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Standard Test Method for Knock Characteristics of Aviation Gasolines by the Supercharge Method[1]

This standard is issued under the fixed designation D 909; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the knock-limited power, under supercharge rich-mixture conditions, of fuels for use in spark-ignition reciprocating aircraft engines, in terms of ASTM supercharge octane or performance number. By operational considerations, this test method is restricted to testing fuels of 85 ASTM supercharge octane number and over.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Annex A7.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1368 Test Method for Trace Concentrations of Lead in Primary Reference Fuels[2]

D 2268 Test Method for Analysis of High Purity[3]

D 2599 Test Method for Lead in Gasoline by X-Ray Spectrometry [4]

D 2699 Test Method for Research Octane Number of Spark-Ignition Engine Fuel[5]

D 2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel[5]

D 3237 Test Method for Lead in Gasoline by Atomic Absorption Spectrometry[6]

D 3341 Test Method for Lead in Gasoline by the Iodine Monochloride Method[6]

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[6]

E 1 Specifications for ASTM Thermometers[7]

3. Terminology

3.1 *Definitions:*

3.1.1 *ASTM supercharge octane number of a fuel below 100*—the whole number nearest the percentage by volume of *iso*octane (equals 100) in a blend with *n*-heptane (equals 0) that matches the knock characteristics of the fuel when compared by this test method.

3.1.2 *ASTM supercharge rating of a fuel above 100*—the amount of tetraethyllead (TEL) in *iso*octane, expressed in millilitres per U.S. gallon.

3.2 ASTM supercharge ratings are normally expressed as octane numbers below 100 and as performance numbers above 100. At 100, a rating may be expressed either as 100 octane number or as 100 performance number. Sometimes it is desirable to convert the ASTM supercharge octane number to performance number. This can be done by using Table 1. Table 2 lists the corresponding performance numbers for various concentrations of tetraethyllead in *iso*octane.

4. Summary of Test Method

4.1 ASTM supercharge octane or performance number of a fuel is determined by comparing its knock-limited power with those for bracketing blends of reference fuels under standard operating conditions. This is done at constant compression ratio by varying the manifold pressure and fuel flow rate, the independent variables of the test, and measuring indicated mean effective pressure (imep) at enough points to define the mixture response curves for the sample and the reference fuels. When the knock-limited power for the sample is bracketed

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.01 on Combustion Characteristics.

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[2] Discontinued, see *1994 Annual Book of ASTM Standards*, Vol 05.01.

[3] Annual Book of ASTM Standards, Vol 05.01.

[4] Discontinued, Replaced by Test Method D 5059, see *1992 Annual Book of ASTM Standards*, Vol 05.02.

[5] *Annual Book of ASTM Standards*, Vol 05.05.

[6] *Annual Book of ASTM Standards*, Vol 05.02.

[7] *Annual Book of ASTM Standards*, Vol 14.03.

TABLE 1 ASTM Conversion of Octane Numbers to Performance Numbers

Octane Number	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Octane Number
						Performance Number					
70	48.3	48.4	48.4	48.5	48.6	48.7	48.8	48.9	49.0	49.0	70
71	49.1	49.2	49.3	49.4	49.5	49.6	49.6	49.7	49.8	49.9	71
72	50.0	50.1	50.2	50.3	50.4	50.5	50.5	50.6	50.7	50.8	72
73	50.9	51.0	51.1	51.2	51.3	51.4	51.5	51.6	51.7	51.8	73
74	51.9	51.9	52.0	52.1	52.2	52.3	52.4	52.5	52.6	52.7	74
75	52.8	52.9	53.0	53.1	53.2	53.3	53.4	53.5	53.6	53.7	75
76	53.8	53.9	54.1	54.2	54.3	54.4	54.5	54.6	54.7	54.8	76
77	54.9	55.0	55.1	55.2	55.3	55.4	55.6	55.7	55.8	55.9	77
78	56.0	56.1	56.2	56.3	56.5	56.6	56.7	56.8	56.9	57.0	78
79	57.1	57.3	57.4	57.5	57.6	57.7	57.9	58.0	58.1	58.2	79
80	58.3	58.5	58.6	58.7	58.8	58.9	59.1	59.2	59.3	59.4	80
81	59.6	59.7	59.8	60.0	60.1	60.2	60.3	60.5	60.6	60.7	81
82	60.9	61.0	61.1	61.3	61.4	61.5	61.7	61.8	61.9	62.1	82
83	62.2	62.4	62.5	62.6	62.8	62.9	63.1	63.2	63.3	63.5	83
84	63.6	63.8	63.9	64.1	64.2	64.4	64.5	64.7	64.8	65.0	84
85	65.1	65.3	65.4	65.6	65.7	65.9	66.0	66.2	66.4	66.5	85
86	66.7	66.8	67.0	67.2	67.3	67.5	67.6	67.8	68.0	68.1	86
87	68.3	68.5	68.6	68.8	69.0	69.1	69.3	69.5	69.7	69.8	87
88	70.0	70.2	70.4	70.5	70.7	70.9	71.1	71.2	71.4	71.6	88
89	71.8	72.0	72.2	72.4	72.5	72.7	72.9	73.1	73.3	73.5	89
90	73.7	73.9	74.1	74.3	74.5	74.7	74.9	75.1	75.3	75.5	90
91	75.7	75.9	76.1	76.3	76.5	76.7	76.9	77.1	77.3	77.6	91
92	77.8	78.0	78.2	78.4	78.7	78.9	79.1	79.3	79.5	79.8	92
93	80.0	80.2	80.5	80.7	80.9	81.2	81.4	81.6	81.9	82.1	93
94	82.4	82.6	82.8	83.1	83.3	83.6	83.8	84.1	84.3	84.6	94
95	84.8	85.1	85.4	85.6	85.9	86.2	86.4	86.7	87.0	87.2	95
96	87.5	87.8	88.1	88.3	88.6	88.9	89.2	89.5	89.7	90.0	96
97	90.3	90.6	90.9	91.2	91.5	91.8	92.1	92.4	92.7	93.0	97
98	93.3	93.6	94.0	94.3	94.6	94.9	95.2	95.6	95.9	96.2	98
99	96.6	96.9	97.2	97.6	97.9	98.2	98.6	98.9	99.3	99.6	99
100	100.0	...	...	...	...	...	...	...	...	...	100

Conversion Equation for Performance Number (PN):
PN = 2800/(128 − Octane number)

between those for two adjacent reference fuels suitably chosen from the prescribed list (see 12.1.2), the rating of the sample is calculated by interpolation at the fuel-air ratio for maximum power for the lower bracketing reference fuel.

5. Significance and Use

5.1 The supercharge test method provides a means of determining the rich-mixture antiknock performance of aviation gasoline. The test method utilizes a single-cylinder engine and requires critical adjustment of the fuel/air ratio and inlet-manifold pressure to establish the knock-limited power characteristic of the gasoline. The knock-limited power rating of the gasoline sample is determined by comparing its knock-limited power level with that of the knock-limited power level of primary reference fuels whose volumetric composition establishes the rating scale. The rating is expressed as an octane number at and below 100 and as a performance number above 100.

5.2 It is customary to express grades of aviation fuel in terms of double numbers. The first number expresses the antiknock quality by its lean-mixture or aviation rating, and the second by its rich-mixture or supercharge rating. See Test Method D 2700.

5.3 This test is used by engine manufacturers, by petroleum refiners and marketers, and in commerce as a primary specification measurement to ensure proper matching of fuel antiknock quality and engine requirement.

6. Apparatus

6.1 The knock testing unit illustrated in Fig. 1 consists of a single-cylinder engine with accessories mounted on a stationary base. It is equipped with controls for varying manifold pressure and fuel flow. The engine and equipment specified in Annex A1 on Apparatus shall be used without modification, and installed as directed in Annex A5 on Installation and Assembly. It is necessary to keep the apparatus in good mechanical condition as described in Annex A4 on Maintenance.

7. Reference Materials

7.1 *ASTM Knock Test Reference Fuels*, conforming to the specifications in A2.9.1 of Annex A2 on Reference Materials and Blending Accessories, are the following:

7.1.1 ASTM *iso*octane (2,2,4-trimethylpentane),

7.1.2 ASTM *n*-heptane,

7.1.3 ASTM 80 octane number blend of 7.1.1 and 7.1.2.

TABLE 2 ASTM Conversion of Tetraethyllead in Isooctane to Performance Numbers

Tetraethyl-lead in *Iso*octane, mL per U. S. gal	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	Tetraethyl-lead in *Iso*octane, mL per U. S. gal
					Performance Number						
0.0	100.0	100.4	100.8	101.2	101.6	102.0	102.4	102.8	103.2	103.6	0.0
0.1	104.0	104.3	104.7	105.0	105.4	105.7	106.1	106.4	106.8	107.1	0.1
0.2	107.4	107.8	108.1	108.4	108.7	109.0	109.3	109.6	109.9	110.2	0.2
0.3	110.5	110.8	111.1	111.4	111.7	111.9	112.2	112.5	112.8	113.0	0.3
0.4	113.3	113.6	113.8	114.1	114.3	114.6	114.8	115.1	115.3	115.6	0.4
0.5	115.8	116.1	116.3	116.5	116.8	117.0	117.2	117.4	117.7	117.9	0.5
0.6	118.1	118.3	118.6	118.8	119.0	119.2	119.4	119.6	119.8	120.0	0.6
0.7	120.2	120.4	120.6	120.8	121.0	121.2	121.4	121.6	121.8	122.0	0.7
0.8	122.2	122.4	122.6	122.8	122.9	123.1	123.3	123.5	123.7	123.9	0.8
0.9	124.0	124.2	124.4	124.5	124.7	124.9	125.1	125.2	125.4	125.6	0.9
1.0	125.7	125.9	126.1	126.2	126.4	126.5	126.7	126.9	127.0	127.2	1.0
1.1	127.3	127.5	127.6	127.8	127.9	128.1	128.2	128.4	128.5	128.7	1.1
1.2	128.8	129.0	129.1	129.3	129.4	129.6	129.7	129.8	130.0	130.1	1.2
1.3	130.2	130.4	130.5	130.7	130.8	130.9	131.1	131.2	131.3	131.5	1.3
1.4	131.6	131.7	131.8	132.0	132.1	132.2	132.4	132.5	132.6	132.7	1.4
1.5	132.9	133.0	133.1	133.2	133.3	133.5	133.6	133.7	133.8	133.9	1.5
1.6	134.1	134.2	134.3	134.4	134.5	134.6	134.8	134.9	135.0	135.1	1.6
1.7	135.2	135.3	135.4	135.6	135.7	135.8	135.9	136.0	136.1	136.2	1.7
1.8	136.3	136.4	136.5	136.6	136.7	136.8	137.0	137.1	137.2	137.3	1.8
1.9	137.4	137.5	137.6	137.7	137.8	137.9	138.0	138.1	138.2	138.3	1.9
2.0	138.4	138.5	138.6	138.7	138.8	138.9	139.0	139.0	139.1	139.2	2.0
2.1	139.3	139.4	139.5	139.6	139.7	139.8	139.9	140.0	140.1	140.2	2.1
2.2	140.3	140.4	140.4	140.5	140.6	140.7	140.8	140.9	141.0	141.1	2.2
2.3	141.1	141.2	141.3	141.4	141.5	141.6	141.7	141.8	141.8	141.9	2.3
2.4	142.0	142.1	142.2	142.3	142.3	142.4	142.5	142.6	142.7	142.8	2.4
2.5	142.8	142.9	143.0	143.1	143.2	143.2	143.3	143.4	143.5	143.6	2.5
2.6	143.6	143.7	143.8	143.9	143.9	144.0	144.1	144.2	144.2	144.3	2.6
2.7	144.4	144.5	144.6	144.6	144.7	144.8	144.8	144.9	145.0	145.1	2.7
2.8	145.1	145.2	145.3	145.4	145.4	145.5	145.6	145.7	145.7	145.8	2.8
2.9	145.9	145.9	146.0	146.1	146.1	146.2	146.3	146.4	146.4	146.5	2.9
3.0	146.6	146.6	146.7	146.8	146.8	146.9	147.0	147.0	147.1	147.2	3.0
3.1	147.2	147.3	147.4	147.4	147.5	147.6	147.6	147.7	147.8	147.8	3.1
3.2	147.9	148.0	148.0	148.1	148.2	148.2	148.3	148.3	148.4	148.5	3.2
3.3	148.5	148.6	148.7	148.7	148.8	148.8	148.9	149.0	149.0	149.1	3.3
3.4	149.2	149.2	149.3	149.3	149.4	149.5	149.5	149.6	149.6	149.7	3.4
3.5	149.8	149.8	149.9	149.9	150.0	150.1	150.1	150.2	150.2	150.3	3.5
3.6	150.3	150.4	150.5	150.5	150.6	150.6	150.7	150.7	150.8	150.9	3.6
3.7	150.9	151.0	151.0	151.1	151.1	151.2	151.2	151.3	151.4	151.4	3.7
3.8	151.5	151.5	151.6	151.6	151.7	151.7	151.8	151.8	151.9	152.0	3.8
3.9	152.0	152.1	152.1	152.2	152.2	152.3	152.3	152.4	152.4	152.5	3.9
4.0	152.5	152.6	152.6	152.7	152.7	152.8	152.8	152.9	153.0	153.0	4.0
4.1	153.1	153.1	153.2	153.2	153.3	153.3	153.4	153.4	153.5	153.5	4.1
4.2	153.6	153.6	153.7	153.7	153.8	153.8	153.9	153.9	154.0	154.0	4.2
4.3	154.1	154.1	154.1	154.2	154.2	154.3	154.3	154.4	154.4	154.5	4.3
4.4	154.5	154.6	154.6	154.7	154.7	154.8	154.8	154.9	154.9	155.0	4.4
4.5	155.0	155.1	155.1	155.1	155.2	155.2	155.3	155.3	155.4	155.4	4.5
4.6	155.5	155.5	155.6	155.6	155.6	155.7	155.7	155.8	155.8	155.9	4.6
4.7	155.9	156.0	156.0	156.0	156.1	156.1	156.2	156.2	156.3	156.3	4.7
4.8	156.4	156.4	156.4	156.5	156.5	156.6	156.6	156.7	156.7	156.7	4.8
4.9	156.8	156.8	156.9	156.9	157.0	157.0	157.0	157.1	157.1	157.2	4.9
5.0	157.2	157.2	157.3	157.3	157.4	157.4	157.5	157.5	157.5	157.6	5.0
5.1	157.6	157.7	157.7	157.7	157.8	157.8	157.9	157.9	157.9	158.0	5.1
5.2	158.0	158.1	158.1	158.1	158.2	158.2	158.3	158.3	158.3	158.4	5.2
5.3	158.4	158.5	158.5	158.5	158.6	158.6	158.7	158.7	158.7	158.8	5.3
5.4	158.8	158.9	158.9	158.9	159.0	159.0	159.0	159.1	159.1	159.2	5.4
5.5	159.2	159.2	159.3	159.3	159.3	159.4	159.4	159.5	159.5	159.5	5.5
5.6	159.6	159.6	159.6	159.7	159.7	159.8	159.8	159.8	159.9	159.9	5.6
5.7	159.9	160.0	160.0	160.1	160.1	160.1	160.2	160.2	160.2	160.3	5.7
5.8	160.3	160.3	160.4	160.4	160.4	160.5	160.5	160.6	160.6	160.6	5.8
5.9	160.7	160.7	160.7	160.8	160.8	160.8	160.9	160.9	160.9	161.0	5.9
6.0	161.0	...	...	...	...	...	...	...	...	...	6.0

