NO.	DESCRIPTION	REMARKS
____		Radiator—Remote Type	
____		Vibration Isolators	
____		Flexible Pipe Section—Radiator Water Inlet	
____		Flexible Pipe Section—Radiator Water Outlet	
____		Flexible Pipe Section—Engine Water Inlet	
____		Flexible Pipe Section—Engine Water Discharge	
____		Adapter—Flexible Pipe Section To Radiator Inlet	
____		Adapter—Flexible Pipe Section To Radiator Outlet	
____		Adapter—Flexible Pipe Section To Engine Inlet	
____		Adapter—Flexible Pipe Section To Engine Outlet	
____		Bolts—Adapter To Flexible Pipe Section	
____		Nuts—	
____		Lockwashers—	
____		Gaskets—	
____		Pipe—Engine To Radiator (inlet and return)	
____		Connectors—Pipe, Engine To Radiator	
____		Thermometer—Engine Water Inlet	
____		Shutter—Radiator Mounted, Automatic Electric	
____		Disconnect Switch—Fan Drive Motor	
____		Enclosure—Radiator Weather Protection	
____		Auxiliary Water Pump—Engine Driven	
____		Auxiliary Water Pump—Electrically Driven	
____		Tank—Hot Well	
____		Mounts—Hot Well Tank	
____		Flexible Pipe Section—Hot Well Engine Inlet	
____		Flexible Pipe Section—Hot Well Engine Discharge	
____		Flexible Pipe Section—Hot Well Radiator Inlet	
____		Flexible Pipe Section—Hot Well Radiator Outlet	
____		Valve—Water Shut-Off (engine water inlet)	
____		Valve—Water Shut-Off (engine water discharge)	
____		Solenoid Valve—Water Shut-Off (engine water inlet)	
____		Solenoid Valve—Water Shut-Off (engine water discharge)	

Spec. Ident.______________________

QTY	ITEM NO.	DESCRIPTION	REMARKS

Cooling System—Heat Exchanger

Note—the heat exchanger core and tank should be considered a part of the engine.

- ____ Flexible Pipe Section—Heat Exchanger Inlet
- ____ Flexible Pipe Section—Heat Exchanger Outlet

Note: For engine mounted and driven auxiliary water pumps, the flexible pipe section would connect to the pump inlet, since the pump discharge would be already connected to the heat exchanger inlet. To prevent vibration transmission, a flexible pipe section should be connected between the pump inlet and the water supply pipe. Thus:

- ____ Flexible Pipe Section—Auxiliary Pump Inlet
- ____ Auxiliary Water Pump—Engine Driven
- ____ Auxiliary Water Pump—Electrically Driven
- ____ Adapters—Flexible Pipe Section To Pipe
- ____ Filter—Raw Water Inlet
- ____ Solenoid—Water Shut-Off (inlet)
- ____ Solenoid—Water Shut-Off (discharge)
- ____ Valve—Water Shut-Off (inlet)
- ____ Valve—Water Shut-Off (discharge)
- ____ Valve—Raw Water Flow Regulator (electric)
- ____ Valve—Raw Water Flow Regulator (pneumatic)
- ____ Thermometer—Raw Water Inlet

Starting—Electric

- ____ Batteries
- ____ Battery Mounting Rack
- ____ Cable—Battery To Cranking Motor
- ____ Connectors—Cable To Cranking Motor Terminals
- ____ Connectors—Cable To Battery Terminals
- ____ Connectors—Battery Series Connections
- ____ Conduit—Battery Cables
- ____ Connectors—Battery Charger To Battery
- ____ Wire—Battery Charger To Battery
- ____ Remote Start Switch

Spec. Ident.____________________

QTY	ITEM NO.	DESCRIPTION	REMARKS

Control Cabinet Options

QTY	DESCRIPTION
____	Wall Mounted Type
____	Floor Mounted Type
____	Cable–Generator To Control Cabinet
____	Wire–Generator To Control Cabinet (control connections)
____	Conduit–Generator To Control Cabinet
____	Conduit–Control Cabinet To Power Distribution

Note: since the generator, controls, instrumentation, transfer switch and automatic starting control can be located in a single enclosure, it is not always necessary to include them separately on the Bill of Material. In fact, several combinations are possible, such as:

The control cabinet and the automatic starting control are one assembly, while the transfer switch is a separate assembly.

The control cabinet, the automatic starting control panel and the transfer switch are each a separate assembly.

In prime power installations, the transfer switch is not required unless one or more units are required to come on the line automatically if the prime unit or units shuts down. Therefore, the Bill of Material should include the switchgear enclosure required to meet the specific needs of the installation.

Detroit Diesel Allison

Division of General Motors Corporation

ENGINE GENERATOR MOUNTING RECOMMENDATION FOR DETROIT DIESEL ENGINES

JUNE, 1976

ENGINEERING TECHNICAL DATA DEPT.

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INTRODUCTION

Large Detroit Diesel engines are being used in greater numbers each year for electric set applications. Whereas the 6-71 and 12V-71 were formerly our popular electric set engines, the 16 cylinder series 71 and 92 and the series 149 engines are now being utilized because of the increased demand for large electric sets for greater electrical power output.

Although engine-generator mounting principles are substantially the same for small and large electric sets, greater care must be applied to structural design and assembly practices associated with large engines that drive single-bearing generators. Along with greater engine weights, the weights of radiators and generators, particularly generator rotors, have increased dramatically. The trend toward the use of large units increases the chance that engine-generator mounting and vibration problems will be experienced.

This bulletin is a review of good mounting design and assembly practices with emphasis on linear vibration measurement and trouble-shooting procedures of electric sets utilizing large Detroit Diesel engines and single-bearing generators.

ENGINE VIBRATIONS

Engine vibrations can result in internal engine and generator damage or they can be transmitted to the structure of the building or ship and become an irritant to the inhabitants. The three major types of vibrations associated with generator sets are torsional, bending, and linear.

Torsional and Bending Vibrations:

Torsional and bending vibrations result in internal engine damage particularly to engine crankshafts and gear trains. This subject is covered in Engineering Bulletin No. 34 titled, "Requirements for Torsional Vibration Analysis and Vibration Dampers", Form 18SA0207.

An approved mathematical torsional and bending vibration analysis is a prerequisite to assembly and testing of all electric sets. This analysis is intended to assure the torsional and flexural integrity of the crankshaft and generator shaft and is entirely separate from the analysis of linear vibrations caused by deficient mounting design and assembly practices.

Linear Vibration:

A common manifestation of mounting design and assembly problems is excessive linear vibration of the complete electric set. Excessive linear vibration, although not necessarily indicative of engine crankshaft or generator rotor shaft failures, may eventually cause failure of other internal generator components. Excessive linear vibration may result in customer complaints if transmitted to the structure of a building or ship. If not corrected, excessive vibration may damage the reputation of the generator set manufacturer and restrict his opportunities for future electric set sales.

POWER GENERATORS

Two-Bearing Generators:

Two-bearing generator sets are normally longer, heavier, and more costly than single-bearing sets. Two-bearing sets require a separate torsional coupling to join the engine and generator shafts that require precision alignment checks during assembly. The coupling must have compatible values of torsional stiffness and inertia. Shaft loading due to degrees of axial, angular and parallel axis misalignment must be considered. A very stiff base is required to maintain shaft alignment and minimize stress and vibration.

Two-bearing electric sets are generally not suited for mobile use, i.e.: at construction sites, for example, where they set on the ground that may be uneven; or for trailer mounted sets and for other applications where operational deflection of supporting structure is likely to occur. Although a torsional analysis is required for two-bearing sets, it is not necessary to perform a bending vibration analysis for the engine crankshaft, as the generator bearings completely support the generator rotor.

Single-Bearing Generators:

Single-bearing generator sets are predominant for all the reasons described to the disadvantage of two-bearing sets. Since the generator rotor is supported on one end only by the rear generator bearing, approximately half of the rotor weight, rotating unbalance and magnetic pull must be supported by the engine crankshaft. Therefore, not only a torsional vibration analysis, but also, a bending vibration analysis of the complex shaft-mass system must be performed for single-bearing electric sets to assure the torsional and flexural integrity of the engine crankshaft and generator shaft.

Frame design of single-bearing generators must be rugged and able to support half the engine weight. The generator drive disc, although torsionally very stiff, is rather flexible in bending. It bolts to the flywheel, and is located by a pilot diameter machined in the flywheel as shown in Figure 1, page 3.

Several factors must be considered when designing engine-to-generator drive assemblies. Figure 1 illustrates the conventional assembly of an engine to a single-bearing generator. From the illustration it can be visualized how important manufacturing tolerances, rotating unbalance, assembly technique, and the mass-elastic system are on torsional and flexural vibratory shaft stresses and linear vibration levels of the electric set.

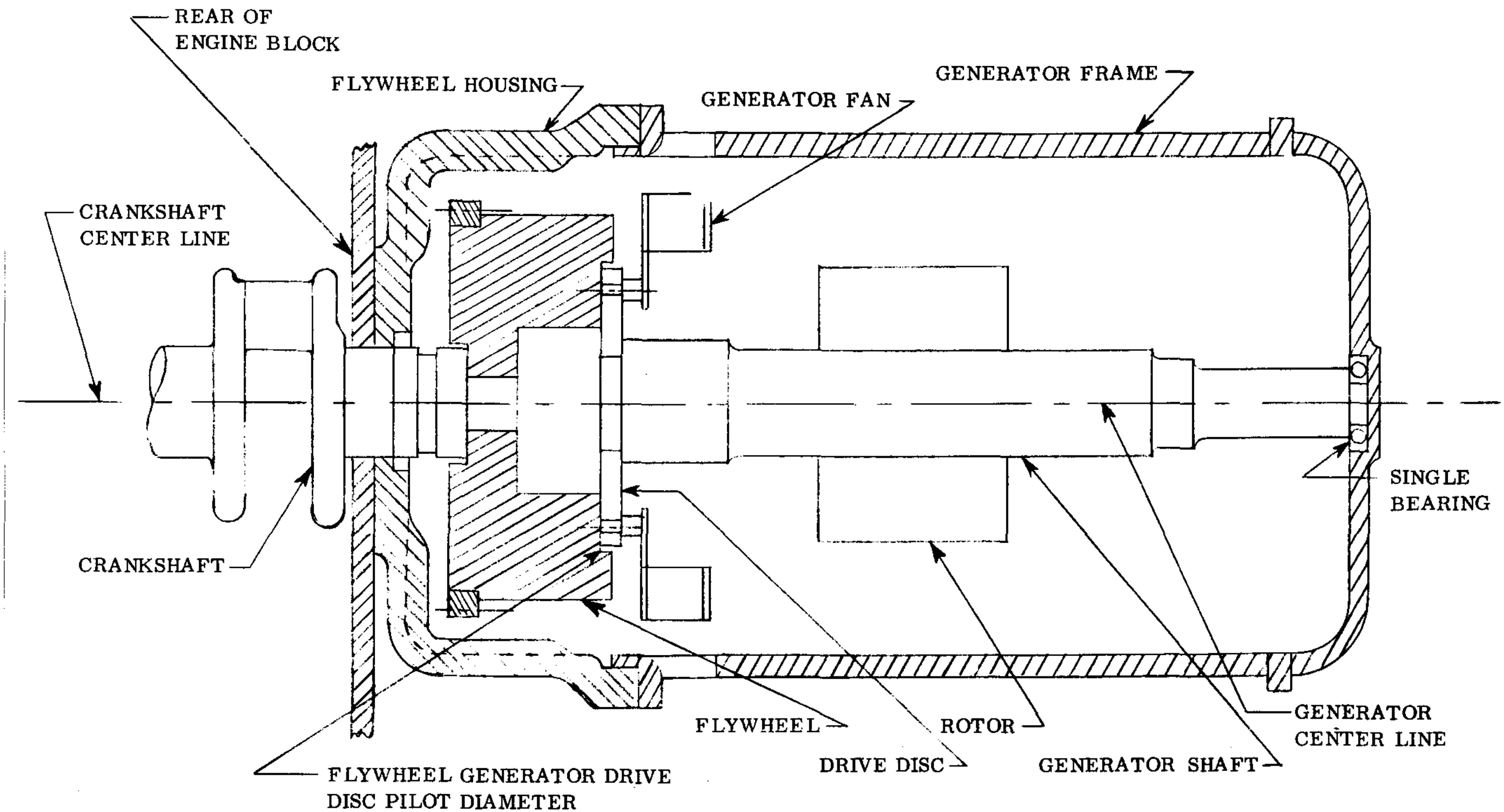


FIG. 1 ENGINE - SINGLE BEARING GENERATOR ASSEMBLY

ENGINE AND GENERATOR ALIGNMENT AND LINEAR VIBRATION CONTROL

Proper alignment of the engine and single-bearing generator is necessary for smooth operation and to minimize bending stress in the relatively flexible flywheel housing. Excessive angular misalignment would cause the drive disc to flex once each revolution and could result in excessive linear vibration of the complete set.