7.2 *Tetraethyllead*, conforming to the specifications and requirements in A2.9.4 of Annex A2 on Reference Materials and Blending Accessories, blended with ASTM *iso*octane is required for making ratings above 100 octane number.

8. Sampling

8.1 Sampling shall be done in accordance with the applicable procedure described in Practice D 4057.

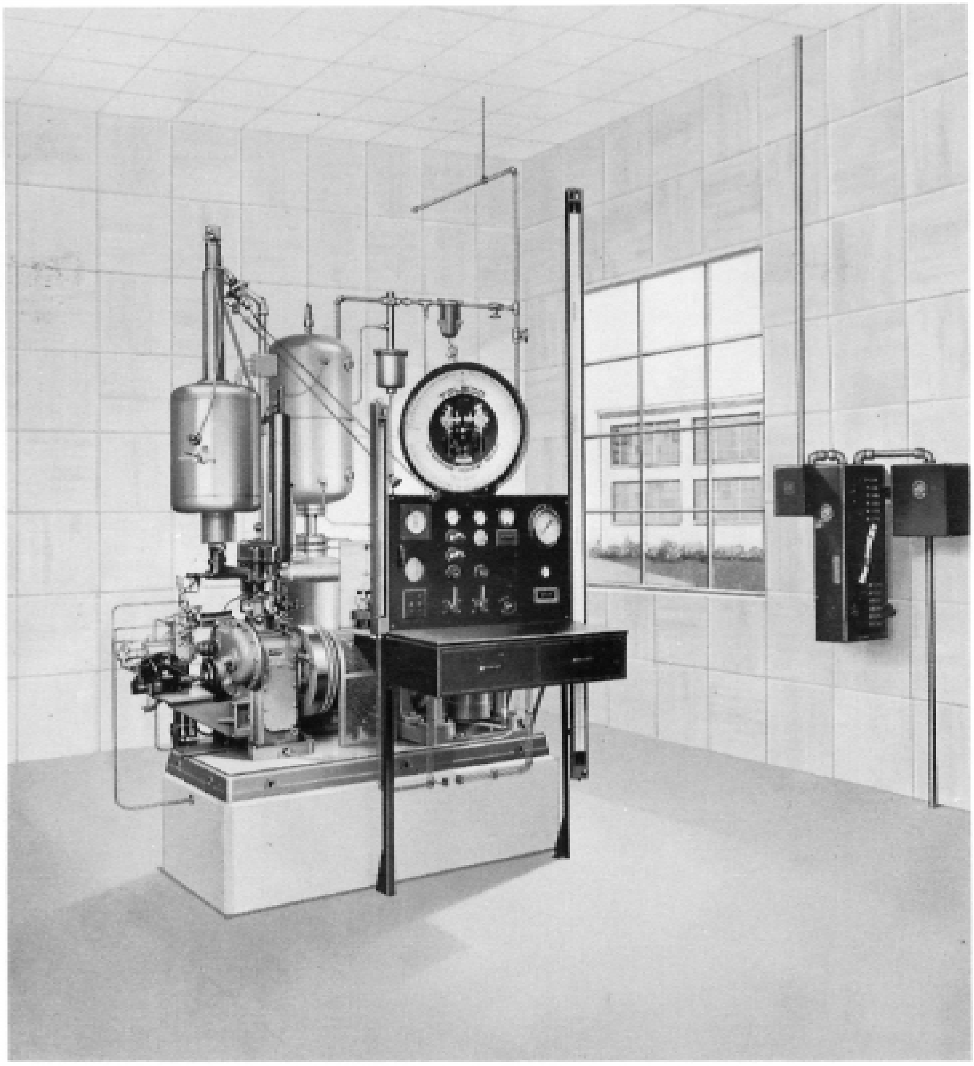


FIG. 1 Supercharge Unit

9. Operating Conditions

9.1 The following standard operating conditions (see Annex A3 on Operation for further details) are mandatory:

9.1.1 *Engine Speed*, 1800 ± 45 rpm, including friction measurement. The maximum variation throughout a test shall not exceed 45 rpm, exclusive of friction measurement.

9.1.2 *Compression Ratio*, 7.0 to 1, fixed by adjustment of the clearance volume to 108 ± 0.5 mL on cylinders of standard bore by the bench tilt procedure, Section A3.2 of Annex A3. Clearance volumes for oversize cylinders are shown in this section. If the Type D-1 detonation meter pickup is used, the clearance volumes are 2 mL less than for the Waukesha plug.

9.1.3 *Spark Advance*, constant, 45°.

9.1.4 *Spark-Plug Gap*, 0.020 ± 0.003 in. (0.51 ± 0.13 mm).

9.1.5 *Ignition Settings*:

9.1.5.1 *Breaker-Point Gap*, 0.020 in. (0.51 mm).

9.1.5.2 Breakerless ignition system basic setting for transducer to rotor (vane) gap is 0.003 to 0.005 in. (0.08 to 0.13 mm).

9.1.6 *Valve Clearances*, 0.008 ± 0.001 in. for the intake, 0.010 ± 0.001 in. for the exhaust, measured with the engine hot and running at equilibrium under standard operating conditions on a reference fuel of 100 octane number at the fuel-air ratio for maximum power and an absolute manifold pressure of 30 in. Hg (101.6 kPa).

9.1.7 *Crankcase Lubricating Oil*, SAE 50, having a kinematic viscosity of 16.77 to 24.96 cSt (mm^2/s) at 210°F (99°C) and a viscosity index of not less than 85. Oils containing viscosity index improvers or multi-graded oils shall not be used.

9.1.8 *Oil Pressure*, 60 ± 5 psi (0.41 ± 0.03 MPa) gage in the oil gallery leading to the crankshaft bearings.

9.1.9 *Oil Temperature*, 165 ± 5°F (74 ± 3°C) at the entrance to the oil gallery.

9.1.10 *Coolant Temperature*, 375 ± 5°F (191 ± 3°C) in the top of the coolant return line from the condenser to the cylinder.

9.1.11 *Fuel-Pump Pressure*, 15 ± 2 psi (0.10 ± 0.01 MPa) in the gallery.

9.1.12 *Fuel-Injector Opening Pressure*, 1200 ± 100 psi (8.2 ± 0.69 MPa) for Bosch nozzle; 1450 ± 50 psi (9.9 ± 0.34 MPa) for Ex-Cell-O nozzle.

9.1.13 *Fuel Injector Timing*—The pump plunger must close the fuel-inlet port at 50 ± 5° after top dead center (atdc) on the intake stroke.

9.1.14 *Air pressure*, 54.4 ± 0.5 psi (0.37 ± 0.003 MPa) absolute at the upstream flange tap of the air-flow meter.

9.1.15 *Air Temperatures*, 125 ± 5°F (52 ± 3°C) in the downstream leg of the air-flow meter and 225 ± 5°F (107 ± 3°C) in the intake-manifold surge tank.

9.1.16 *Intake Air Humidity*, 70 (max) grains of water/lb (0.00997 kg of water/kg) of dry air.

9.1.17 *Standard Knock Intensity*, light knock as determined by ear. In determining the light knock point, it is advisable to adjust first to a fairly heavy knock by varying either the manifold pressure or the fuel flow, return to knock-free operation, and finally adjust to the light-knock conditions. Light-knock intensity is a level definitely above the commonly defined least audible "trace knock;" it is the least knock that the operator can definitely and repeatedly recognize by ear. Knock-intensity indicators (see A1.15 of Annex A1) may be used as an aid to the ear in obtaining standard knock intensity.

9.1.18 *Satisfactory Engine Condition*—The engine should cease firing instantly when the ignition is turned off. If it does not, operating conditions are unsatisfactory. Examine the engine for defects, particularly for combustion chamber and spark plug deposits, and remedy such conditions before rating fuels.[8]

10. Starting and Stopping the Engine

NOTE 1—For protection of both the operator and the equipment, careful study of Annex A3 on Operation should be made.

10.1 *Starting the Engine*—Turn on the cooling water. While the engine is being motored by the dynamometer, turn on the ignition, and then start fuel injection and adjust the fuel-air ratio for maximum power by means of the fuel control knob.

10.2 *Stopping the Engine*—Avoid valve warpage and unnecessary heat stress by operating the engine on unleaded fuel for several minutes at atmospheric manifold pressure or below. Prevent excessive washing of the cylinder walls by stopping the fuel injection before turning off the ignition. To avoid possible corrosion and warping, close both valves by turning the flywheel to top dead center on the compression stroke. Turn off the cooling water.

11. Standard Engine Performance

11.1 With the operating conditions of Section 9 established, it is necessary that the engine performance fall within the limits prescribed in 11.1.1 and 11.1.2. Unless the power curve and the mixture response curves for the reference fuels conform to these limits, the test unit is unsatisfactory for rating fuels and corrective steps are necessary.

11.1.1 *Power Curve*, for *iso*octane plus 6 mL of tetraethyllead per U.S. gallon must show a peak of 164.5 ± 3 imep by varying the fuel flow and using standard operating conditions at a constant manifold pressure of 40 in. Hg (135.4 kPa) absolute (see Fig. 2 and Fig. 3).

11.1.2 *Knock-Limited Power Curves*—At all fuel-air ratios between 0.08 and 0.12, the knock-limited power curves for the reference fuel blends shall conform within ±5 % imep to those shown in the reference fuel framework (see Fig. 4). This framework has been established for ASTM supercharge knock test units operating under properly standardized conditions. The imep spread between any two adjacent reference fuel curves as determined with the engine shall agree with the spread of the corresponding framework curves within ±30 % of the latter value.

12. Determination of Knock-Limited IMEP

12.1 Obtain the knock-limited imep of a fuel at any test point by operating the engine at the fuel-air ratio and manifold pressure required for standard knock intensity.

12.1.1 *Stabilization of Conditions*—After standard knock intensity has been obtained, it is necessary to stabilize engine temperatures. During this period minor adjustments of the manifold pressure and fuel flow may be required to maintain standard intensity.

12.1.2 *Observations*—When the conditions have been stabilized, record observations for determination of test results and control of engine operation. Brake and friction torques, and fuel- and air-flow rates are required for fuel ratings; coolant, oil, and intake-air temperatures, and oil and absolute manifold pressures are desirable as indications of operating conditions. To ensure that the test points are adequately defining the knock-limited power curve, plot the curve as the points are determined.

12.1.3 *Power Determination*—Engine power output is expressed as imep, which is defined as the sum of the brake and friction measurements. Determine brake torque at the stabilized knock condition from the scale reading of the power absorbing unit, and express it as brake mean effective pressure (bmep). Determine the torque required to motor the engine from the scale reading of the power absorbing unit after each brake torque determination by quickly stopping the fuel injection and motoring the engine. Read the friction torque and express it as friction mean effective pressure (fmep).

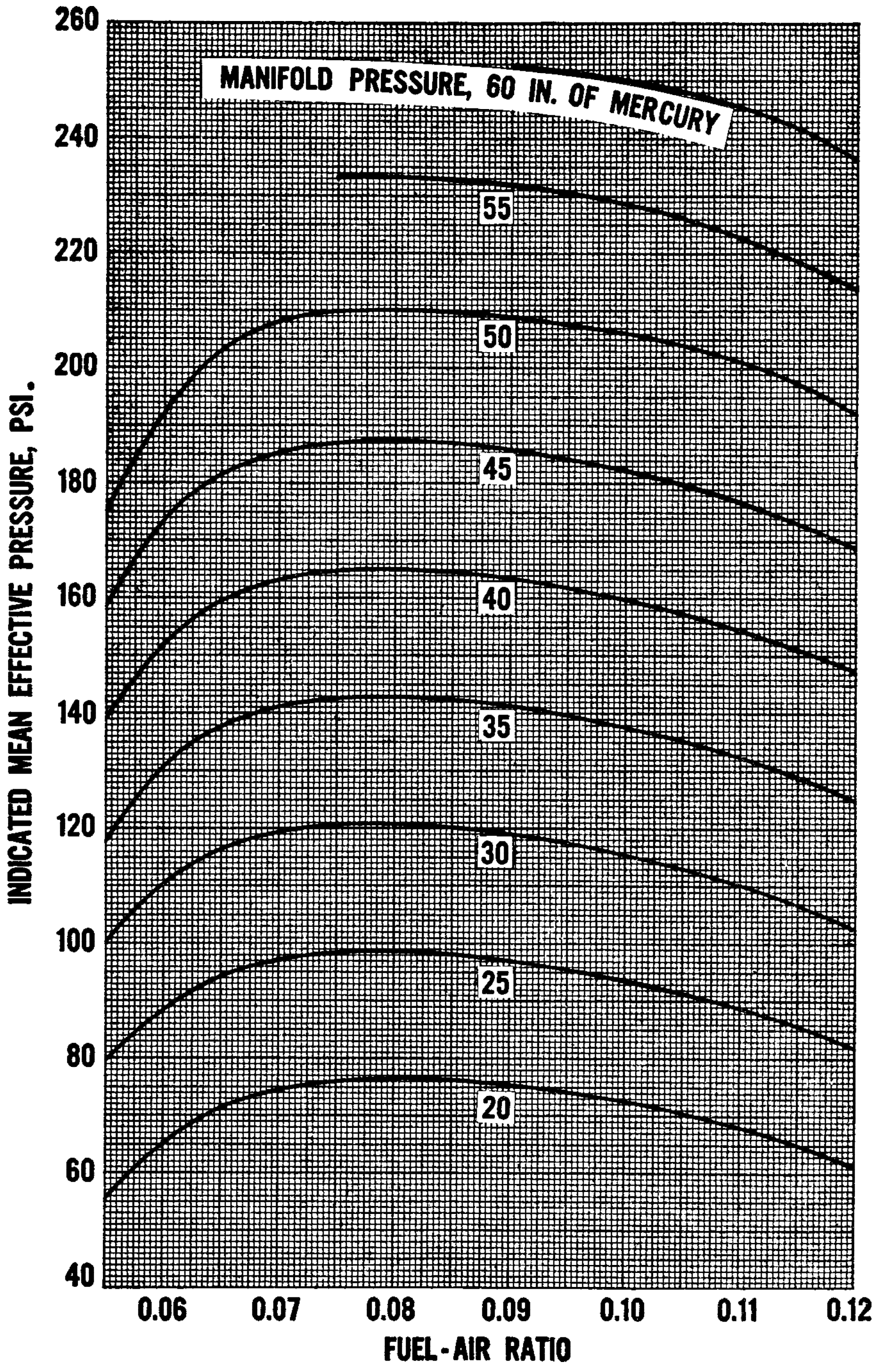
12.1.4 *Fuel-Air Ratio*—The ratio of the weights of fuel and air supplied to the engine during equal operating intervals is the fuel-air ratio. With the engine operating under the stabilized knock conditions, determine the fuel- and air-flow rates by observing the respective measuring devices. In practice, the air- and fuel-flow rates are recorded as minutes per 0.25 lb (0.11 kg) of air and minutes per 0.25 lb (0.11 kg) of fuel, thus allowing the calculation of fuel-air ratio directly from the data.

13. Rating a Sample

13.1 Obtain knock-limited power curves for the sample and two bracketing reference fuels as follows:

13.1.1 *Knock-Limited Power Curve for Sample*—Determine the knock-limited power curve for the sample from a series of knock-limited imep points established by the procedure and

[8] Copies of this framework are avilable in pads of 50 8½ by 11 in. data sheets from ASTM International Headquarters. Request PCN ADJD090902.



These Curves are for *Iso*octane plus 6.0 mL of Tetraethyllead per U.S. Gallon.

FIG. 2 Average Power Curves at Several Constant Manifold Pressures

accompanied by the control observations outlined in 12.1.2. This curve corresponds to that of Fig. 5, determined by points 1 to 6. The knock-limited imep points should be distributed throughout a fuel-air ratio range from approximately 0.08 to 0.12 to define the knock-limited power curve. The following plan of testing, with the points determined in the order mentioned, has been found most satisfactory:

13.1.1.1 *Determine the First Point* on the knock-limited power curve at approximately 0.08 fuel-air ratio by adjusting the mixture control of the fuel pump at an arbitrarily selected manifold pressure until maximum brake torque is obtained. If knock occurs, reduce the manifold pressure and continue the adjustment of the fuel pump until a maximum brake torque is obtained without knock. Maintaining this setting, increase the manifold pressure until standard knock is obtained, checking as required in 9.1.17. When equilibrium has been reached, record the observations.

13.1.1.2 *To Determine Additional Points,* adjust the mixture control of the fuel pump to enrich the mixture and increase the manifold pressure by arbitrary increments (see Fig. 5, Points 2,

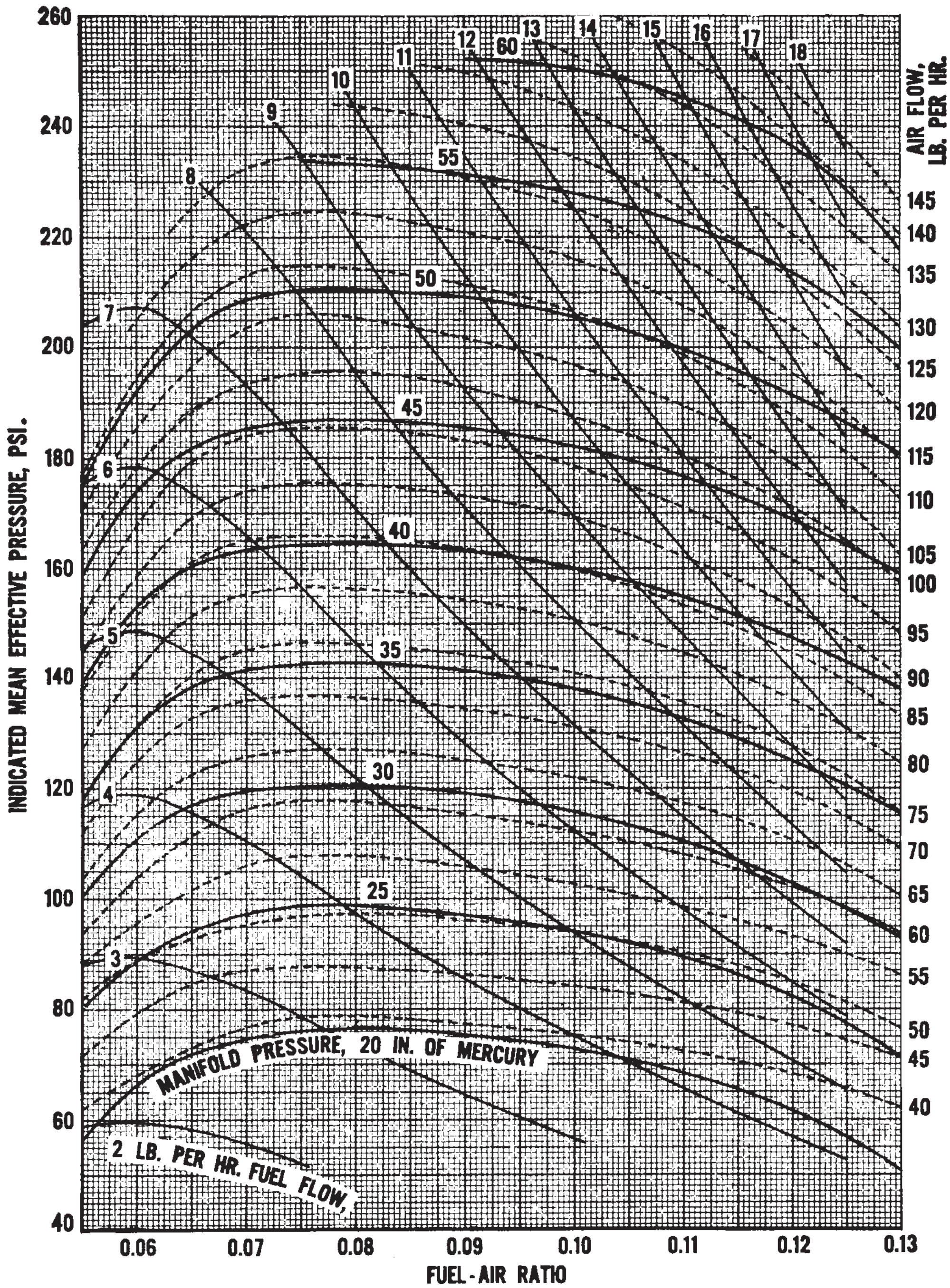


FIG. 3 Average Power, Fuel Flow, and Air Flow Curves at Several Constant Manifold Pressures

3). Following each change, slowly adjust the mixture until standard knock intensity is obtained, checking as required in 9.1.17. When equilibrium has been reached, record the observations. Near the peak of the knock-limited power curve (see Fig. 5, Points 4, 5, 6), it is more convenient to change the mixture control of the fuel pump by arbitrary increments and adjust the manifold pressure for standard knock intensity. When equilibrium has been reached, record the observations. At very rich mixtures make certain that the engine is firing regularly. At least six points are required to define the knock-limited power curve. Four should be on the rising portion of the curve and two at richer mixtures to determine accurately the maximum imep and the fuel-air ratio at which it occurs.