For good commercial practice, excessive linear vibration is commonly considered to exceed 0.005 inch (0.13 mm) double amplitude, when measured on main structural members only such as engine block or generator frame.

Alignment can be checked after assembly of the set on its base by alternatively loosening half the bolts that secure the generator frame to the flywheel housing. If a gap appears between the generator frame and flywheel housing, then misalignment is indicated. Shims placed between the generator mounting feet and the base can correct this misalignment.

If linear vibration is still excessive, then it may be due to residual flywheel and generator rotor unbalance occurring in phase and therefore additive. Reindexing the generator drive disc on the flywheel angularly to another set of bolts can shift the residual unbalances out of phase and reduce linear vibration significantly.

Flywheels are static balanced to within one (1) inch-ounce mass (720 mg·m) with ring gear installed. Generator rotors should also be balanced to within one (1) inch-ounce mass (720 mg·m). Some generator rotors are not balanced with the fan and drive disc attached. However, the above reindexing procedure is usually capable of correcting for this slight additional unbalance.

If linear vibration is still excessive after making the above corrections, then the generator drive disc may not be fully seated within its pilot in the flywheel. One edge of the drive disc may be bent and riding up on the flywheel pilot diameter. It is practically impossible to visually observe that the drive disc is seated properly. Improper seating of the drive disc may thus result in shifting one end of the rotor off-center from the crankshaft centerline by the amount of clearance between retention bolts and holes in the drive disc.

The recommended method to assure proper seating of the drive disc on the flywheel is to loosen the bolts retaining the disc to the flywheel. Then, retighten bolts enough to partially compress the lockwashers. Start and operate the engine briefly at approximately 600 rpm (600 r/min) to permit the drive disc to seat. Stop the engine and tighten the bolts to the specified torque.

Linear vibration meters are recommended as standard tools for electric set manufacturers. Numerous types are available on the market at various price ranges. Each Detroit Diesel Allison Regional Sales and Service Office is equipped with a linear vibration meter. Information on these meters may be obtained from Detroit Diesel Allison Division, Technical Service Engineering Department in Detroit, Michigan.

The above examples of linear vibration problems due to assembly practices are the most common. In rare cases, generator drive disc or flywheel pilot diameter concentricity may be suspected to exceed manufacturing specifications.

Flywheel concentricity can be readily checked by removing the generator and securely mounting a precision dial indicator on the flywheel housing. With the indicator stylus contacting the drive disc pilot diameter in the flywheel observe the total indicator excursion while the engine is barred over. Flywheel concentricity should be within 0.005 inch (.13 mm) total indicator reading.

Suspected generator drive disc concentricity deficiencies should be resolved by the generator manufacturer.

VIBRATION ISOLATORS

Vibration isolators serve to isolate substantially all of the normal electric set linear vibration from the building or other structure that comprises the final installation site. Vibration isolators are not to be considered a substitute for assembling a smooth-running electric set. It is expected that good commercial practice will be followed during electric set assembly, as outlined in the text covering alignment and linear vibration. Vibration isolators should not be confused with special shock-resistant supports.

Spring Type Isolators:

For most stationary, land-based electric set installations, good quality spring-type vibration isolators are recommended. Regardless of type, vibration isolator efficiency should be 96 to 98 percent at the working deflection point. An adjustment feature is desirable to assure uniform deflection of isolators, as the supporting floor is often imperfectly flat. An integral rubber pad under each isolator is recommended to reduce transmission of noise into the supporting structure. Isolators should be equipped with a flange containing holes for location and hold-down bolts.

Rubber Type Isolators:

Rubber-in-shear type isolators are also satisfactory provided they contain an adjustment feature to equalize deflection and provided the elastomer retains its efficiency at low temperatures and is highly resistant to permanent set and deterioration from ozone, heat, lube oil, fuel oil and commercial floor-cleaning compounds.

Rubber-in-shear type isolators are most desirable for shipboard installations because these isolators inherently resist overturning the electric set under severe pitch and roll conditions that may be encountered in service at sea.

Placement of Isolators:

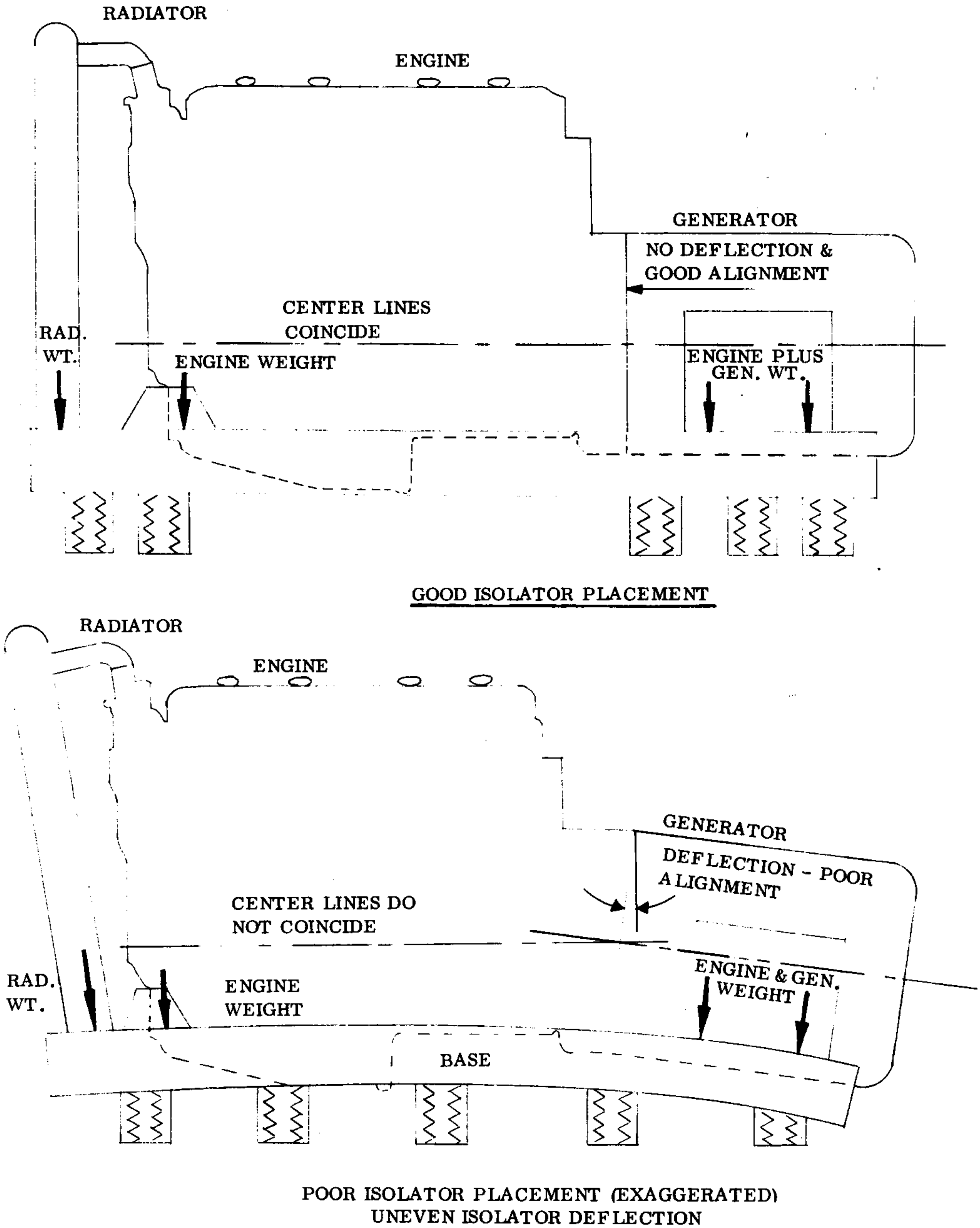
Placement of isolators along the electric set base is more critical on large, long base electric sets. Small electric sets may require no more than four vibration isolators and due to short base length, isolators may be located near the four corners of the electric set base without causing base deflection problems. Heavier, long-base electric sets pose an additional problem of multiple isolator placement due to the relative flexibility of longer base side rails.

Many electric set manufacturers find it most economical to select one size spring-type vibration isolator for most of their product line to keep part numbers to a minimum and to simplify procurement. When a number of the same size vibration isolators is to be used, the isolators must be located along the base side rails in groups near the points where the weight of each electric set component is applied to the base. Refer to Fig. 2, page 7 to compare the effects of good and poor isolator placement. Poor placement causes base deflection that may result in electric set misalignment which in turn increases linear vibration. An additional side effect of misalignment is that flywheel housing flexural stress is increased and effective sealing of the engine cylinder block and flywheel housing end-plate gaskets may be compromised.

Proper placement of vibration isolators usually permits the use of base side rails of minimum stiffness and thereby may reduce the cost of the base structural materials.

Testing of Isolator Placement:

Sometimes a linear vibration complaint may originate from the customer after an electric set has been shipped and operated at the installation site, even though vibration levels were measured and found to be within limits of good practice during testing at the generator set manufacturer's shop. There are various reasons for such a complaint.



POOR ISOLATOR PLACEMENT (EXAGGERATED)
UNEVEN ISOLATOR DEFLECTION

FIG. 2

One reason for the vibration complaint could be because the electric set manufacturer assembled and tested the set with the base resting on his shop floor rather than supported by spring-type vibration isolators. No two floors are exactly alike in flatness. The uneven floor at the installation site could cause sufficient base deflection to adversely affect alignment and increase linear vibration.

Shop testing by the electric set manufacturer should be accomplished with the electric set base supported properly by spring isolators. When later installed on identically positioned spring isolators, properly adjusted for uniform deflection, electric set alignment will be maintained.

Shop testing a set on spring isolators, then omitting the isolators at final installation, may also result in misalignment and excessive linear vibration. When spring-type vibration isolators are not used at the final installation site, then the only way to assure good alignment and to minimize some of the effects of vibration is to repeat the engine-generator alignment procedures at the final site.

ELECTRIC SET BASE DESIGN RECOMMENDATIONS

An electric set base serves several useful purposes. The base provides a convenient sub-structure for lifting, transporting and installation of the set. The base may also provide a support for a set-mounted radiator, maintaining the radiator in good alignment with the engine-driven fan. Furthermore, the base may provide suitable attaching points for hoods, fuel inlet and outlet, lube oil drain, coolant drains, air box drains, manual fuel priming pump and fuel cup, and in some cases, an integral fuel tank.

The most important function of an electric set base is to maintain good alignment between engine and generator. In other words, the base should be relatively stiff so that, when the set is mounted properly on vibration isolators, harmful deflection will be minimized. When use of vibration isolators is not practical because the electric set must rest directly on the ground, or if isolators are not used for other reasons and the supporting surface is of doubtful flatness or subject to operational deflection, then a cradle-type engine-to-generator mounting arrangement is recommended, especially for large engines. Therefore, generator set installation dictates the type of base to be used. Generally, if the generator set is to be moved, a compound base (cradle mount) should be used. For example, generator sets for construction sites, sets on skids, sets in trailers and marine applications should have a compound base (cradle mount). If the generator set is placed in a permanent, non-moving installation, such as in a hospital basement, the use of cradle mounts is at the discretion of the designer.