13.1.2 *Knock-Limited Power Curves for Reference Fuels*—Immediately bracket the knock-limited power curve of the test sample by determining those for two *adjacent* blends of reference fuels selected from the following list:

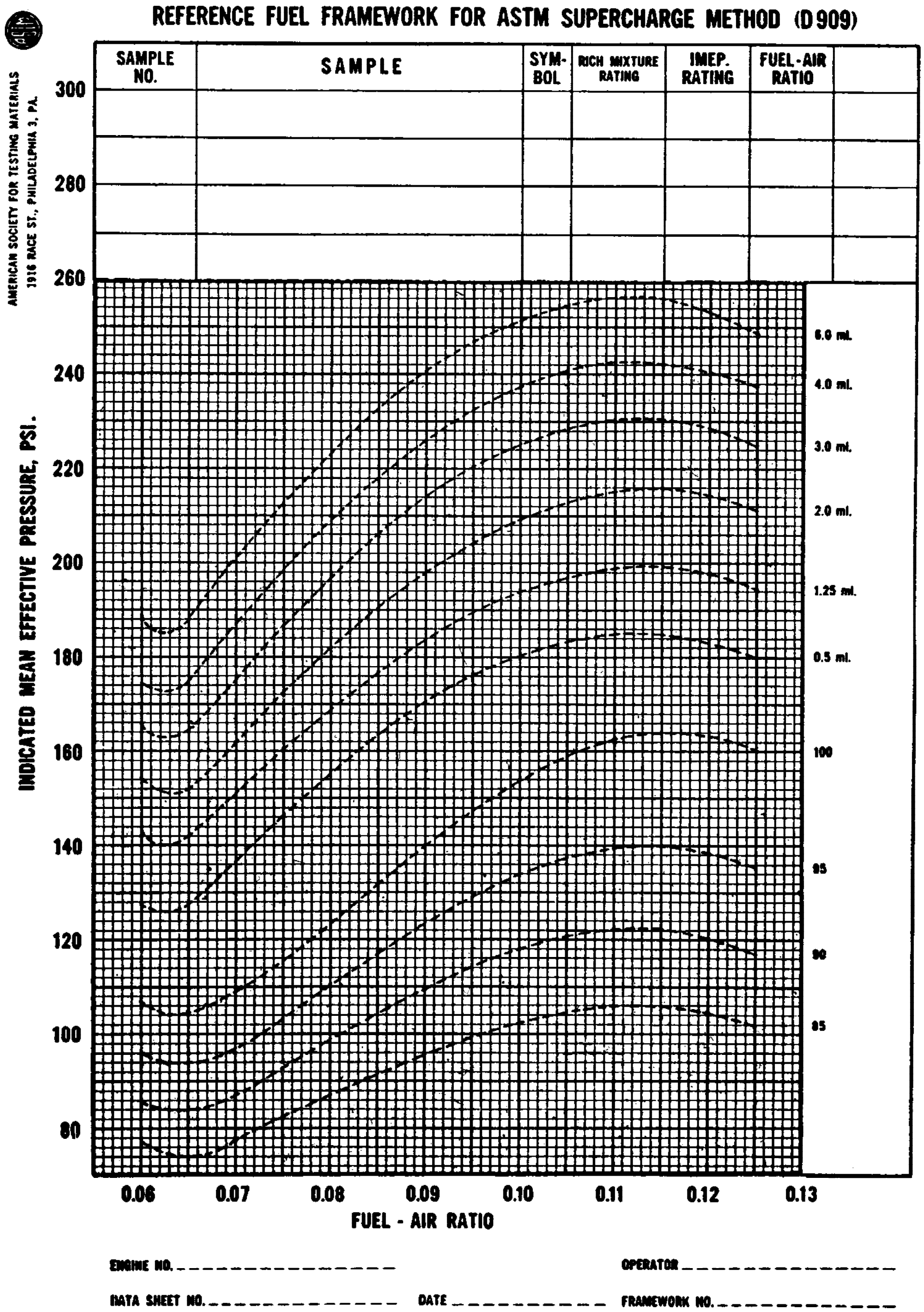


FIG. 4 Reference Fuel Framework[4]

ASTM *Iso*octane , vol %	ASTM *n*-Heptane , vol %	Tetraethyllead in *Iso*octane , mL/U.S. gal
85	15	...
90	10	...
95	5	...
100	...	...
100	...	0.5
100	...	1.25
100	...	2.0
100	...	3.0
100	...	4.0
100	...	6.0

Only these blends, prepared from the ASTM knock test reference fuels (see Section 8) may be used. The TEL content shall be determined by Test Method D 2599, D 3237, or D 3341.

14. Calculation and Report

14.1 Plot the knock-limited power curves for the sample and the bracketing reference fuels as a graph with fuel-air ratio as the abscissa and knock-limited imep as ordinate (see Fig. 4). The rating of the sample at any fuel-air ratio is that of the ASTM reference fuel which would result in the same imep

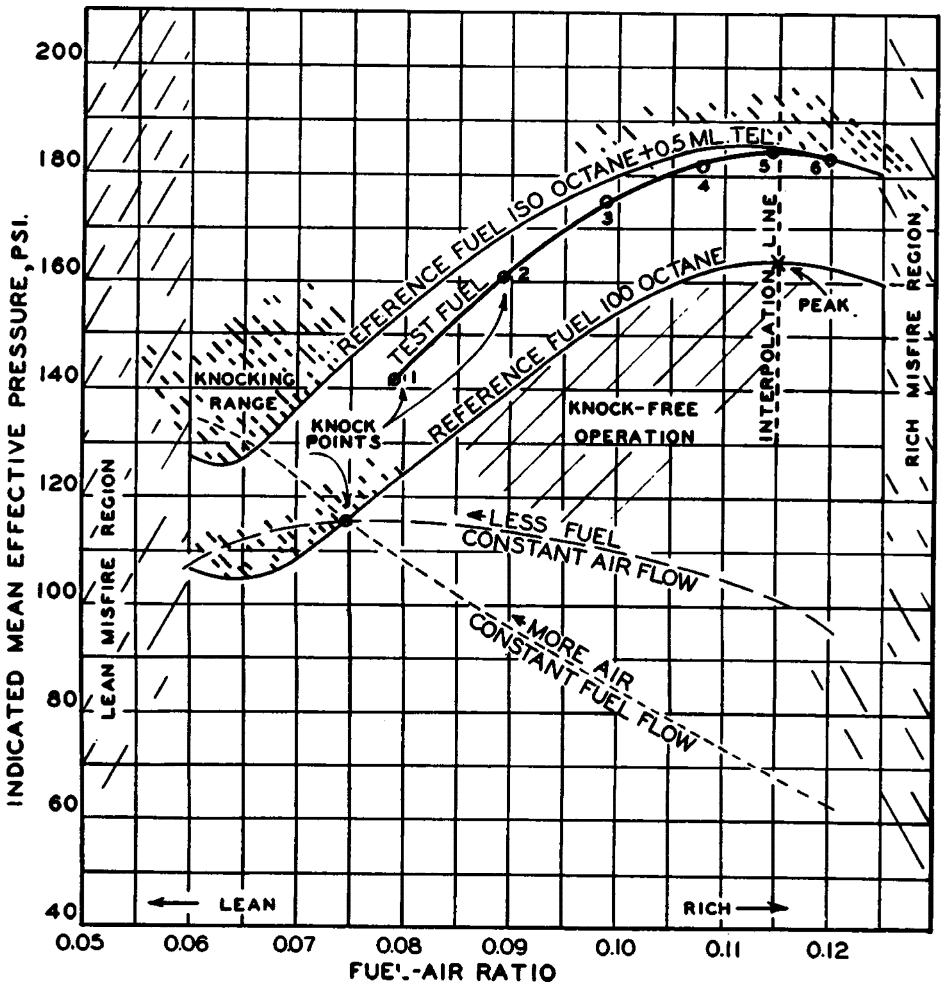


FIG. 5 Development of Knock-Limited Power Curves

when the engine is operated at standard knock intensity at the same fuel-air ratio as the sample. Determine the ASTM supercharge rating of the sample by linear interpolation between the knock-limited imep values for the sample and the bracketing reference fuels at the fuel-air ratio for maximum knock-limited imep of the lower-bracketing reference fuel. When the curve for the sample is above that for the upper-bracketing reference fuel at the fuel-air ratio for the peak of the lower-bracketing reference fuel, make the interpolation by using the imep at the intersection of the curve for the sample and a straight line connecting the peaks of the bracketing reference fuel curves.

14.2 Report ratings below 100 octane number to the nearest integer. When the interpolated figure ends with 0.50, round to the nearest even number; report for example, 91.50 as 92, not 91.

14.3 Report ratings above 100 octane number in concentrations of TEL per U.S. gallon rounded to the nearest 0.01 mL TEL/gal. Convert these ratings to performance numbers using Table 2.

15. Precision and Bias

15.1 *Precision*:

15.1.1 *Repeatability*—In the range from 1.25 to 2.00 mL TEL/U.S. gal (129.6 to 138.4 performance number), the difference between two test results obtained by the same operator with the same engine under constant operating conditions on identical test specimens within the same day would, in the long run, in the normal and correct operation of the test method, exceed 0.145 mL TEL/U.S. gal in only one case in twenty. Since the relationship between mL TEL/U.S. gal and performance number is not linear, representative repeatability statistics in units of performance number are tabulated in Table 3.

15.1.2 *Reproducibility*—In the range from 1.25 to 2.00 mL TEL/U.S. gal (129.6 to 138.4 performance number), the difference between two single and independent test results obtained by different operators in different laboratories on

TABLE 3 Repeatability and Reproducibility Values

Supercharge Rating		Repeatability		Reproducibility	
ML TEL/US gal.	PN	ML TEL/US gal.	PN	ML TEL/US gal.	PN
1.25	129.6	0.14	2.0	0.23	3.2
1.30	130.2	0.14	1.9	0.26	3.6
1.40	131.6	0.14	1.8	0.32	4.2
1.50	132.9	0.14	1.7	0.39	5.0
1.60	134.1	0.14	1.7	0.48	5.6
1.70	135.2	0.14	1.6	0.57	6.6
1.80	136.3	0.14	1.5	0.68	7.3
1.90	137.4	0.14	1.5	0.80	8.2
2.00	138.4	0.14	1.3	0.93	9.2

identical test specimens would, in the long run, in the normal and correct operation of the test method, exceed the value of R in only one case in twenty, where R is defined by the equation

$$R = 0.116x^3 \tag{1}$$

where
x = the average of the two test results in mL TEL/U.S. gal.

15.1.2.1 The reproducibility values in Table 3 exemplify the values of R over the applicable range. Since reproducibility varies with level and the relationship between mL TEL and performance number is not linear, reproducibility limits in units of performance number are also tabulated in Table 3.

15.1.3 *Interlaboratory Test Program*—The above precision statements are based on test results obtained by the ASTM Aviation National Exchange Group from 1988 to 1998. During this period, four aviation gasoline samples having supercharge ratings in the range from 1.25 to 2.00 mL TEL/U.S. gal were tested each year by 15–23 participating laboratories. A report of the data and analysis used to establish the precision statements is available as a research report.[9]

15.1.4 *Precision Below 1.25 mL TEL/U.S. Gal and Above 2.00 mL TEL/U.S. Gal*—There is not sufficient data to establish the precision of this test method for samples having supercharge ratings below 1.25 mL TEL/U.S. gal or above 2.00 mL TEL/U.S. gal.

15.2 *Bias*:

15.2.1 This test method has no bias because the supercharge rating of aviation gasoline is defined only in terms of this test method.

[9] Available from ASTM International Headquarters. Request RR:D02–1467.

ANNEXES

(Mandatory Information)

A1. APPARATUS

A1.1 APPARATUS

A1.1.1 The apparatus described in this annex is to be used without modification. It consists of a single cylinder engine and accessories mounted on a stationary base. It is equipped with controls for varying manifold pressure, fuel flow, and loading. Suitable instruments are provided for the measurement of these variables. The complete unit is known as the "ASTM-CFR Engine" and is marked by a plate or other approved means with a combination of the respective emblems of the American Society for Testing and Material and the Coordinating Fuel Research Committee, thus:

A1.1.2 At present the sole authorized manufacturer of the ASTM-CFR engine is the Waukesha Engine, Dresser Inc., 1000 West Street, Paul Ave., Waukesha, WI 53188. Other manufacturers may be approved in the future, but testing laboratories should not purchase testing units, except from the Waukesha Engine, Dresser Inc., without ascertaining whether such units have been approved. Inquiries in this connection should be directed to Secretary, Committee D-2 on Petroleum Products and Lubricants, 2101 L Street, N.W., Washington, DC 20037.

A1.1.3 All necessary instruments and accessories are furnished with the unit. A parts list for ASTM-CFR engines can be obtained from the Waukesha Engine Div.