Simple Base:

A simple base may be defined as a rectangular steel frame consisting of side rails, made from I-beam or ship channel material, tied together by several cross-members of similar material, welded to the side rails. The front engine support is commonly attached to a cross-member and the generator usually attaches to the side rails at two places on each side of the generator, see Figure 3, page 10. Vibration isolators are normally located between the side rails and the floor at the installation site.

Electric sets utilizing small engines require only short bases that are relatively stiff. Large engines require much longer bases. Frequently, cost considerations result in side rails of relatively less stiffness for the longer lengths. Therefore, a simple base requires the exercise of good judgement in its application with large engines and generators.

Design and fabrication of long side rail simple bases involves substantially the same procedures as short bases. One additional precaution on long bases is to provide enough cross-member construction to assure that side rail resonant frequency is well removed from the engine first order excitation.

Side rails of bases are usually provided with threaded holes to accommodate jacking screws, used to raise the electric set when placing vibration isolators between the side rails and the floor. Jacking screws are then removed after isolators have been adjusted to carry the electric set weight.

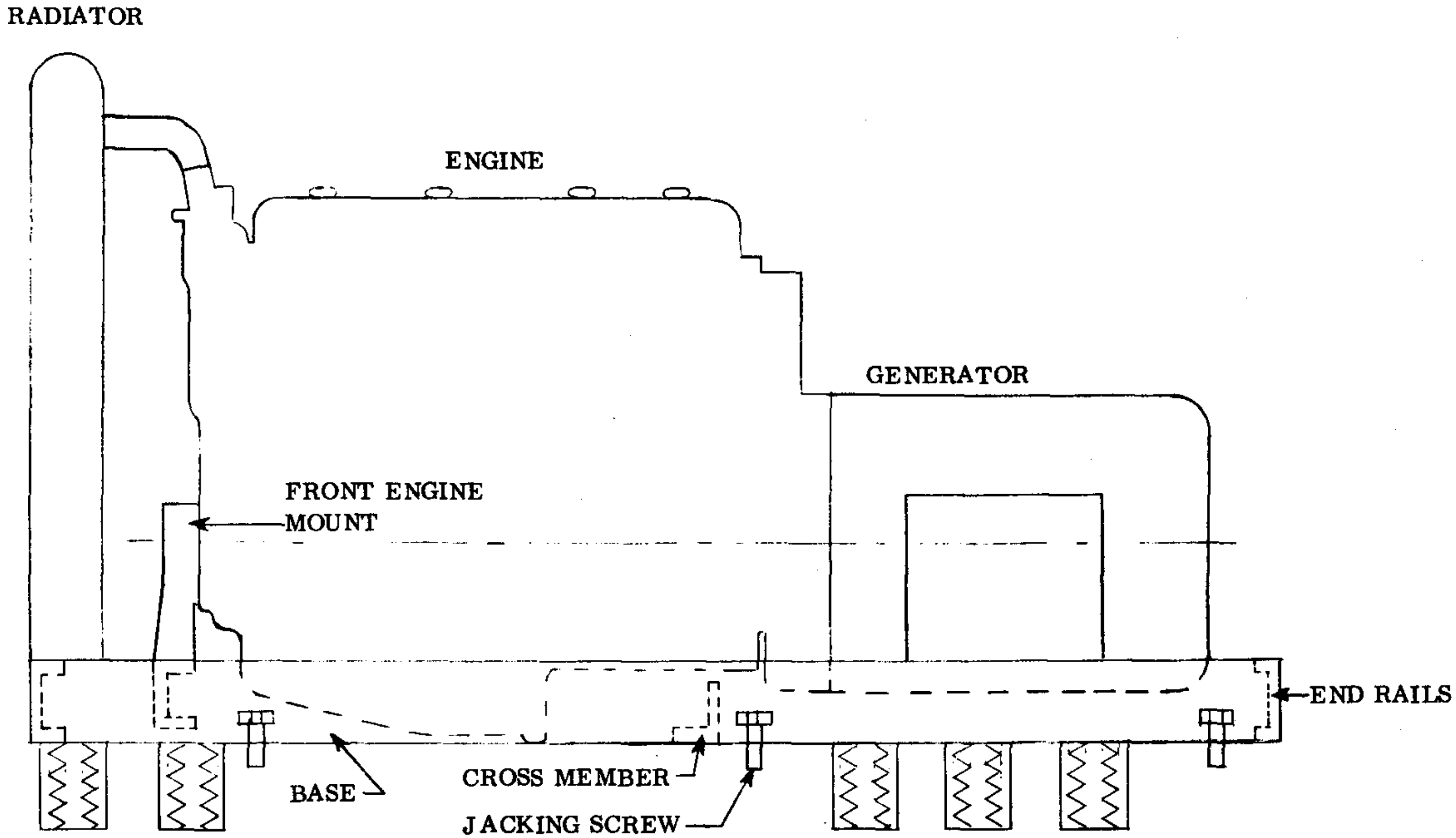


FIG. 3 - SIMPLE BASE-DIRECT MOUNT

Compound Base (Cradle Mounting):

A compound base may be defined as a simple base that supports the front of the engine by a trunnion mount and supports the rear of the engine and the generator through a cradle-type mount, see Figure 4, page 12.

A cradle-type engine-to-generator mounting together with trunnion-type front engine support comes nearest to maintaining an effective three-point electric set mounting. This mounting arrangement has proven to be most tolerant of base deflection and aids in retaining engine-generator alignment and reducing flywheel housing stress. A properly designed cradle mount effectively combines the generator and engine flywheel housing together on very stiff cradle beams that are secured to the flywheel housing mounting pads and the generator mounting feet. Each cradle beam is then attached to each base side rail at one point. Therefore, the two rear points of contact between cradle beams and base side rails together with the front trunnion support, effectively provide the desired three-point mounting arrangement. However, poorly designed or carelessly assembled cradle mounting arrangement will not achieve the desired results. Precautions must be taken in the design and assembly of the cradle beams to assure that they are sufficiently stiff to maintain engine-to-generator alignment when supported at only a single point.

Calculations to determine the proper position for the single point support of each cradle beam to the base side rail should be accurate. Otherwise, flywheel housing bending moment may be excessive. Figure 5, page 13, provides the method to calculate the support point for the desired zero bending moment between the rear of the cylinder block and the rear end plate.

In order to minimize the increase in height of a cradle-mounted electric set, it is recommended that the generators selected be so constructed that the mounting feet are repositioned from a plane near the bottom side of the generator frame to a plane nearer the shaft centerline. Most generator manufacturers offer the low mounting foot position. When ordering a generator, it is necessary to specify a higher mounting foot position to effect a reduction in overall height.

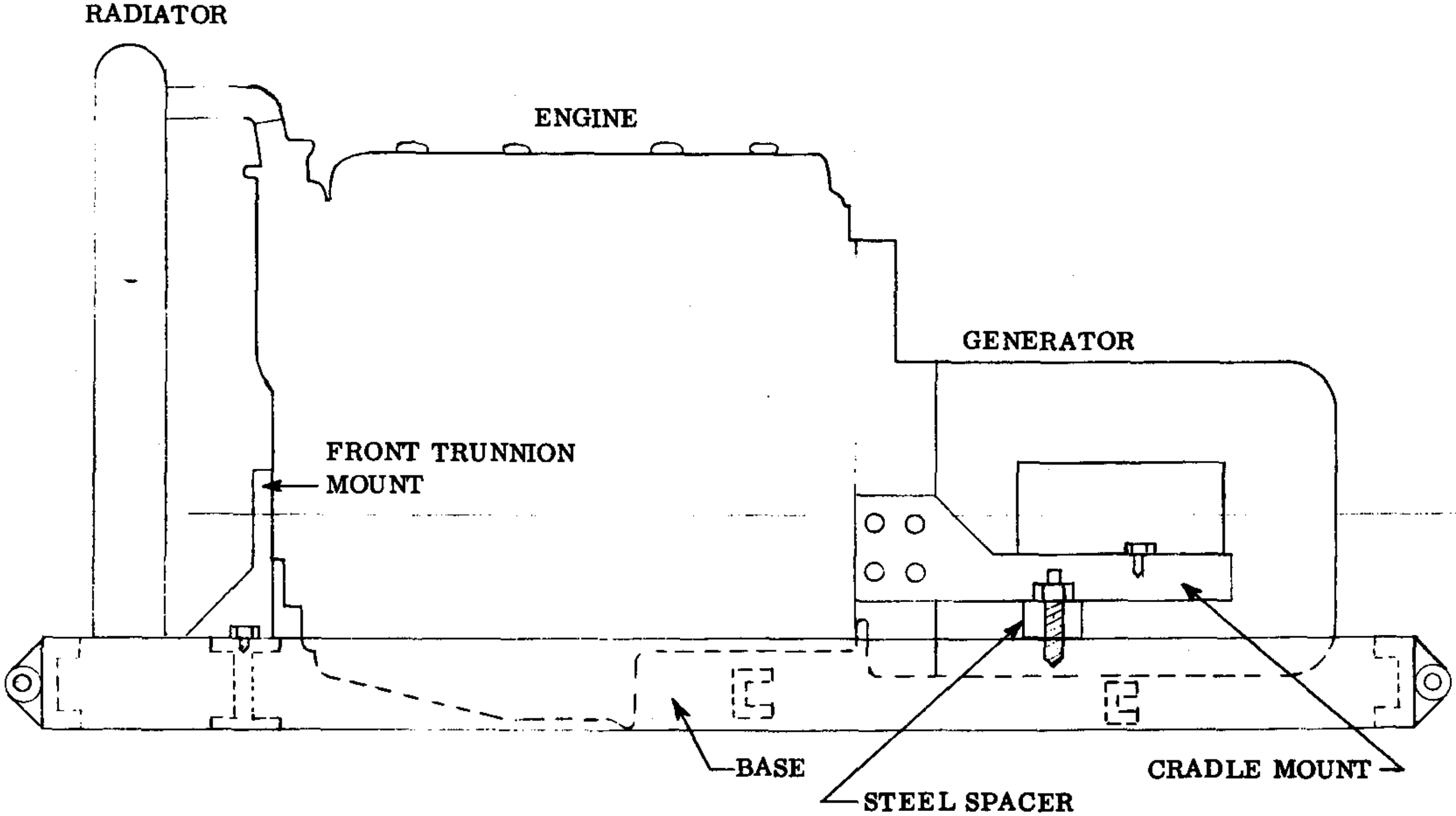
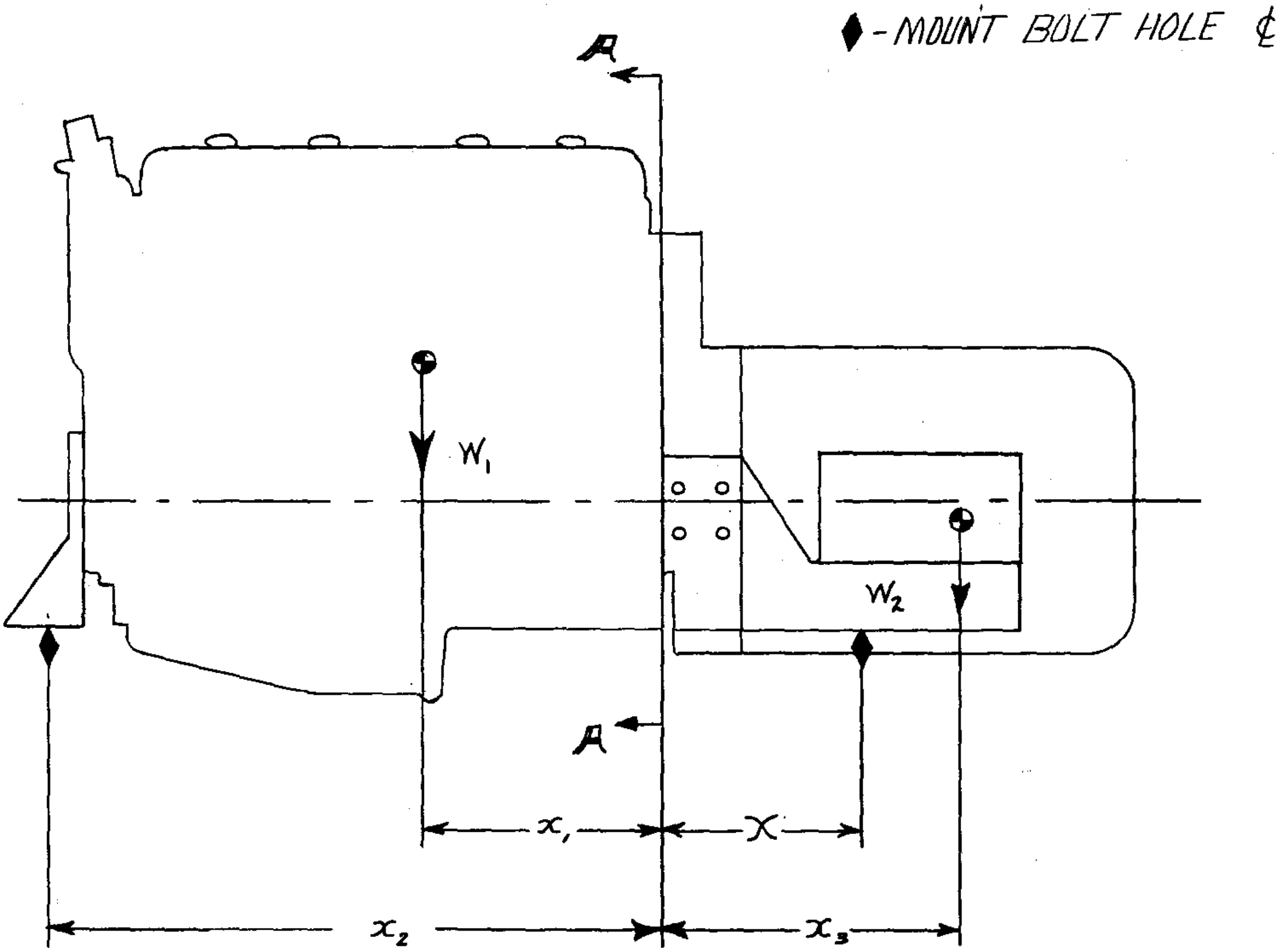


FIG. 4 :- SIMPLE BASE WITH CRADLE MOUNT

FOR CRADLE TYPE MOUNT

ENGINE ____________

GENERATOR ____________



A - A IS SECTION WHERE ZERO BENDING MOMENT IS DESIRED. (REAR FACE OF BLOCK)

MASS (WEIGHT) OF ENGINE	W_1 =	____________
MASS (WEIGHT) OF GENERATOR	W_2 =	____________
DISTANCE TO ENGINE C.G.	X_1 =	____________
DISTANCE TO ℄ FRONT MOUNT	X_2 =	____________
DISTANCE TO GENERATOR C.G.	X_3 =	____________
DISTANCE TO ℄ REAR MOUNT	X =	____________

$$X = \frac{W_2 X_3 X_2}{W_1 (X_2 - X_1) + W_2 X_2}$$

$$X = \frac{(\quad)(\quad)(\quad)}{(\quad)(\quad - \quad) + (\quad)(\quad)}$$

$$X = \underline{\qquad\qquad}$$

FIG. 5

Front Engine Supports:

The two basic types of front engine supports in common use are trunnion-type and rigid-type.

A trunnion-type front support permits limited fore and aft movement of the engine, and permits some rotational movement of the engine about the axis of the crankshaft. A trunnion support reduces engine and generator twisting stresses due to any base distortion that may result from placement of the electric set on an uneven surface. Outdoor construction and strip-mining sites, where electric sets are sometimes required to rest on the ground, are typical examples of situations wherein trunnion-type front engine supports may prove to be useful.

A rigid-type front engine support consists of a cast or wrought angle bracket that is then bolted to a cross-member of the base. Since a rigid-type front support resists movement of the front of the engine in all directions, added precautions must be taken during electric set assembly to avoid built-in structural twist. With the engine and generator bolted together and resting freely on the base, care must be taken to assure that any transverse gap between the front engine support and the base is shimmed before tightening the bolts that secure the front support to the base. Otherwise the entire engine-generator-base structure will be prestressed due to a built-in twist.

FOUNDATION CONSIDERATIONS

The force exerted by the mass (weight) of the engine-generator set and the force of vibrations due to operation, spread over its base area, must be less than the pressure bearing capacity of the foundation material. If the pressure bearing capacity is insufficient, the unit will sink into the ground.

To determine the pressure in lb/ft^2 (kPa) of the generator set on the foundation (ground), the total mass of the set is divided by the projected area in square feet (m^2) of the bottom surface of the base frame rails, i.e.:

$$\text{Pressure on foundation } (lb/ft^2) = \frac{\text{Total mass of set (lbs)} \times 144}{\text{Projected frame rail area (inches}^2)}$$

$$\text{Pressure on foundation (kPa)} = \frac{\text{Total mass of set (kg)} \times .01^*}{\text{Projected frame rail area } (m^2)}$$

* .00980665 Actual.

The pressure bearing ability of the supporting surface determines how much projected area is required. Fill soil and marshy ground require greater bearing areas than hard pan or undisturbed clay surfaces. Seasonal changes, from winter to summer operation, may present changes in the ability of the soil to support the unit because of freezing and thawing conditions. The following chart can be used as a guide in determining the pressure bearing ability of rock and soil foundations.

Foundation Material	Pressure - Bearing Capacity lb/ft^2	(kPa)
Hard rock - granite, etc.	50, 000 - 200,000	2394.01 - 9576.05
Medium rock - shale, etc.	20,000 - 30,000	957.61 - 1436.41
Hardpan	16,000 - 20,000	766.08 - 957.61
Soft rock	10,000 - 20,000	478.80 - 957.61
Compacted sand and gravel	8,000 - 12,000	383.04 - 574.56
Hard clay	8,000 - 10,000	383.04 - 478.80
Gravel and coarse sand	8,000 - 10,000	383.04 - 478.80
Loose, medium and coarse sand; compact fine sand	3,000 - 8,000	143.64 - 383.04
Medium clay	4,000 - 8,000	191.52 - 383.04
Loose fine sand	2,000 - 4,000	95.76 - 191.52
Soft clay	- 2,000	- 95.76

Where the bearing surface area of the generator set mounting rails is insufficient, then floation pads, i.e.: heavy wide planks or railroad ties are used to reduce the ground pressure on soil type foundations.

A unit that is mounted on a solid foundation, i.e.: a cement pad or a building floor should use isolators between the unit base rails and the foundation. The loading pressure on the foundation will depend on total engine-generator set mass and the number and size of isolator pads. If mass is equally distributed over all isolators, the foundation (floor) pressure is:

$$\text{Floor unit pressure} = \frac{\text{Total electric set mass}}{\text{Pad area x No. of pads}}$$

Thus, floor pressure can be reduced by increasing the number of isolation pads.

If the load is not equally distributed, the maximum floor pressure occurs under the pad supporting the greatest proportion of load (assuming all pads are the same size):

$$\text{Floor unit pressure} = \frac{\text{Force on heaviest loaded pad}}{\text{Pad area}}$$

The engine-generator set supplier is usually required to furnish calculated floor unit pressure in lb/ft^2 (kPa) of pad area.

SUMMARY

This bulletin has outlined the need for good engine-to-generator alignment and some of the methods to correct misalignment. Also, the need for the proper mounting of the engine and generator to the base and the placement of isolators under the base to prevent strains within the generator set and vibrations to the structure of the building or ship cannot be over emphasised. A reliable and smooth operating generator set is the result of the manufacturer building the set to meet the physical requirements of the application where it will be used.

DDA PROPULSION ENGINES APPROVED BY AMERICAN BUREAU OF SHIPPING AND LLOYD'S REGISTER OF SHIPPING

AMERICAN BUREAU OF SHIPPING

Engine	Injector	BHP	Full Load rpm
3-53	N45	86	2800
4-53	N45	128	2800
6V-53	N45	181	2800
4-71N	N55	120	1800
	N70	165	2300
6-71N	N55	180	1800
	N70	265	2300
6-71T	N90	335	2300
8V-71N	N55	240	1800
	N70	335	2300
8V-71TI	N90	435	2300
12V-71N	N55	360	1800
	N70	500	2300
12V-71TI	N90	675	2300
16V-71N	N55	480	1800
	N70	666	2300
12V-149	120	700	1800
	130	800	1900
12V-149TI	150	960	1800
16V-149	120	1205	1800
	130	1060	1900
16V-149TI	150	1280	1800

LLOYD'S REGISTER OF SHIPPING - PROPULSION ENGINES

Engine	Injector	BHP	Full Load rpm
3-53	N45	86	2800
4-53	N45	136	2800
6V-53	N45	181	2800
3-71N	N70	78	1800
4-71N	N70	165	2300
6-71N	N70	265	2300
6-71T	N90	335	2300
12V-71N	N55	360	1800
12V-71N	N70	500	2300
12V-71TI	N90	675	2300
8V-71N	N55	240	1800
	N70	335	2300
8V-71TI	N90	435	2300
16V-71N	N55	480	1800
	N70	666	2300
12V-149	130	700	1800
	130	800	1900
12V-149TI	150	870	1800
	150	960	1900
16V-149	130	930	1800
	130	1060	1900
16V-149TI	150	1160	1800
	150	1280	1900