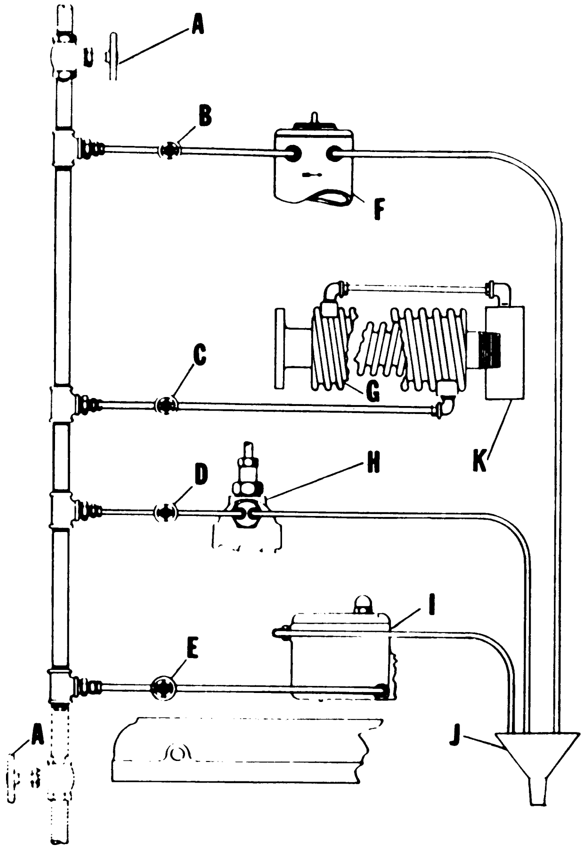
A1.1.4 Subsequent sections of this annex describe the specific units of the apparatus that are to be used. A summary of equipment for this test method appears in Table A1.1.

TABLE A1.1 Summary of Preferred Equipment for Supercharge Engine

Cylinder	variable compression
Valve gear	enclosed or open
Rocker arm bushing	needle
Intake valve	plain, with rotator
Exhaust valve	sodium cooled, with rotator
Valve felts	both valves
Piston	aluminum
Compression rings:	
Type	wedge
Number required	3
Oil control rings:	
Type	wedge
Number required	2
Crankcase	CFR-48
Rotating balance weights	CFR-48, light
Camshaft, deg overlap	30
Ignition	capacitor discharge
Spark plug (Champion):	
Type	M76R
Copper gasket	solid
Humidity control	compressed air
Fuel system	manifold injection
Pump timing	inlet port closes at 50 ± 5 deg atdc, inlet stroke
Injection pump:	8
Plunger diameter, mm	0.100 to 0.116
Lift at port closure, in	Bosch, ADNOSD 21
Injector	
Injector line	⅛
Bore, in	20 ± 2
Length, in	

A1.2 Cylinder Cooling System

A1.2.1 The evaporative cooling system is equipped with a flexible coolant return pipe and a water-cooled reflux condenser above the coolant level to provide sufficient cooling capacity. Ethylene glycol is used as the coolant. A diagram of the cooling system is shown in Fig. A1.1.



A—Optional Locations of Main Water Valve.
B—Control Valve to Condenser.
C—Control Valve to Exhaust Manifold.
D—Control Valve to Supercharge Fuel Cooler.
E—Control Valve to Oil Cooler.
F—Coolant Condenser.
G—Water Jacketed Exhaust Manifold.
H—Supercharge Fuel Injection Pump.
I—Oil Cooler.
J—Drain to Sewer.
K—Exhaust Spray Ring.

FIG. A1.1 Typical Diagram of Cooling System.

A1.3 Crankcase Ventilation

A1.3.1 The CFR-48 crankcase is equipped with lip-type oil seals and a breather valve.

A1.3.2 Crankcase ventilation is furnished by a breather valve at A, Fig. A1.2, on the left crankcase door. The breather valve assembly uses a hollow cup made of plastic which is installed open end downwards so that its lift is limited by the screw on the cap. The outlet is fitted for a ¾-in. pipe to conduct the crankcase vapors out of the laboratory and must not be connected to the engine exhaust. A condensation trap should be provided to prevent moisture from running back into the crankcase.

A1.4 Engine Specifications

A1.4.1 A single cylinder engine of continuously variable compression ratio is specified. Descriptive dimensions are listed in Table A1.2.

A1.5 Cylinder

A1.5.1 The cylinder is made in one piece integral with the cast-iron head, bored and honed, and has a Brinell hardness of 196 to 269. Cylinders of standard bore are preferred equipment, but rebored cylinders up to a maximum of 0.030 in. oversize may be used. *A micrometer*, suitably mounted, is used to measure the height of the cylinder with respect to the piston.

A1.6 Piston and Rings

A1.6.1 *Piston*—The five-ring, aluminum-alloy piston has a full floating hollow piston pin held in position by piston-pin retainers. Piston clearances are:

Top land	0.022 ± 0.002 in.
Intermediate lands	0.017 ± 0.002 in.
Skirt	0.011 ± 0.0005 in.

A1.6.2 *Rings*—Three wedge type compression rings and two wedge type oil control rings are required. The set consists of a chromium-plated top compression ring, two plain compression rings, and two narrow-faced oil control rings. When new, ring-gap clearances are 0.015 to 0.020 in. for the compression rings, and 0.010 to 0.018 in. for the oil rings.

A1.7 Valves and Valve Seats

A1.7.1 The intake valve (⅜-in. stem) is Stellite faced. The sodium-cooled exhaust valve (7⁄16-in. stem) is Eatonite faced. Both valve-seat inserts are made of solid Stellite.

A1.7.2 The standard face angle for values and inserts is 45°.

A1.8 Valve Guides, Springs, and Push Rods

A1.8.1 *Valve Guides*—The cast-iron alloy valve guides are heat treated and hardened. They are pressed into the cylinder with the shoulder on the guide not quite touching the cylinder to prevent distortion.

A1.8.2 *Valve Springs*—The valve springs are treated to resist corrosion.

A1.8.3 *Push Rods*—Push rods with lock-nut adjustments are used.

A1.9 Wiring Diagram

A1.9.1 The wiring diagram of the safety control, compensator, and heater circuits is shown in Fig. A1.3.

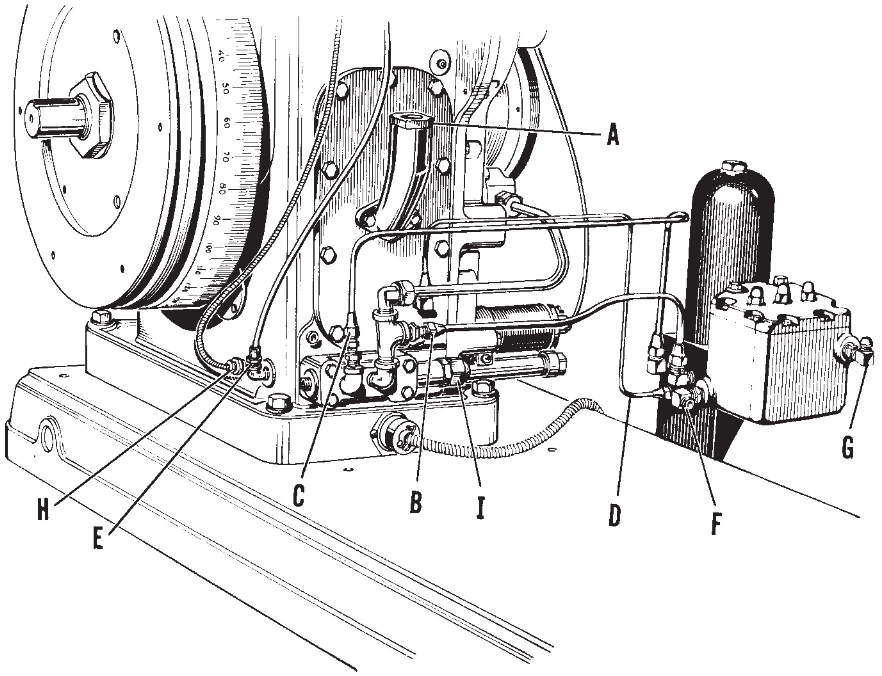
A1.10 Ignition System

A1.10.1 A coil ignition system is preferred. The Bendix CBR 4-1 magneto, shown in Fig. A1.4, may also be used. Type M76R spark plug manufactured by the Champion Spark Plug Co. is used with a solid copper gasket. A neon tube spark indicator is built into the engine.

A1.11 Exhaust System Components

A1.11.1 *Flexible Exhaust Pipe*—A water-cooled flexible exhaust pipe, 1¼-in. minimum internal diameter and about 18 in. (457 mm) long, must be used. The special flange and spacer shown in Fig. A1.5 is used for the connection to the surge tank. A quick-opening ¾-in. pipe valve may be installed in the flexible exhaust pipe, as shown, to check for resonance. If the indicated power is altered appreciably when the valve is opened, discharging the exhaust to the atmosphere, resonance is indicated and the system must be altered to correct it.

A1.11.2 *Water Spray*—Experience has shown that the use of water injection is advantageous. The brass ring for water injection is illustrated in Fig. A1.5. Water injection is accomplished by the brass spray plate bolted between the flange to the



CFR-48 CRANKCASE

A—Breather.
B—Oil Line to Cooler—Filter.
C—Cooled Oil Return to Engine.
D—Filtered Oil Return to Engine.
E—Oil Pressure Gage Line.
F—Cooling Water Inlet.
G—Cooling Water Outlet.
H—Thermal Bulb of Oil Temperature Indicator.
I—Oil Pressure Adjustment.

FIG. A1.2 Lubrication System Connections for Engines Using By-Pass Type Oil Filter with Integral Cooler.

TABLE A1.2 Engine Specifications

	CFR-48	High-Speed Engine
Compression ratio	variable	variable
Standard bore, in	3.25	3.25
Stroke, in	4.50	4.50
Displacement, cu in	37.33	37.33
Valve seat insert, ID, in	1.187	1.187
Connecting-rod bearing:		
diameter, in	2.50	2.50
length, in	1.625	1.625
Front main bearing:		
diameter, in	3.00	2.50
length, in	2.50	2.25
Rear main bearing:		
diameter, in	3.00	2.50
length, in	3.031	4.906
Piston pin, floating, diameter, in	1.25	1.25
Connecting-rod, center-to-center, in	10.00	10.00
Timing-gear face, in	1.00	1.00
Piston rings, number	5	5
Valve ports, minimum diameter, in	1.25	1.25
Spark plug size, mm	18	18
Weight of engine (approx), lb	880	650
Weight of complete unit (approx) lb	4850	4650

flexible exhaust pipe and the surge tank inlet. Spray holes direct the water spray toward the centerline of the exhaust pipe and away from the engine.

A1.11.3 *Surge Tank*—The surge tank has a minimum inside diameter of 10 in. (254 mm), a minimum outside diameter of 10 ¾ in. (273 mm) and a minimum volume of 1 ft^3 (0.02 m^3), Fig. A1.6. It should be mounted horizontally, if possible, and rigidly supported to avoid strain on the flexible exhaust pipe which should slope downward from the engine about ¼ in. A trap should be provided in all water drain lines.

A1.11.4 *Exhaust Back Pressure*—The exhaust back pressure at the surge tank should be as low as possible, but in no case should it be outside the limits of 0 to 10 in. (254 mm) of water.

A1.11.5 *Discharge Pipe*—To comply with A1.11.4, it is desirable to use a discharge pipe of 2-in. (50.8-mm) minimum diameter, 30 ft (9.14 m) maximum length, and containing no more than three elbows or other restrictions. It is desirable to have a separate exhaust system for each engine. If a discharge pipe is used for a multiple exhaust system, adequate capacity must be provided, so that the back pressure can be maintained within the limits set in A1.11.4.

A1.12 Fuel Supply System

A1.12.1 Fuel is injected into the intake elbow of the induction system by an injection pump and nozzle (see Fig. A1.7). The fuel-injection line is made of steel tubing having an inside diameter of 0.125 in. and length of 20 ± 2 in. (508± 50.8 mm). The injection pump is connected to the engine with a flexible drive coupling. A small circulating pump supplies fuel to the injection pump from the fuel container shown in Fig. A1.8. A system of valves in the supply and return lines, and a fuel weighing device (see Fig. A1.9), permit measurement of fuel consumption.