DDA AUXILIARY ENGINES APPROVED BY AMERICAN BUREAU OF SHIPPING AND LLOYD'S REGISTER OF SHIPPING

AMERICAN BUREAU OF SHIPPING

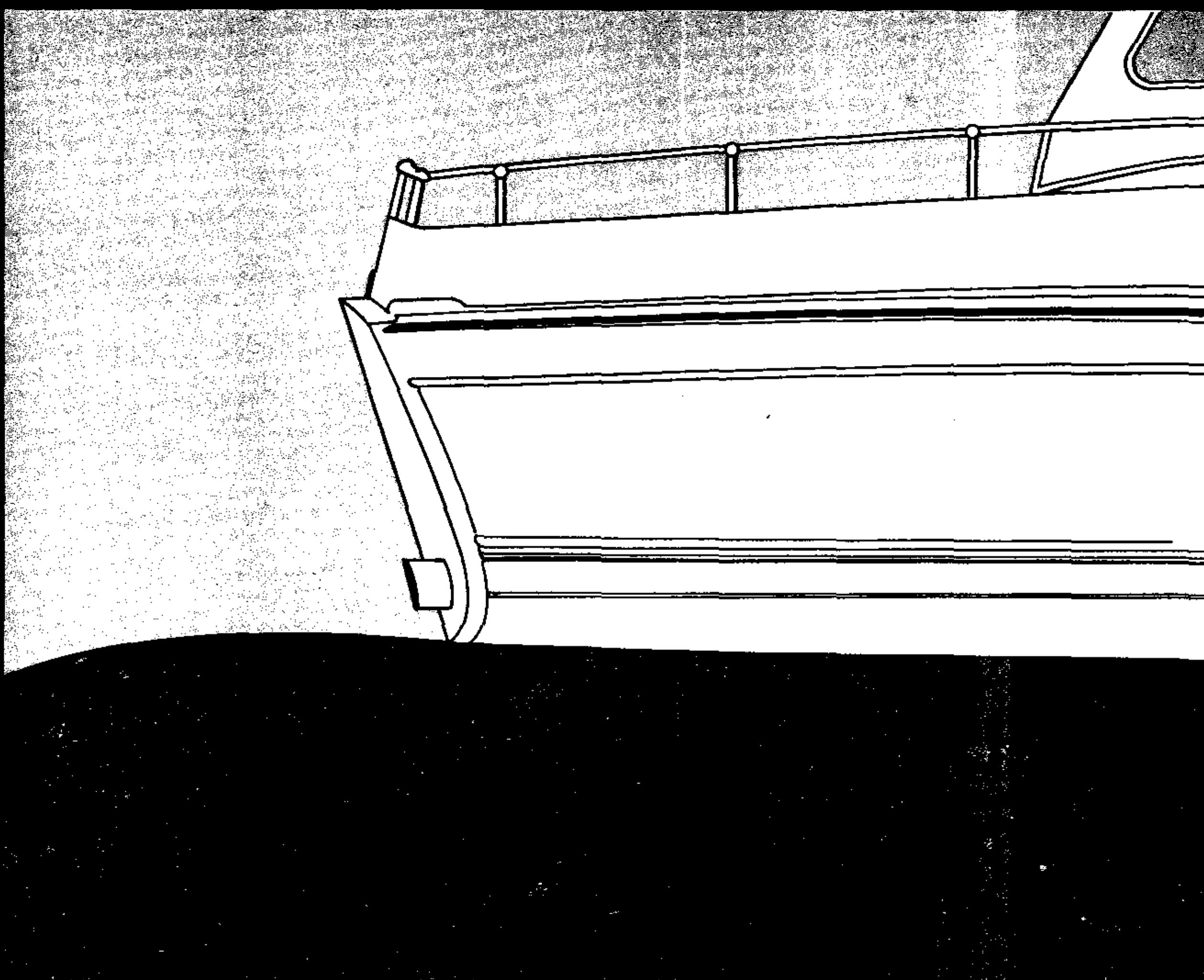
Engine	Injector	BHP	Full Load rpm
2-71	70	65	2000
3-71	70	110	2300
4-71N	70	110	1500
	70	130	1800
4-71T	90	145	1500
	90	165	1800
6-71N	70	160	1500
	70	195	1800
6-71T	90	220	1500
	90	260	1800
8V-71N	70	215	1500
	70	260	1800
8V-71T	90	295	1500
	90	335	1800
12V-71N	70	320	1500
	70	390	1800
12V-71T	90	435	1500
	90	525	1800
16V-71N	70	430	1500
	70	515	1800
16V-71T	90	685	1800
12V-149	130	600	1500
	130	700	1800
12V-149T	150	825	1500
	150	975	1800
12V-149TI	150	817	1500 Jacket Water Intercooling
	150	960	1800 " " "
	180	896	1500 85°F. Water Intercooling
	180	1050	1800 " " "
16V-149TI	150	1090	1500 Jacket Water Intercooling
	150	1280	1800 " " "
	180	1195	1500 85°F. Water Intercooling
	180	1400	1800 " " "

LLOYD'S REGISTER OF SHIPPING

Engine	Injector	BHP	Full Load rpm
4-71N	N70	110	1500
	N70	130	1800
4-71T	N90	145	1500
	N90	165	1800
6-71	N70	160	1500
	N70	195	1800
6-71T	N90	220	1500

Detroit Diesel Allison

ELEMENTS OF MARINE PROPULSION



Foreword

This booklet contains a wealth of technical data condensed into practical language and simple formulae which will enable the layman to appreciate the factors involved in boat performance . . . be it a high-speed pleasure craft, a medium-speed commercial fishing vessel, or a slow-speed work boat.

The information and examples offered were gleaned from many knowledgeable sources and chosen for their simplicity and ease of understanding. However, any conclusion reached from applying this data should be considered as a general guideline.

It is suggested that you seek the service of a naval architect and contact a Detroit Diesel Allison Distributor before you commit yourself to a specific marine propulsion system.

Table of Contents

Hull Conformations

The first subject to be covered in a discussion of marine design and power is hull conformation. Within this subject there are only two general hull types:

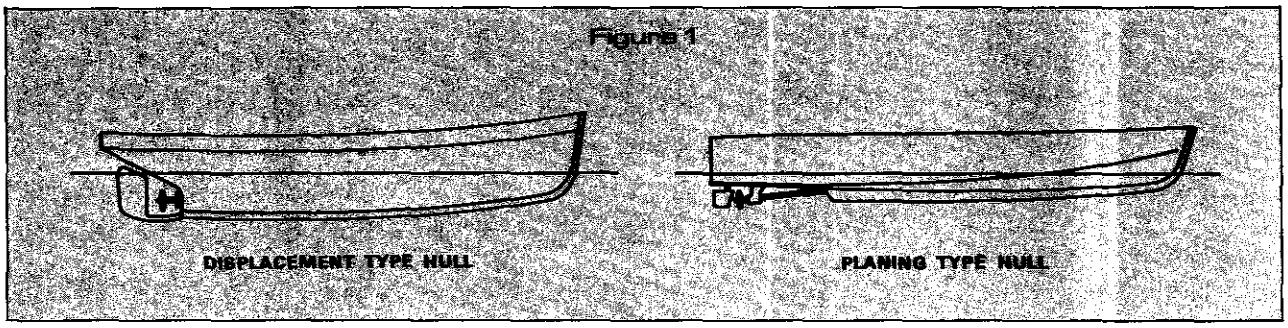
1. Displacement
2. Planing

However, there are hulls which have some characteristics of both, known as semi-displacement hulls.

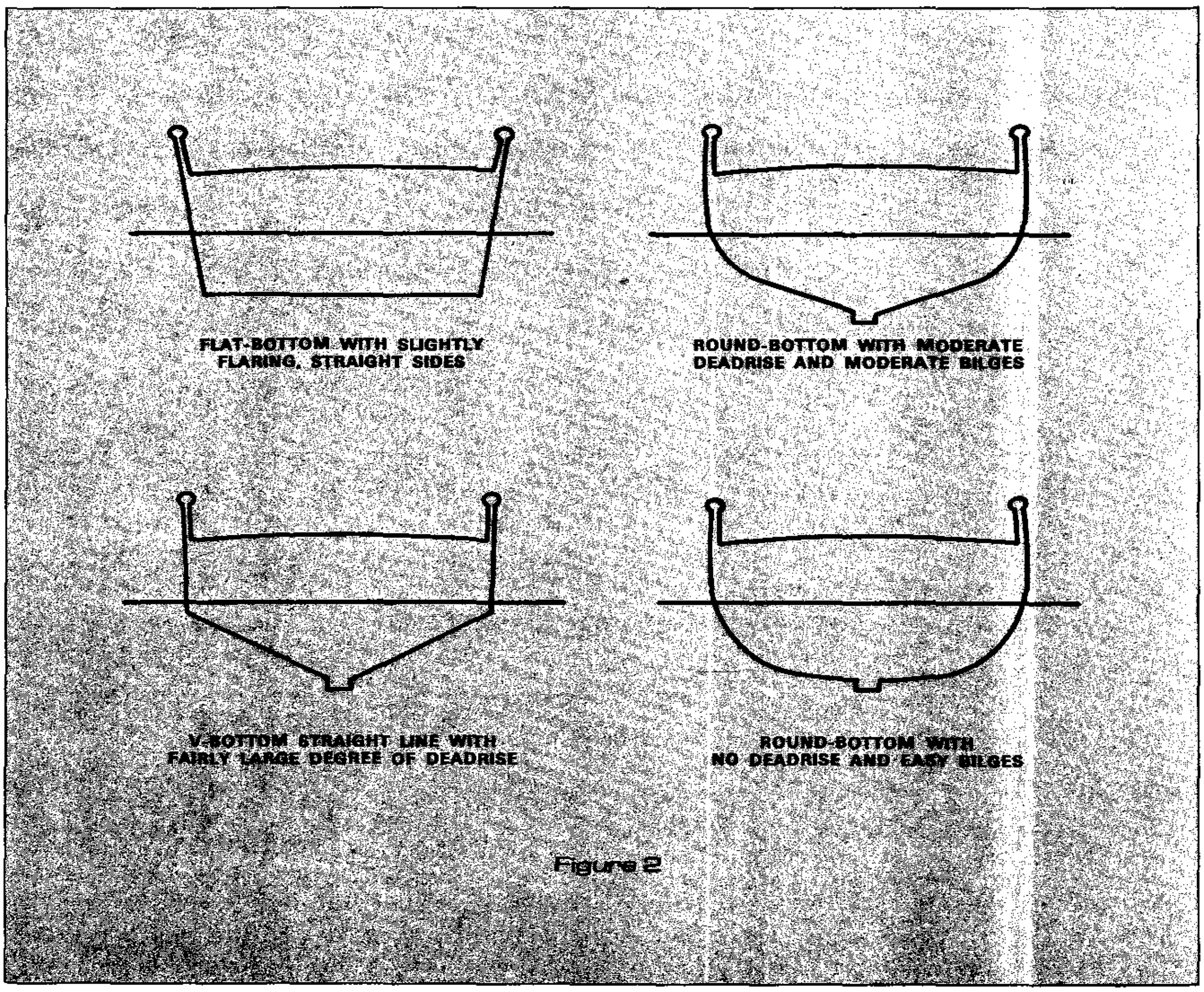
In addition, there are three general classifications of hull bottom shapes. These are:

1. Flat bottom
2. Vee bottom
3. Round bottom

Figures 1 & 2 provide side views of the types of hulls and cross sections of various bottom conformations.



Various Hull Sections



[illegible]ary Conceptions [illegible]

A displacement type hull replaces an amount of water equal to its own weight no matter what its speed through the water. It is so shaped that the bow cuts a wedge in the water which the forebody then moves aside to the extent of the midsection. Aft of the midsection, the hull is shaped to allow the water to converge at the stern in a natural flow and reduce drag to a minimum.

When a hull is propelled through the water at low speeds, its forward motion causes a system of waves to be formed along the length of the boat. The length between one wave crest and another is directly proportional to the speed at which the boat is propelled through the water. A second series of waves emanates from the stern of the vessel. If the speed is such that the forward wave is at its highest point when the wave formed by the stern is at its lowest, cancellation of the two systems will occur, thereby neutralizing the drag carried by the wave set up from the stern. This is considered the most efficient condition for propelling a boat through the water (see Fig. 3).

SCHEMATIC DRAWING OF HULL IN WATER

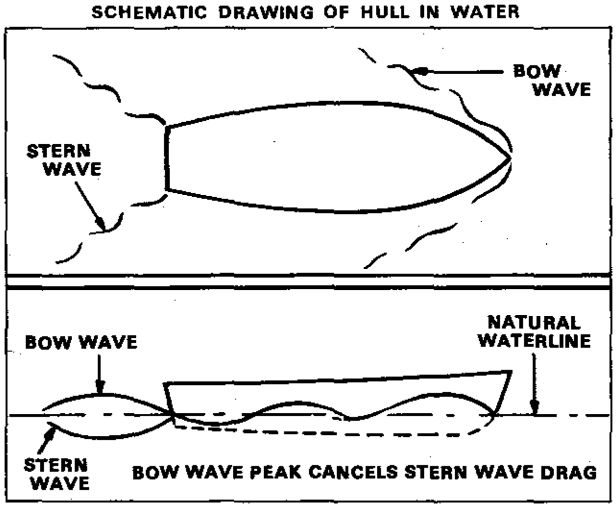


Figure 3

These "optimum" conditions are, as a rule, achieved when the speed in knots divided by the square root of the waterline length (in feet) equals either .9 or 1.10.

$$\frac{V}{\sqrt{LWL}} = 0.9 \text{ or } 1.1$$

Where V = Speed in knots, and
LWL = Loaded Waterline length (in ft.)

This assumes the hull to be of a normal displacement form with a reasonable beam to length ratio.

The "optimum" of $\frac{V}{\sqrt{LWL}} = 0.9$ or 1.1 is simply used as a base to establish the most practical speed of a displacement hull. Beyond this point the horsepower per knot increase becomes economically unfeasible. Thus, from data taken on a large sample of displacement hulls, a general formula for estimating a boat's "maximum feasible" speed was developed where 1.34 times the square root of the loaded waterline length (in feet) equals the boat's speed in knots.

$$1.34\sqrt{LWL} = V$$

LWL = Loaded waterline length
V = Speed in knots.