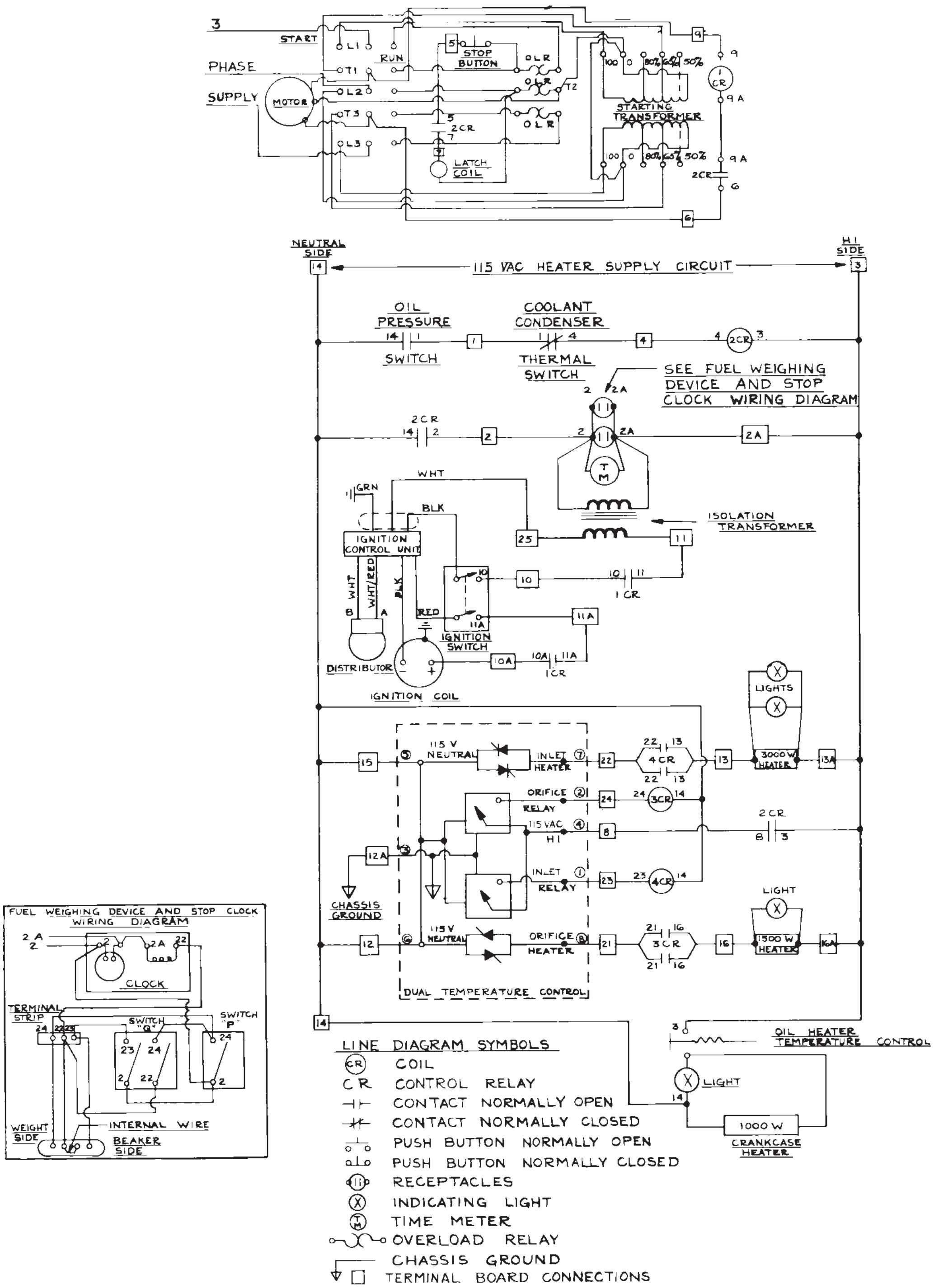
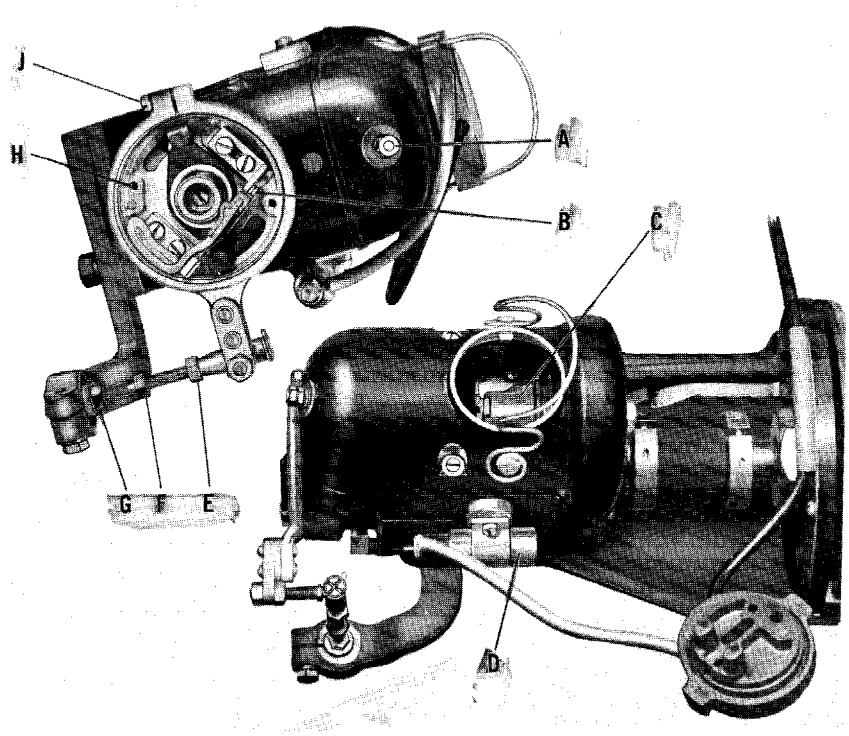


FIG. A1.3 Wiring Diagram for Supercharge Unit

The entire fuel system is controlled at the panel board of the engine, and involves manipulation of two three-way valves, two switches, and a weight lever for the fuel scales. Two filters protect the delicate parts of the fuel-injection pump, one of the edge type at the supply can, and the other a sintered bronze filter at the injection pump. A pump circulates SAE 30|☐ oil to lubricate the plunger of the injection pump.



A—Ground wire terminal
B—Breaker points
C—Distributor
D—Resistor
E—Upper timing adjustment locknut
F—Timing adjustment screw
G—Lower timing adjustment locknut
H—Breaker point plate
J—Timing adjustor clamp screw

FIG. A1.4 Magneto

A1.13 Intake Air Heaters

A1.13.1 Two thermostatically controlled heaters (1500 W and 3000 W) are used to preheat the air to the correct temperature before it enters the engine.

A thermometer having a range from 100 to 300°F (38 to 149°C) and graduated in 2°F (or 1°C) divisions, 85F or 85C in Table A1.3, is mounted in the surge tank as indicated by *DD*, Fig. A1.10.

A1.14 Air Induction System

A1.14.1 The air induction system is shown in Fig. A1.11. Air under pressure with a maximum of 70 grains of moisture per pound (0.00997 kg of water per kilogram) of dry air enters the induction system through filter *M* to eliminate entrained solids, and then passes through an auto-regulating valve *L* before entering the air flowmeter. This consists of an ASME sharp-edge orifice *G* in a flange mounting, connected to water manometer *F*. The manometer is calibrated in minutes per 0.25 lb of air thus simplifying calculation of fuel-air ratios. A typical calibration curve for air flow through the sharp-edged orifice is shown in Fig. A1.12.

Two tanks, one on each side of the flowmeter orifice *G*, Fig. A1.11, are used to reduce pulsation to a minimum. Air leaving the downstream tank passes through another pressure-regulating valve (see Fig. A1.13) before it enters the intake-manifold surge tank. This tank, *EE*, is used between the air inlet to the engine and the pressure regulating valve. The regulator and tank control the manifold pressures under which the engine operates. The tank is connected to the inlet of the engine by a bellows (see Fig. A1.14) surrounded by a guard. A100-in. mercury manometer *W* (see Fig. A1.11) measures the manifold or boost pressure. Both water and mercury manometers can be equipped with check valves as extra equipment to prevent water or mercury from being carried into the induction system.

A1.15 Detonation Meters

A1.15.1 An approved detonation meter may be used as an aid to the ear in determining standard knock intensity.Meters on the approved list are models KM-1, 102-A, and GPI-1. The KM-1 meter and the 102-A meter are both obsolete types not presently available. The GPI-1 meter is available from Waukesha Engine Div., Waukesha, Wis. It is considered an improved type as an aid to the ear in the determination of standard knock intensity.

A1.16 Pressure Lubrication

A1.16.1 *Lubrication Diagrams*—Pressure feed is used to lubricate the main bearings, connecting-rod bearings, piston pin, camshaft bearings, idler gear stud, balancer shaft bearings, and gears. A schematic lubrication diagram is shown in Fig. A1.15, and the oiling system external connections in Fig. A1.2. An oil-pressure–actuated safety switch is provided for protection of the air heaters.

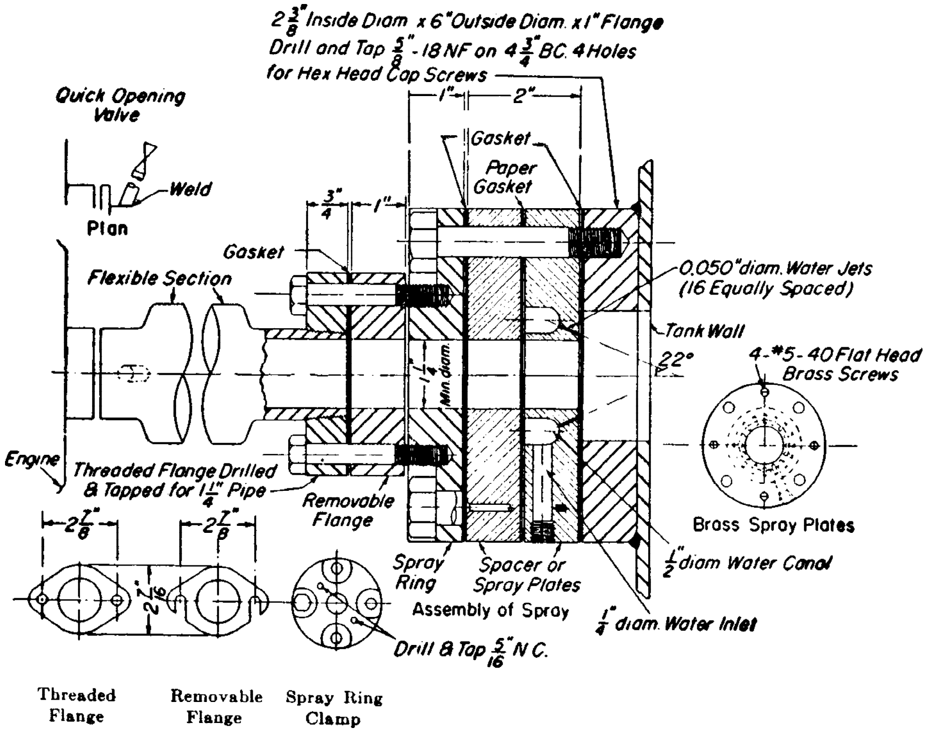
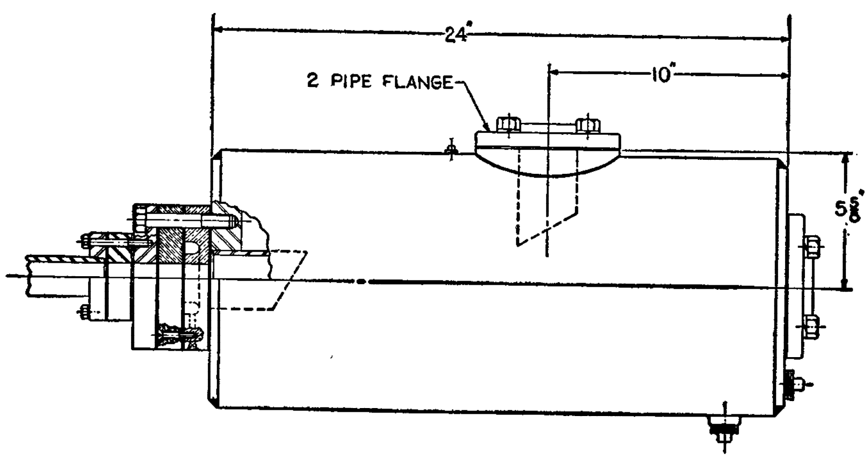


FIG. A1.5 Flexible Exhaust Pipe Assembly



Tank to be lagged if water injection is not used.