[illegible] and Power

In order to properly estimate speed and power requirements, it is first necessary to understand the terms and components used in making these calculations:

LWL = Loaded waterline length, in feet. This is the actual length of the immersed portion of the vessel —*not total length.*

B = Loaded waterline beam or beam at maximum width of vessel at loaded waterline, in feet.

D = Moulded draft. Depth at midship from waterline to bottom of boat in feet. Do not include keel (which protrudes below hull), propeller shafting, propellers, rudders, or skin thickness.

C_b = Block coefficient. The ratio of a vessel's weight (displacement) to that of a rectangular block of water having the same length, width and depth as the underwater portion of the hull. See following table, Fig. 4.

$$C_b = \frac{W \times Q}{L \times B \times D}$$

Q = Cu. ft. of water per long ton. (Salt water 35, fresh water 36.)

W = Displacement. Weight of volume of water displaced by vessel and equal to weight of vessel in long tons (2240 lbs.). Displacement must *not* be confused with gross or net tonnage which are measurements of a ship's internal volume in units of 100 cu. ft.

Estimating Block Coefficient (C_b)

	C_b Range
Semi-displacement and Planing Hulls	
Yachts and Crew Boats	.40 to .50
Displacement Hulls	
Light Cargo and Fishing Vessels	.40 to .55
Heavy Cargo, Fishing Boats and Tugs	.50 to .65
River Tow Boats	.55 to .70
Self-propelled Barges	.70 to .90
Barges	.85 to .90

Figure 4

Displacement, as used in the following formulas, is the actual weight of the loaded vessel. Gross and net tonnage are volume measurements and should never be used.

Displacement is calculated as follows:

$$W = \frac{L x B x D x C_b}{Q}$$

With the above information we can proceed to discuss estimated speed formulas.

Displacement Hull Speed

To approximate the speed of this type of hull, use the Nomograph as shown in Fig. 5. The displacement, loaded waterline length and S.H.P. must be known quantities. Using these known factors and applying them in Steps 1 through 5, it is comparatively easy to obtain an *approximate* speed for any standard type *displacement hull.*

A practical application would be as follows:

Light cargo vessel
Length overall—80′
Loaded waterline length—73′
Loaded waterline beam—18.6′
Moulded draft (amidship)—7.2′
Shaft horsepower—340

Using block coefficient table, (Fig. 4) and general knowledge of the particular boat, the block coefficient (C_b) would be approximately .50, chosen arbitrarily between .40 and.55.

Then, calculating for displacement,

$$W = \frac{73' \times 18.6 \times 7.2' \times .50}{35} = 138 \text{ long tons}$$

Nomograph See Page 6 Figure 5

1. Convert displacement (W) to $W^{7/6}$ on scale A.
2. To obtain S.H.P. displacement coefficient, divide shaft horsepower by $W^{7/6}$

$$\frac{S.H.P.}{W^{7/6}} = \text{S.H.P. displacement coefficient.}$$

Top Scale—A:
Convert W to $W^{7/6} = 310$
Divide $\frac{340}{310} = 1.1$ S.H.P. displacement coefficient

3. Convert S.H.P. displacement coefficient to speed length ratio on scale B, below S.H.P. displacement coefficient.

Middle Scale—B:
Convert S.H.P. displacement (1.1) to speed/length ratio.
Reading 1.15

Speed-Length ratio

4. Convert loaded waterline length in ft. to its square root on scale C.

$$\sqrt{LWL}$$

Bottom Scale—C:
Convert load waterline length to $\sqrt{LWL}$ or $\sqrt{73} = 8.55$

5. Multiply $\sqrt{LWL}$ by speed length ratio to obtain speed in knots. To convert to miles per hour multiply speed in knots by 1.152.

Final step, multiply speed length ratio by $\sqrt{LWL}$ or 1.15 x 8.55 = 9.9 knots.
One knot = 1.152 MPH. To convert knots to miles, simply multiply 9.9 x 1.152 = 11.4 MPH

NOTE:
When installing a replacement engine in a boat *the speed prior to change should be carefully checked* and run comparatively through the nomograph to give a more accurate speed prediction. This will provide a correction factor for use when comparing the nomograph's predicted speed and the boat's actual speed.

Actual speed (previous power) = 12 knots
Chart speed (previous power) = 14 knots

$$\text{Correction factor} = \frac{12}{14} = .86$$

Chart speed (new power) = 18 knots
Actual Speed (new power) = .86 x 18 = 15.4 knots.

Figure 6 is a chart which, for estimating purposes, is reasonably good. It shows the influence of length, displacement, etc. and is easy to use for rapid estimates. The chart is explained below and can be used as shown by the example.

The curved line indicates the average of a great many forms and trials over a period of years. For repowering vessels, the results of previous installations can be plotted on the chart. If the results do not coincide with the reference curve shown, a curve of similar characteristics can be drawn through an established performance point and parallel to the existing curve. This new curve, then, will apply to that specific hull and can be used for the basis of subsequent repowering calculations.

This chart is for displacement type hulls *only.* When information indicates that it falls outside the range of the chart, it should not be used because the boat may be in transition between displacement type and planing (semi-planing) or may even be of the planing type. If the hull is of the planing type the Nomograph in Fig. 7 must be used.

The following example illustrates how Fig. 6 may be used. Given a set of boat specifications such as:

Shaft Horsepower—230
Displacement—40 long tons
Loaded Waterline Length—100 feet

Select the given S.H.P. at the bottom of the nomograph. Then follow the curved line to the horizontal line corresponding to the LWL of this particular boat. Follow an imaginary vertical line up until it intersects with the displacement of this boat (lines angling up and to the right). At this point, proceed on a horizontal straight line until intersection with the broad base line curve. Again proceed on a vertical straight line until intersecting with the proper boat's LWL line (angling up and to the left). Finally, follow a straight horizontal line to the left-hand margin, which gives the boat's predicted speed. Figure 6 has a dotted line which traces the path of this example.

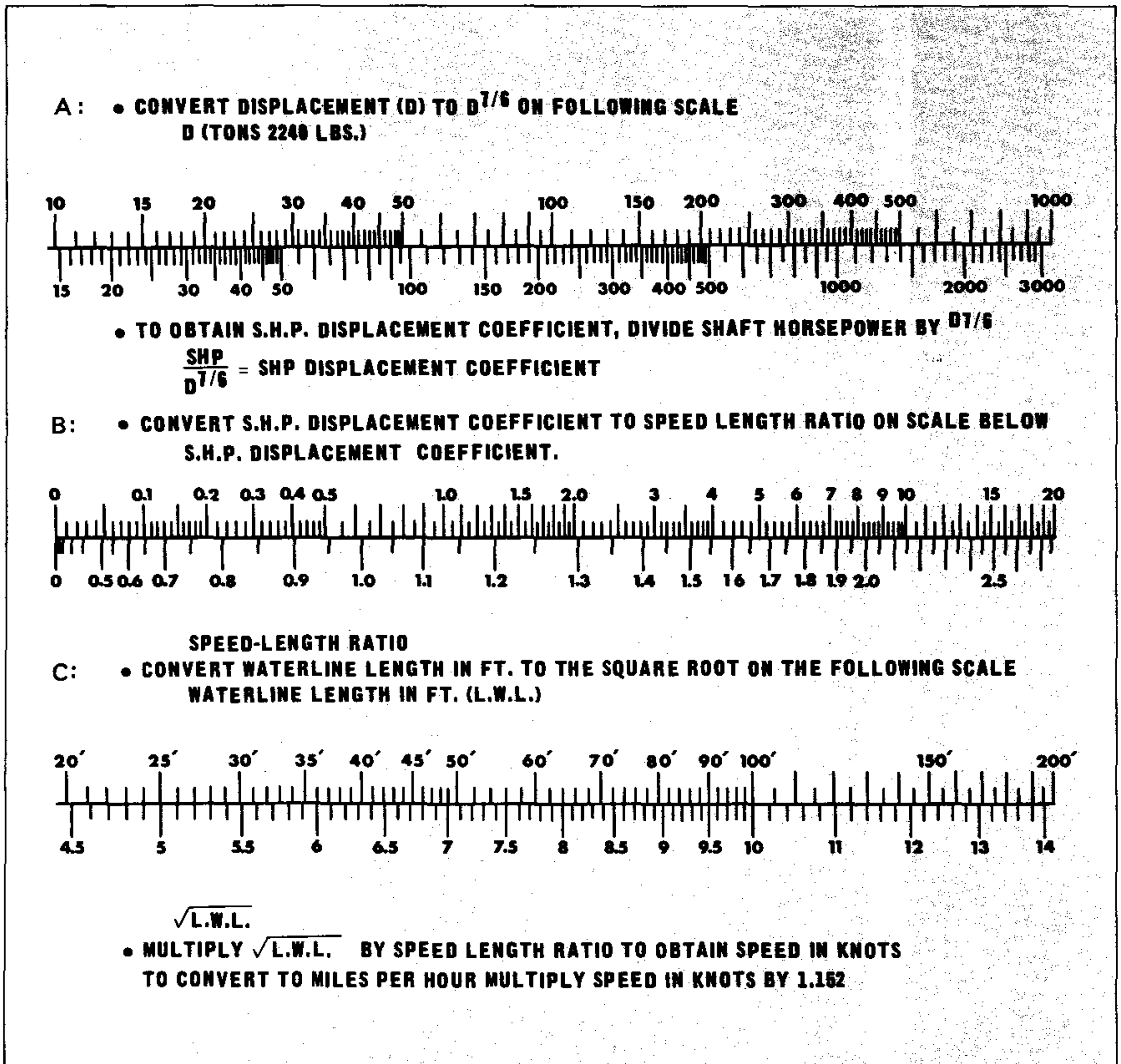


Figure 5

Displacement Type Vessel

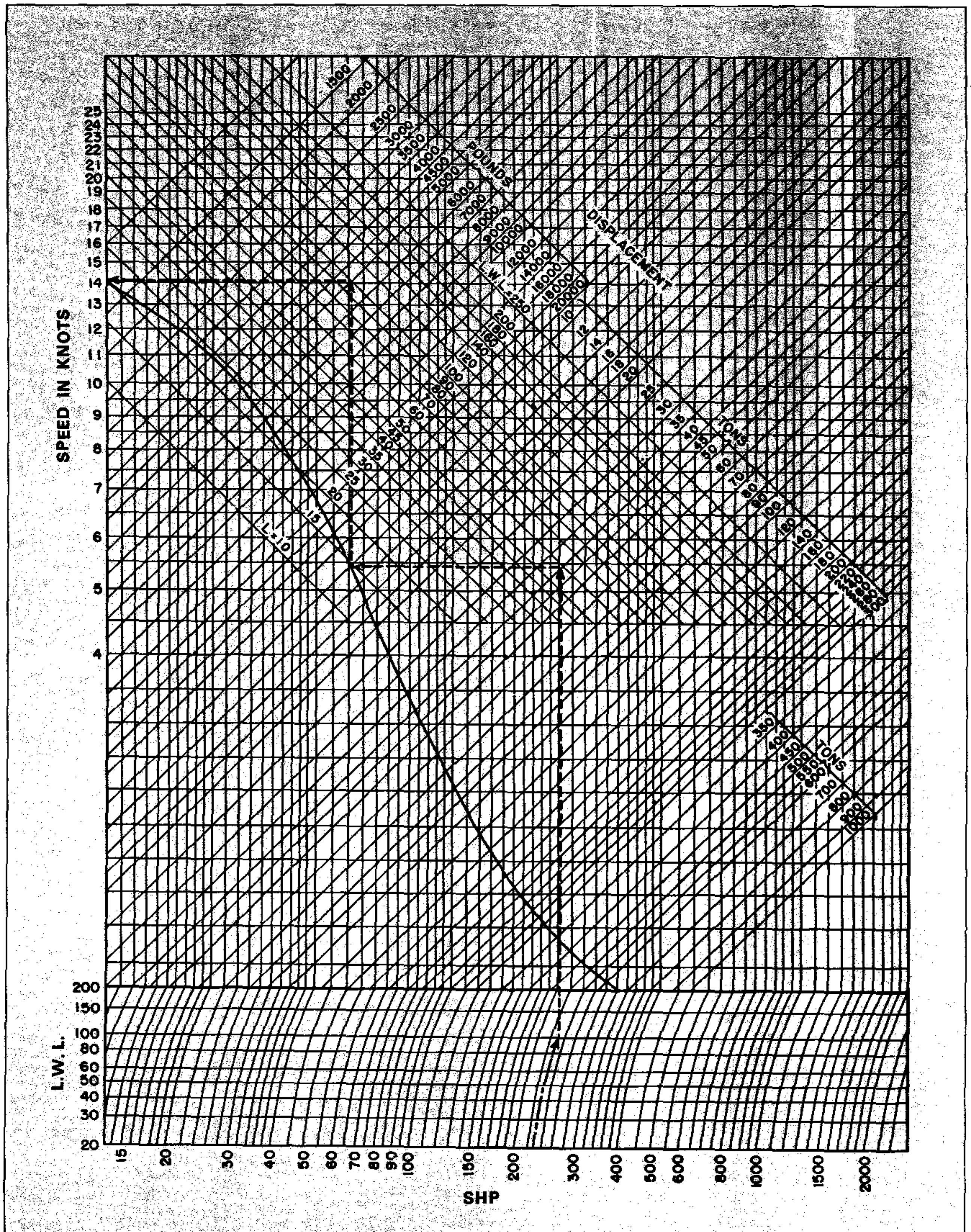


Figure 6

When a boat's speed becomes sufficient to drive it towards the surface, the bottom of the hull acts as a plane. When these conditions prevail, the boat is said to be "planing."

Planing can be defined as the stage at which the dynamic forces caused by the motion of the hull through the water begin to make their lifting influence felt.

There are, of course, many degrees of planing, ranging from the stage where the water ceases to close in immediately behind the stern, to the stage where almost nothing of the boat is actually in the water as it skims over the surface.

Formulas for calculating the speed of planing hulls are many and varied because of the complexity of factors that affect performance at higher speeds. One of the more widely used is the coefficient "K" method. This method is comparatively easy to use and produces sound, "in the ballpark" estimates for higher speed craft.

$$V = K\sqrt{\frac{SHP}{W}}$$

"K" is a coefficient depending on hull form and speed/length ratio.

The following table lists the values of "K" for various type hulls that have been determined by experience. Obviously this is a crude method, but it could be more sophisticated by determining from actual experience more accurate "K" values for particular hull shapes.

	Values of "K"		
Loaded Water Line in feet	Round Bilges, Flat at Transom	Vee Bottom Hard Chine: Not Stepped	Vee Bottom Hard Chine: Stepped
20	2.25	2.75	3.60
25	2.40	2.90	3.80
30	2.60	3.15	3.96
35	2.80	3.40	4.15
40	3.05	3.65	4.30
45	3.24	3.85	4.48
50	3.34	4.00	4.60

Approximate speed of planing hulls

$$V = K\sqrt{\frac{SHP}{W}}$$

V = Speed in Knots
W = Displacement in Long Tons
K = Hull Coefficient

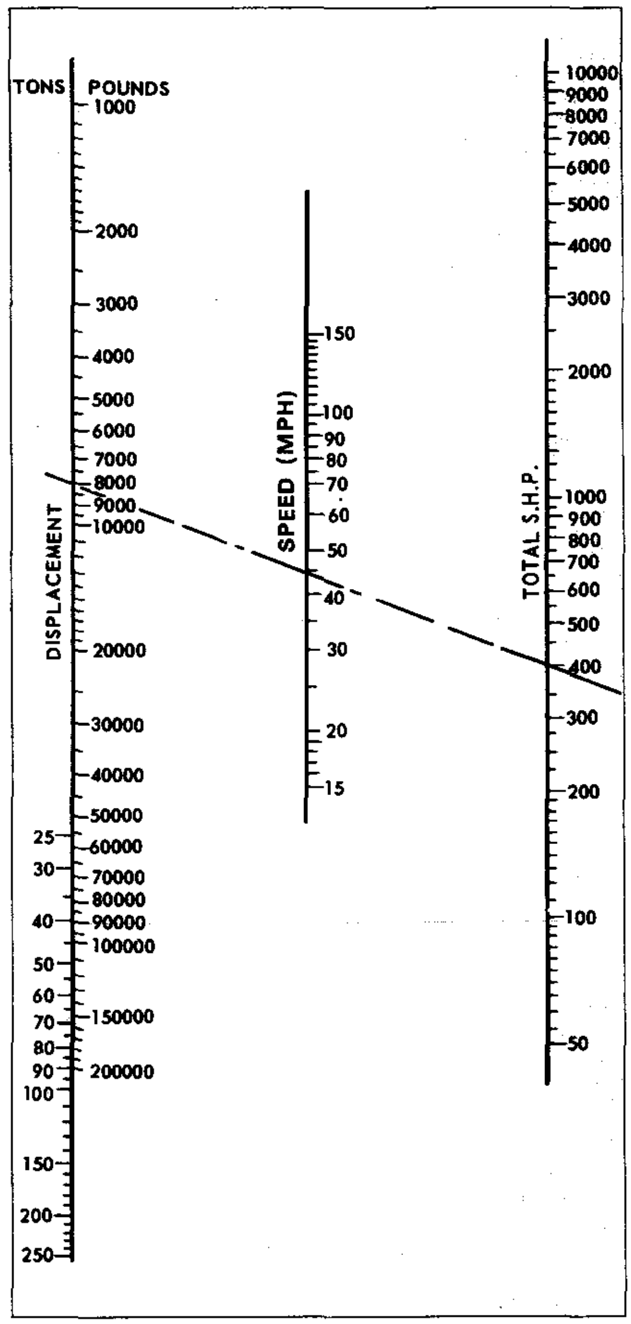
As an example, here is an actual case history—a 32 ft. aluminum crew boat, Vee Chine hull, 12,400 lbs. displacement and powered by a pair of Detroit Diesel 6V-53N engines.

SHP = 180 x 2 = 360
W = 12,400 lbs. or 5.53 long tons
K = 3.4 (taken from preceding table, Vee Chine)

$$V = \sqrt{\frac{360}{5.53}}$$

$$3.4 \times \sqrt{65} = 3.4 \times 8.05 = 27.4 \text{ knots}$$

V = 27.4 knots x 1.152 = 31.5 MPH



As the calculations predicted, the boat actually did 32 MPH during its trial runs.

As an assist in performing the square root computation,

$$\sqrt{\frac{SHP}{W}} = \sqrt{\frac{360}{5.53}} = \sqrt{65} = 8.05$$

the bottom "C" scale of Fig. #5 may be used. Perform the division indicated inside the square root sign first. Then read 65 on the top side of scale C and its square root, 8.05, will be directly beneath.

Another method for estimating the speed of planing hulls is shown on the nomograph labeled Fig. 7. To obtain an estimated speed in MPH, simply draw a straight line between two known factors. This provides reasonable results for boats up to 10° deadrise.

For example, if a boat weighs 8000 pounds and has 400 SHP, draw a straight line between 8000 pounds on the first scale (left) and 400 SHP on the third scale. Mark the point where this line intersects the middle scale and read the speed, 45 MPH. To convert to Knots, divide by 1.152.

PLEASE REMEMBER THAT THESE FORMULAS ARE FOR GENERAL GUIDANCE ONLY AND CANNOT BE USED TO GUARANTEE PERFORMANCE.

The most basic problem of marine propulsion is the transformation of engine power into thrust by means of some form of propulsive device. Because of its efficiency and simplicity, the propeller has become the most widely used propulsive device.

A screw propeller is basically an axial flow pump.

The rotation of the propeller shaft (RPM) and the angle of the propeller blade, known as pitch, combine to form a thrust force on the propeller shaft. Thrust is transmitted through the shaft to the thrust bearing, which is the principal point where the forces generated by propeller rotation act upon the hull.

There are many factors to be taken into account in selecting a propeller, from the practical to the very theoretical. The thing to remember is that there is no known formula which will automatically give the ideal propeller size for a given boat. You can merely approximate. The only *true* test is the "trial and error" method.

To permit the reader to more intelligently reason through a specific propeller problem, a better understanding of the factors involved is necessary.

The major terms used when discussing propellers are:

1. Diameter
2. Pitch
3. Slip
4. Pitch Ratio

DIAMETER is twice the distance from the centerline of the propeller hub to the tips of the blade, or the diameter of the circle scribed by the tips of the blades.

PITCH is the angle the blade makes in relationship to the center line of the hub and is normally expressed as the distance, in inches, that the blade would advance in one revolution, if the propeller were a screw working in a solid substance. Thus, the theoretical distance in inches covered in one minute could be measured by RPM x pitch. However, we are not dealing with a solid and it is here that a loss of forward motion occurs known as "slip."

SLIP is the difference between the theoretical distance and actual distance covered in a given period of time. This relationship is usually expressed in a percentage calculated as follows:

$$\%\ \text{slip} = \frac{\text{Theoretical distance} - \text{Actual distance}}{\text{Theoretical Distance}}$$

$$\text{Where theoretical distance} = \frac{\text{Engine RPM}}{\text{Reduction Ratio}} \times \frac{\text{Pitch (inches)}}{12} \times \frac{60}{5280}$$

PITCH RATIO expresses the relation between the diameter and the pitch of the propeller. To obtain pitch ratio, divide the pitch by the diameter. If a 60" wheel has a pitch ratio of .7, it has a pitch of 42" (60 x .7) and is known as a 60 x 42 propeller.

A general guide in the selection of an approximate pitch ratio for various types of applications is as follows:

Deep water tug boat	.50—.55
River towboat	.55—.60
Heavy round bottom work boat....	.60—.70
Medium wt. round bottom work boat	.80—.90
Planing hull	.9—1.2

Of course, there are many variations of the above to meet operating conditions.

Remember, all propellers are a compromise. However, it is generally good practice to utilize the largest propeller diameter possible within practical limitations. These limitations are:

1. Size of aperture in which propeller is to be installed.

2. Type of operation—towboat, crewboat, pleasure craft, etc.
3. Shaft angle required for larger propeller.
4. Weight of propeller, shafting and gear boxes relative to boat's size.

Number of Propeller Blades

Three-bladed propellers are more efficient over a wider range of applications than any other propeller. Therefore, most of our calculations are based on this type of wheel.

In theory, the prop with the least number of blades (i.e. two) is the most efficient. Diameter and technical limitations, in most cases, make a greater number of blades necessary. Four and sometimes five-bladed propellers are used in cases where an objectionable vibration peak is developed within the operating range when using a three-blade propeller.

Four-bladed propellers are often used to increase blade area on tow boats operating in limited draft. They are also used on wood vessels where dead wood ahead of the propeller restricts water flow. However, two blades passing dead wood at the same time can cause objectionable hull vibration.

All other conditions being equal, the efficiency of a four-blade propeller is approximately 96% that of a three-blade propeller having the same pitch ratio and blades of the same proportion and shape.

A "rule of thumb" method for estimating four-blade propeller requirements is to select a proper three-blade propeller from propeller selection charts, then multiply pitch for the three-blade propeller by .914. Maximum diameter of a four-blade propeller should not exceed 94% of the recommended three-blade propeller's diameter. Therefore, we multiply diameter by .94 to obtain the diameter of a four-blade propeller.

For example, if a three-blade recommendation is:

48 x 34
Multiply pitch (34") by .914" = 31"
Multiply diameter (48") by .94" = 45"
Four-blade recommendation = 45" x 31"

As a word of caution, remember that this is a *general* rule . . . for estimating only. Due to the wide variation in blade area and contour from different propeller manufacturers, consult your particular manufacturer before final specifications are decided upon.

An old waterfront rule of the thumb for all propeller selection is:

"Towboats—big wheel, small pitch"
"Speedboats—little wheel, big pitch"

All other applications can be shaded between these two statements of extremes.