FIG. A1.6 Exhaust System Surge Tank

A1.16.2 *Oil Filter*—The connections for the oil filter are shown in Fig. A1.2. On CFR-48 and high-speed crankcases there must *not* be a plug in the main passage inside the oil relief-valve body when using a by-pass filter alone, or the bearings will receive no oil. This plug, Item 36 in Fig. A1.16, is used only with the full-flow or combination cooler-filter unit to divert all the oil through the unit. Supercharge units require the oil cooler.

A1.16.3 *Oil Pump*— On the CFR-48 crankcase a gear-type pump is mounted externally on the gear cover, with external connecting lines.

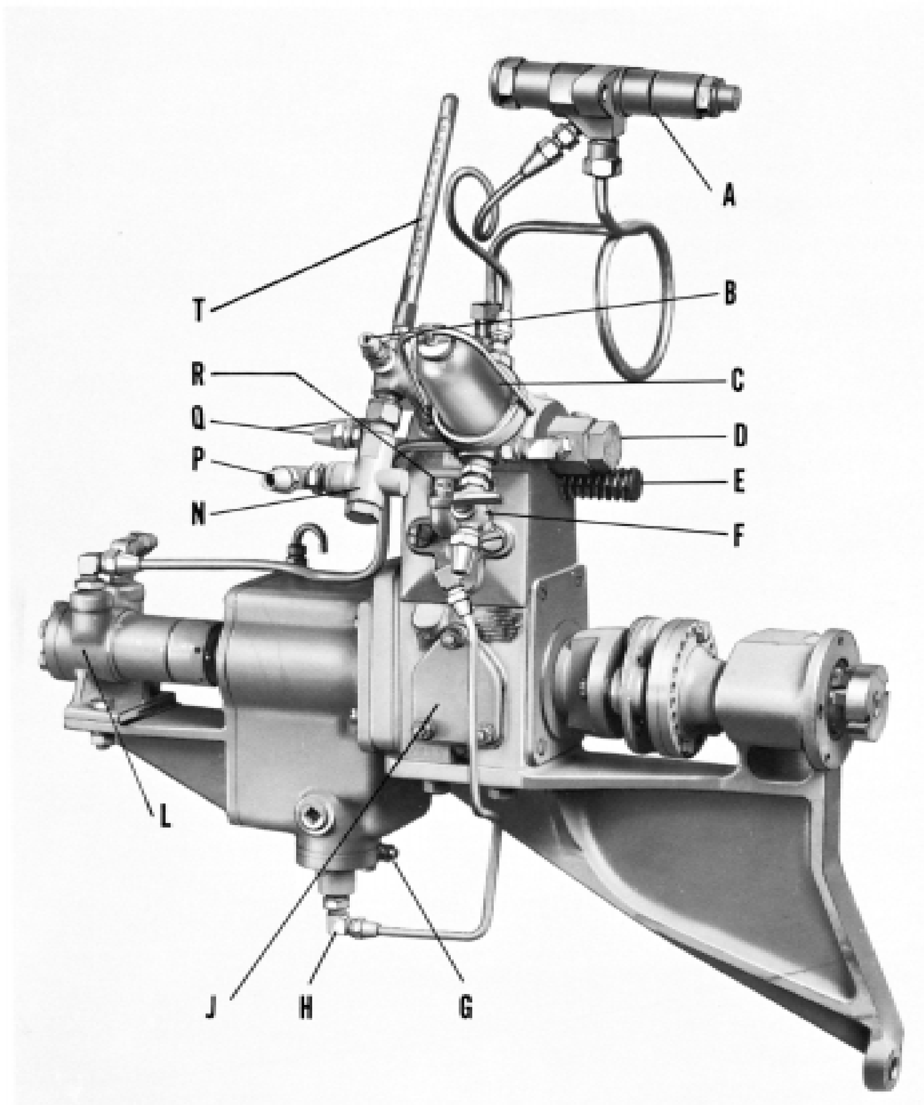
A1.16.4 *Oil Heater*—A 1000-W electric heater is mounted on the base of the crankcase to provide rapid warmup.

A1.16.5 *Oil Temperature Indicator*—A thermometer in the housing of the lubricating-oil relief valve shows the temperature of the oil supplied to the main bearings. A gage on the panel shows oil-sump temperature.

A1.16.6 *Pressure Gage*—An oil pressure gage having a range from 0 to 100 psi (0 to 0.69 MPa) is used.

A1.16.7 *Valve Stem Lubrication*—Positive pressure lubrication to the rocker arms is provided. Felt washers are used on the valve stems. A valve and rocker arm cover (see Fig. A1.17) ensures an oil mist around the valves.

A1.16.8 *Oil Pressure*—The oil relief valve is set by means of adjusting screw *I* (see Fig. A1.2) to maintain an oil pressure of 60 psi (0.41 MPa) (see A4.30).



(*a*) FRONT VIEW

A—Injection nozzle
B—Connection for fuel pressure gage
C—Surge dampener
D—Fuel filter
E—Fuel control rack
F—Air bleed
G—Oil drain cock of fuel pump reservoir
H—Oil line of fuel pump
J—Provision for mounting Bosch fuel pump

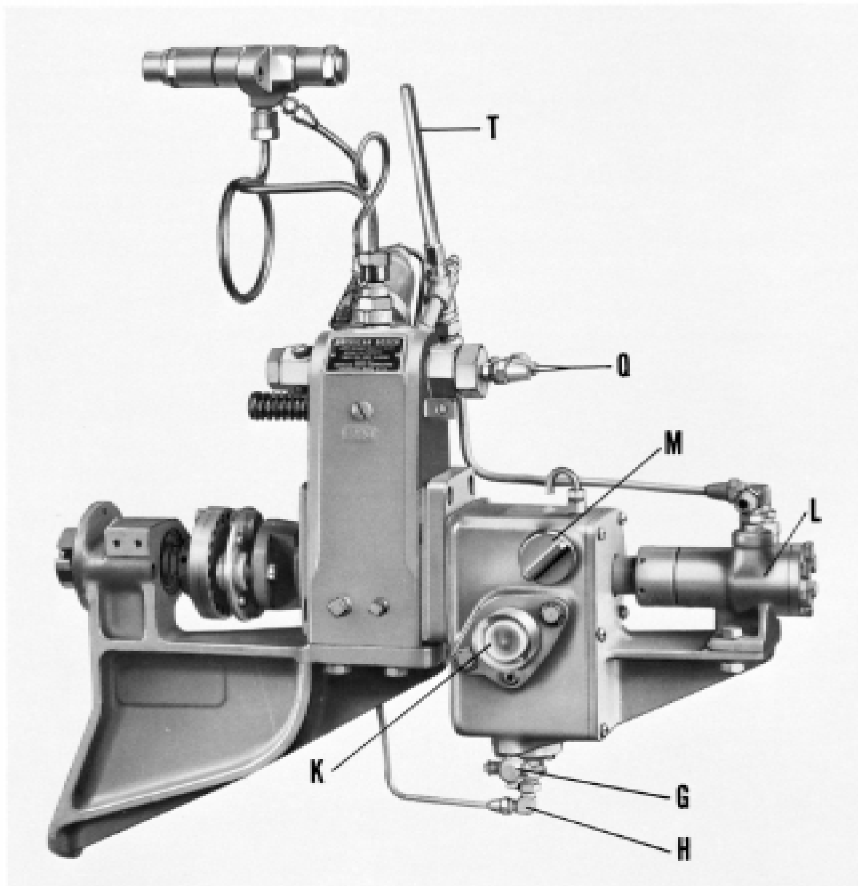
FIG. A1.7 Fuel Injection System

A1.17 Shafts, Rods, and Crankcase

A1.17.1 *Camshaft*—The camshaft has a valve lift of 0.312 in. It is a case-hardened forging.

A1.17.2 *Connecting Rod*—The connecting rod is fitted with a replaceable precision-type bearing. It is made of heat-treated steel, of channel section for maximum rigidity. The rod is rifle-drilled for forced-feed lubrication of the piston pin and spray cooling of the under side of the piston. The big-end bearing is removable and is of the precision type.

A1.17.3 *Crankcase*—Only the CFR-48 and high-speed engines are used. Sectional views of the CFR-48 engine are shown in Fig. A1.18 and Fig. A1.19.



(*b*) REAR VIEW

K—Oil level Window
L—Fuel pump, rotary type
M—Oil filter cap
N—Fuel relief valve
O—Fuel control rack
P—Connection for fuel return line
Q—Water connections for fuel cooler
R—Oil line of fuel pump breather
T—Provision for mounting Bosch fuel pump

FIG. A1.7 *(continued)*

A1.17.4 *Crankshaft*—The crankshaft is forged, fully machined, counterbalanced, heat-treated, and nitrided. It is drilled for full-pressure lubrication to the connecting rod.

A1.17.5 *Main Bearings*—The CFR-48 crankcase is equipped with sleeve-type precision bearings which are easily replaced without requiring line reaming.

A1.17.6 *Balancing*—On the CFR-48 crankshaft, the crankpin and the big-end mass of the connecting rod are balanced by counterweights bolted to the crank cheeks. The primary reciprocating mass is balanced by rotating weights mounted on the two balancer shafts rotating in opposite directions. The weights on the balancer shafts are designed to match the piston-assembly weights. The solid steel weights without lead plugs must be used to balance the aluminum piston.

A1.18 Dynamometer

A1.18.1 A 25-hp alternating-current electric dynamometer, capable of maintaining an engine speed of 1800 ± 45 rpm, starts the engine and absorbs the power developed by it. The 60-Hz dynamometer is connected to the engine by two flexible couplings and is of the cradle type, power being measured by the pull exerted on a springless dial scale. Oil dashpots on both scale *G* (see Fig. A1.20) and dynamometer *B* (see Fig. A1.21) damp the power pulsations, thus reducing fluctuations of the scale pointer. The 50-Hz dynamometer is belted by three V-belts, using a special flywheel pulley.

A1.18.2 The piston clearance of the dynamometer dashpot is 0.019 ± 0.001 in. The piston operates in an oil having a Saybolt Universal viscosity of 290 s at 80°F. Backlash of the