Propeller Tip Speed

Propeller tip speed is the speed, in MPH, travelled by the tips of the propeller blades. The greater the tip speed, the more power consumed in pure turning effort. A 30" propeller with a tip speed of 60 MPH will absorb about 12 horsepower in pure turning effort. This, in itself, is a horsepower loss because it contributes nothing to the forward thrust. Generally, propellers greater than 30" in diameter should not have a tip speed over 60 MPH. On smaller propellers, under 20", tip speeds should not exceed 120 MPH.

$$T = \frac{D \times \text{Shaft RPM} \times 60 \times 3.14}{12 \times 5280}$$

Where T = Tip speed in MPH
D = Propeller diameter in inches

Cavitation

When propeller rpm is increased to a point where suction ahead of the propeller reduces the water pressure below its vapor pressure, vapor pockets form, interrupting the solid flow of water to the propeller. This condition is known as cavitation.

One of the more common causes of cavitation is excessive tip speed (a propeller turning too fast for water to follow the blade contour). Cavitation can usually be expected to occur at propeller tip speeds exceeding 130 mph. Cavitation results in a loss of thrust and damaging erosion of the propeller blades.

Reduction Gears

Selection of the reduction gear ratio is one of the important decisions to be made in any marine power installation. A range of reduction ratios is normally provided to assure optimum performance under a given set of operating conditions. It is difficult to discuss selecting the proper reduction gear ratio without including several other factors. A partial listing of some of the other factors include: anticipated boat speed, type of boat, usage of boat, proper pitch ratio, propeller tip speed and engine horsepower. Figure 8 shows what reduction ratios will be found in typical boats operating today.

Propeller Overhang

The maximum distance from the stern bearing to the propeller should be limited to no more than one shaft diameter. Propeller shafts are apt to vibrate and produce a whip action if these limits are exceeded. This condition is greatly accelerated when a propeller is out of balance due to faulty machining or damage.

Multiple Propellers

The most efficient method of propelling a boat is by the use of a single screw. However, there are other factors which, when taken into consideration, make the use of a single propeller impossible.

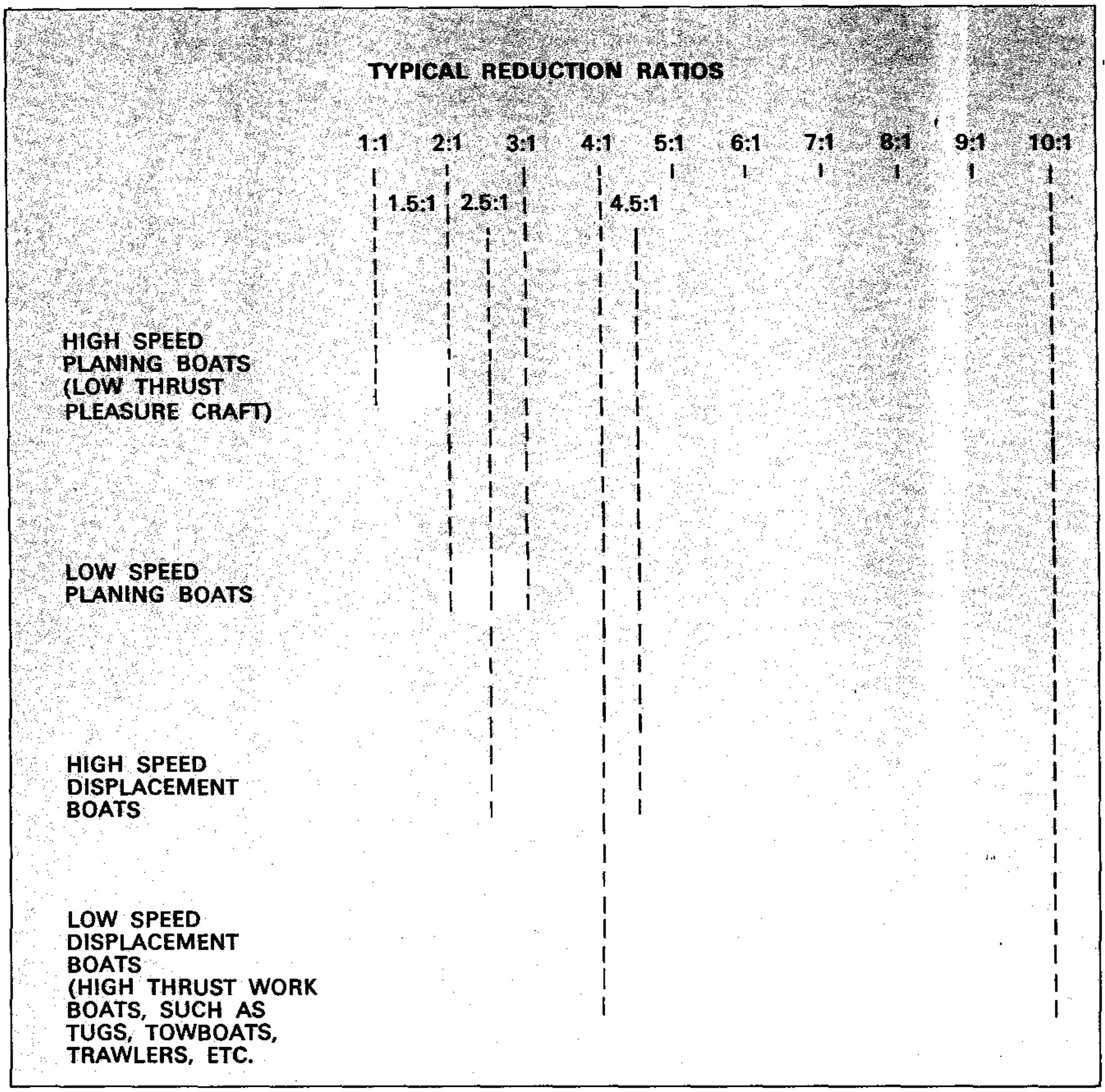


Figure 8

If a boat has to operate in shallow water, the diameter of the propeller is limited. Therefore, it can be necessary to install two and sometimes three propellers to permit a proper pitch ratio for efficient propulsion.

Another condition requiring multiple propellers is encountered when higher speed yachts need more horsepower than a single engine can develop and still be accommodated in the engine space.

As a general rule to follow for calculation in this text, total SHP of *all* engines is used when making estimated speed calculations. For calculating propeller size, SHP of *each* individual engine is used.

Propeller rotation is determined from behind the vessel, facing forward. The starboard side is on the right and the port side on the left. Rotation of the propeller is determined by the direction of the wheel when the vessel is in forward motion. Thus, a clockwise rotation would describe a right-hand propeller and a counter-clockwise rotation would be a left-hand propeller (Fig. 9).

Right-hand propellers are most frequently used in single screw installations. Twin screw vessels in the U.S. are normally equipped with outboard turning wheels. However, there are some installations where inboard turning wheels will be found.

A rotating propeller tends to drift sideways in the direction of the rotation. In a single screw vessel this can be partially offset by the design of the sternpost and the rudder. In a twin screw vessel this can be completely eliminated by using counter-rotating propellers.

The question of inboard and outboard rotating propellers has been debated many times. Authorities on the subject have agreed that there is little or no adverse effect in maneuverability with either rotation.

The connecting link in a boat's propulsion package is the propeller shaft. This portion of the drive train serves the dual function of transmitting engine torque to the propeller and propeller thrust to the thrust bearing.

Propeller shafts are classified into two groups, tailshafts and lineshafts. The section or sections of the shafting totally within the hull are termed lineshafts.

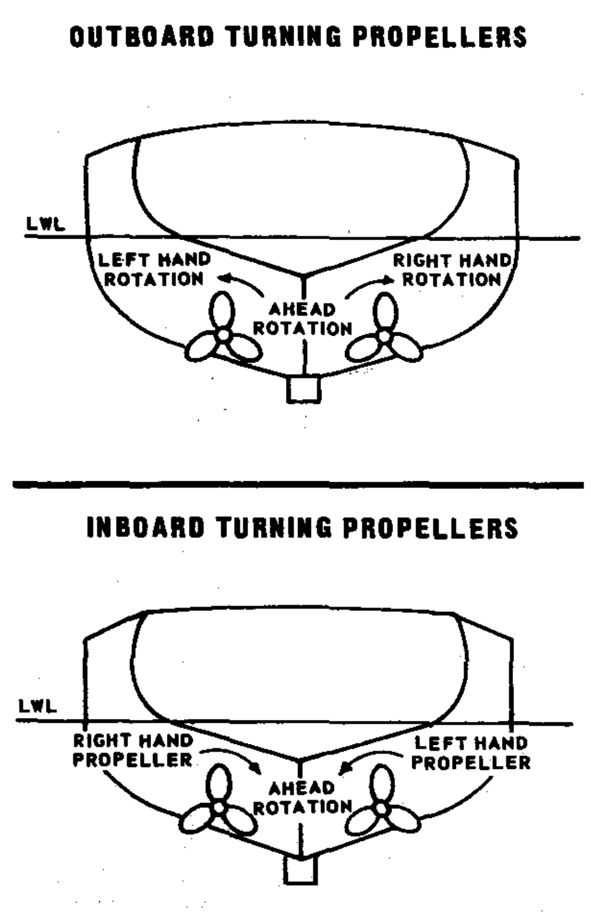


Figure 9

Tailshafts are that portion which is partially or totally exposed to water outside the hull. Because this section of the shaft is subjected to such erosive forces as water, sand, and bending movements due to propeller overhang, it is generally good practice to use a tailshaft that is heavier than the lineshaft.

Recommended shaft sizes for various shaft materials will be found in the nomograph labeled Figure 10.

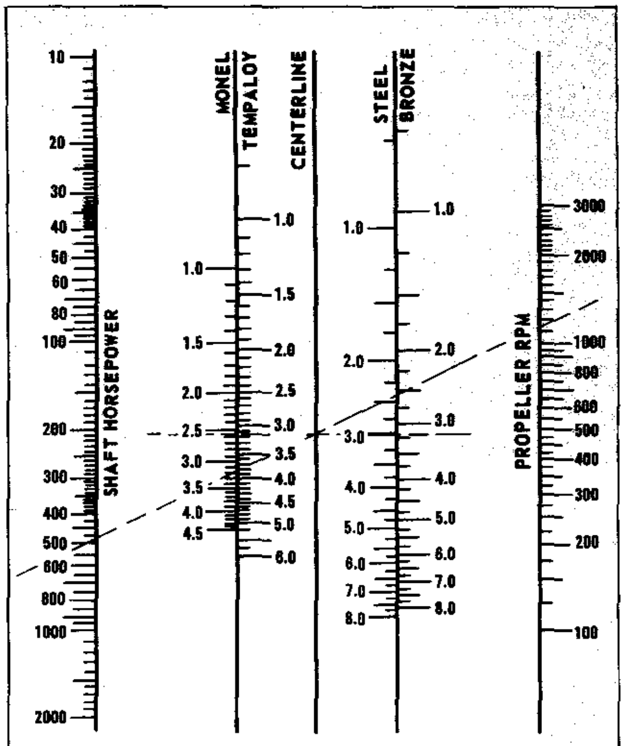


Figure 10

Instructions:
Rule a line connecting the selected S.H.P. and propeller RPM. At the point where this line intersects the center line, draw a horizontal line through the scales indicating tailshaft diameter, in inches, for the material to be used. Lineshaft diameters can generally be reduced by 5% from these values.

Example:
Select a bronze shaft for an engine with a rated S.H.P. of 478 at 2300 RPM, Light duty (Yacht) service, and 2:1 gear.

Solution: Using rated S.H.P. of 478

$$\text{Shaft RPM} = \frac{2300}{2} = 1150$$

Draw a line connectng 478 S.H.P. and 1150 RPM. From the point where this line intersects the centerline, draw a horizontal line through vertical shaft size scales as shown. Read 3.25 inches on scale marked bronze. Where necessary, correct to nearest standard shaft size.