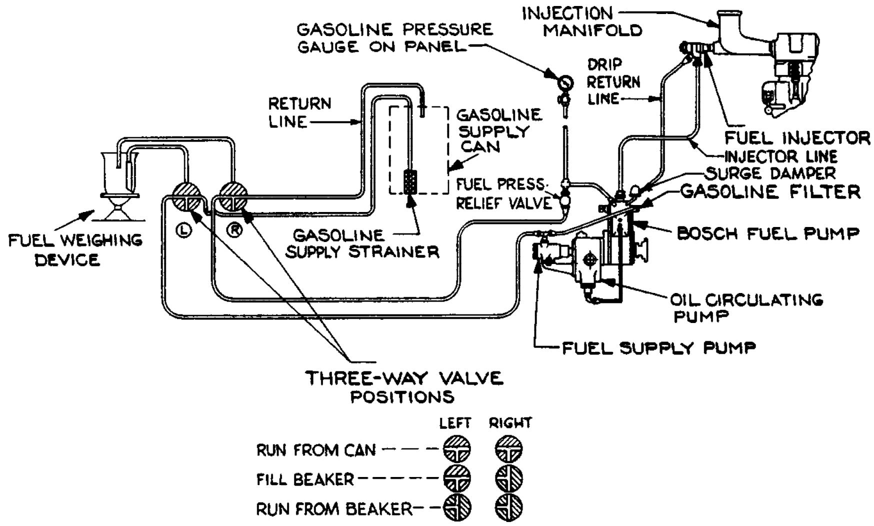
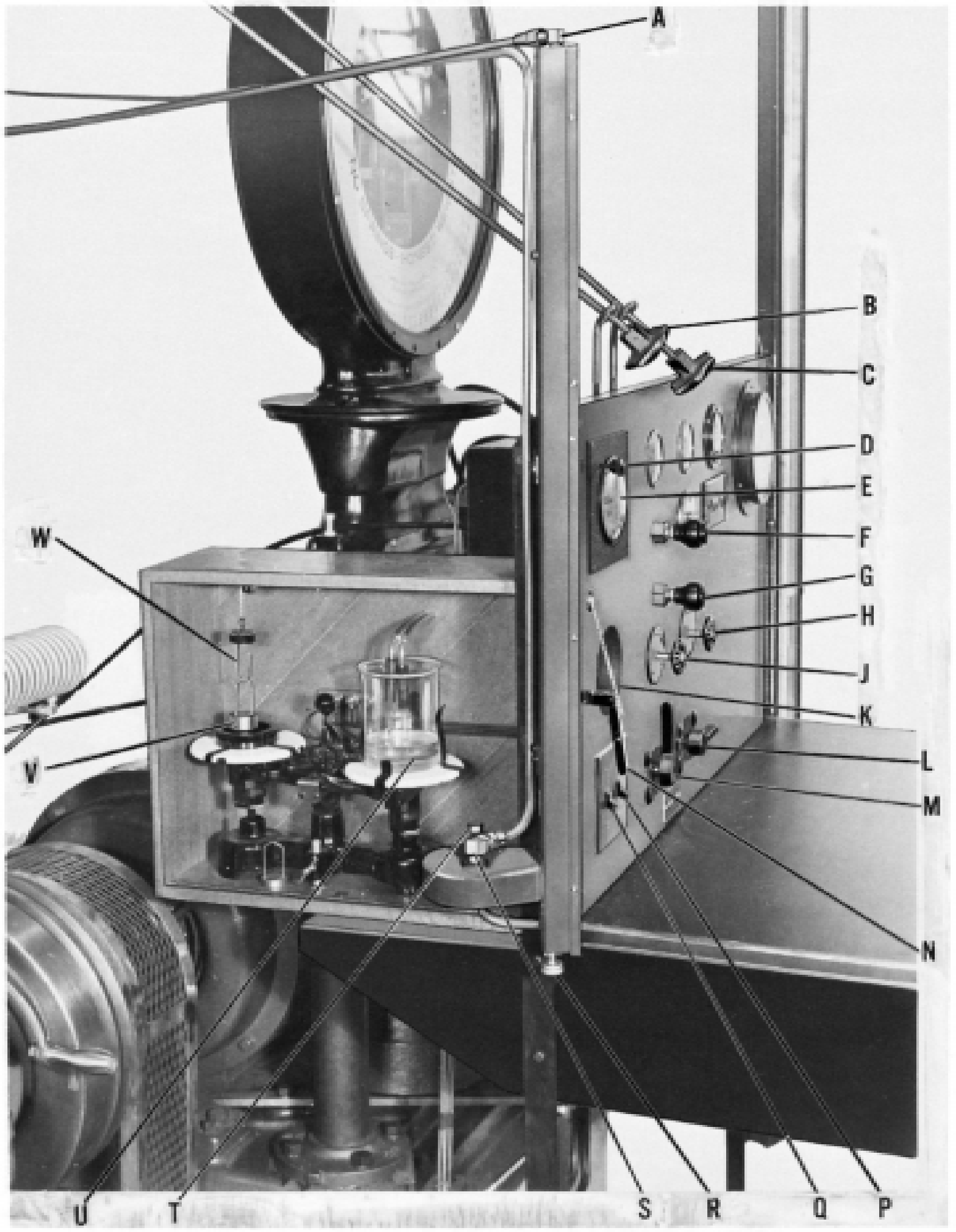


FIG. A1.8 Diagram of Fuel System

linkage between the scale and dynamometer, when shifting from motoring to power absorption, is eliminated by two independent links and pre-loading of the scale. To simplify calculations, the scale is calibrated in mean effective pressure (mep). Details of the dynamometer scale head are shown in Fig. A1.22.



A—Water manometer connection to orifice
B—Control knob for atmospheric bleed valve
C—Control knob for air adjusting valve
D—Stop clock reset
E—Stop clock
F—Control knob for fuel shutoff
G—Control knob for fuel injection
H—Air bleed valve for adjusting orifice pressure valve
J—Air pressure valve for adjusting orifice pressure valve
K—Fuel scales observation window
L—Right hand fuel valve
M—Left-hand fuel valve
N—Lever for setting scale weights
P—Right-hand control switch for stop clock
Q—Left-hand control switch for stop clock
R—Zero adjustment for water manometer
S—Water manometer connection to orifice
T—Water manometer filler plug
U—Fuel weighing beaker
V—Special fuel weight
W—Hook for lifting scale weight

FIG. A1.9 Fuel Weighing Device and Controls

TABLE A1.3 Specifications for ASTM Thermometers for Supercharge Method[A,B,C]

	ASTM No.	82F-80	82C-80	84F-80	84C-80	85F-80	85C-80	87F-80	87C-80
	IP No.								
	Name	Fuel Rating, Engine		Fuel Rating, Orifice Tank		Fuel Rating, Surge		Fuel Rating, Coolant	
	Reference Fig. No.	11		11		11		8	
	Range	0 to 220°F	−15 to 105°C	75 to 175°F	25 to 80°C	100 to 300°F	40 to 150°C	300 to 400°F	150 to 205°C
	For test at			125°F[D]	51.7°C[D]	225°F[D]	107.2°C[D]	375°F[D]	190.6°C[D]
A	Immersion, mm	30[E]		249[E]		181[E]		40[E]	
	Graduations:								
	Subdivisions	2°F	1°C	1°F	1°C	2°F	1°C	1°F	1°C
	Long lines at each	10°F	5°C	5°F	5°C	10°F	5°C	5°F	5°C
	Numbers at each	20°F	10°C	10°F	10°C	20°F	10°C	10°F	10°C
	Scale error, max	2°F	1°C	2°F	1°C	2°F	1°C	2°F	1°C
	Special inscription	ASTM 82F or 82C 30 mm IMM		ASTM 84F or 84C 249 mm IMM		ASTM 85F or 85C 181 mm IMM		ASTM 87F or 87C 40 mm IMM	
	Expansion chamber:								
	Permit heating to	260°F	125°C	215°F	100°C	340°F	170°C	440°F	225°C
B	Total length, mm	159 to 165		378 to 387		305 to 314		169 to 175	
C	Stem OD, mm	6.0 to 7.0		6.0 to 7.0		6.0 to 7.0		6.0 to 7.0	
D	Bulb length, mm	6 to 11		6 to 11		6 to 11		6 to 11	
E	Bulb OD, mm	5.0 to 6.5		5.0 to 6.5		5.0 to 6.5		5.0 to 6.5	
	Scale location:								
	Bottom of bulb to line at	0°F	−15°C	75°F	25°C	100°F	40°C	300°F	150°C
F	Distance, mm	62 to 70		284 to 292		213 to 221		72 to 80	
G	Length of graduated portion, mm	65 to 81		62 to 79		54 to 77		59 to 82	
	Ice-point scale:								
	Range								
H	Bottom of bulb to ice-point, mm								
	Contraction chamber:								
I	Distance to bottom, min, mm							21	
J	Distance to top, max, mm								
	Stem enlargement:								
K	OD, mm	8.0 to 9.0		8.0 to 9.0		8.0 to 9.0		8.0 to 9.0	
L	Length, mm								
M	Distance to bottom, mm	28 to 32		247 to 251		179 to 183		38 to 42	

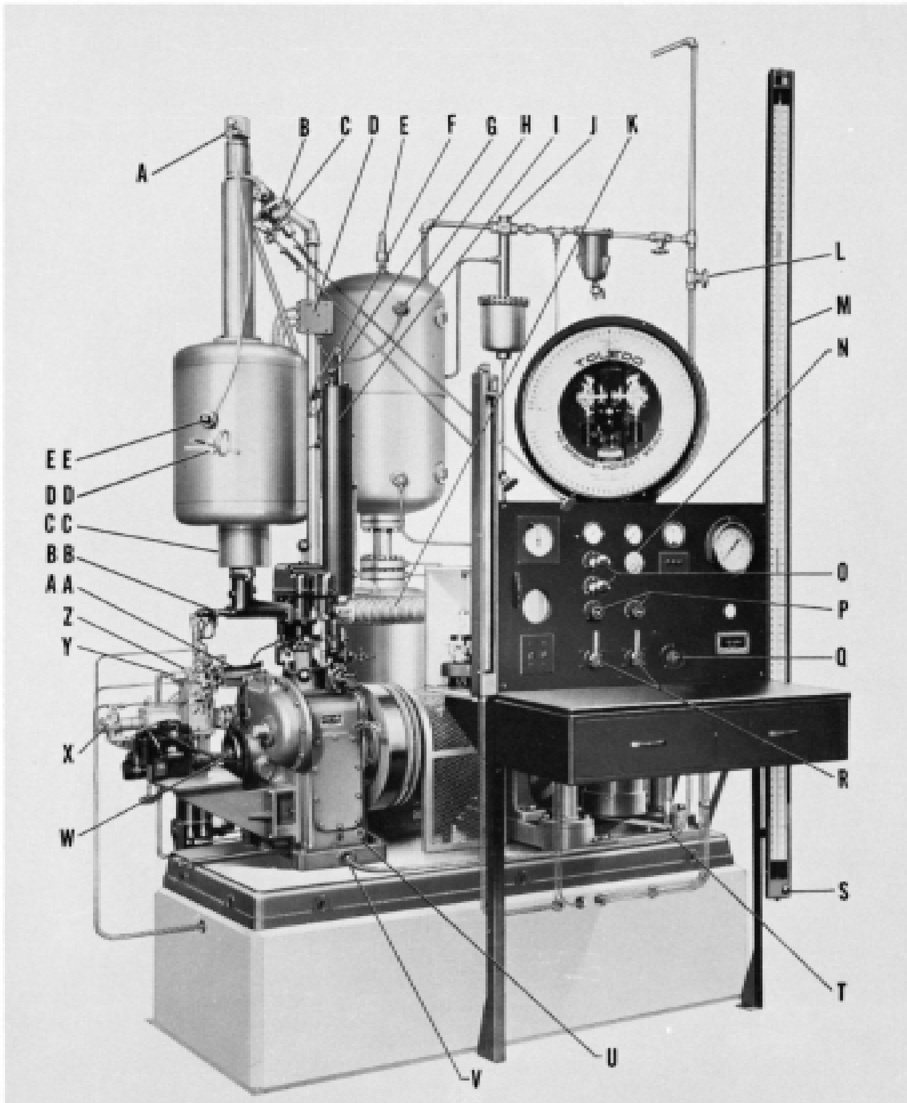
[A] These specifications have been reproduced from Specification E 1.

[B] Both types of these thermometers, Fahrenheit and Celsius, are standard equipment; however, the Fahrenheit thermometers have been designated“ preferred.” The only significance of this designation is that they will be supplied on all orders unless otherwise specified.

[C] Celsius thermometers are not currently available.

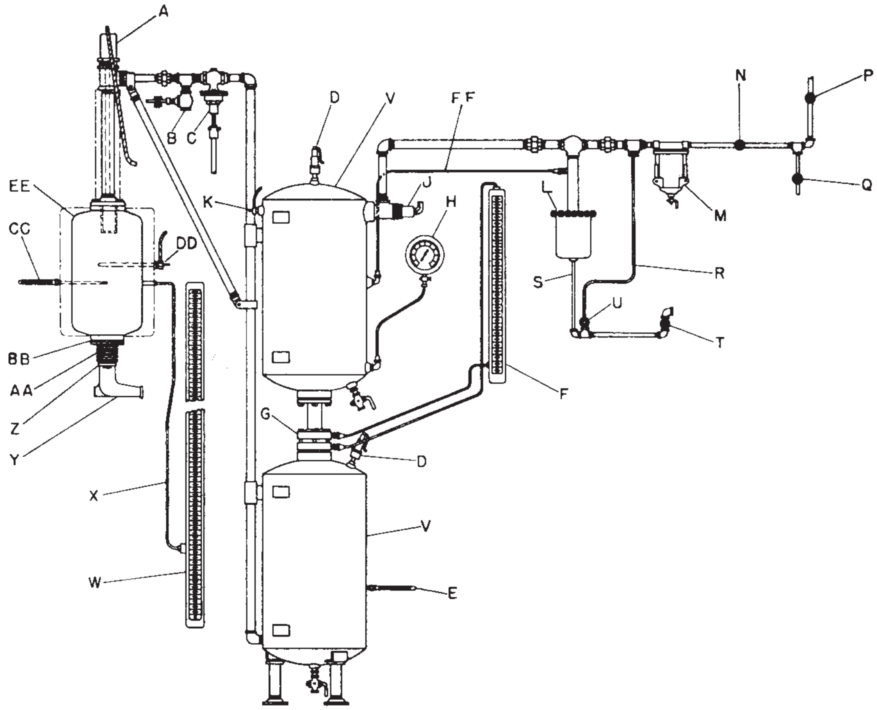
[D] The test temperature shall be indicated by an arrow whether the graduation corresponding to that point is numbered or not.

[E] Immersion line shall be omitted.



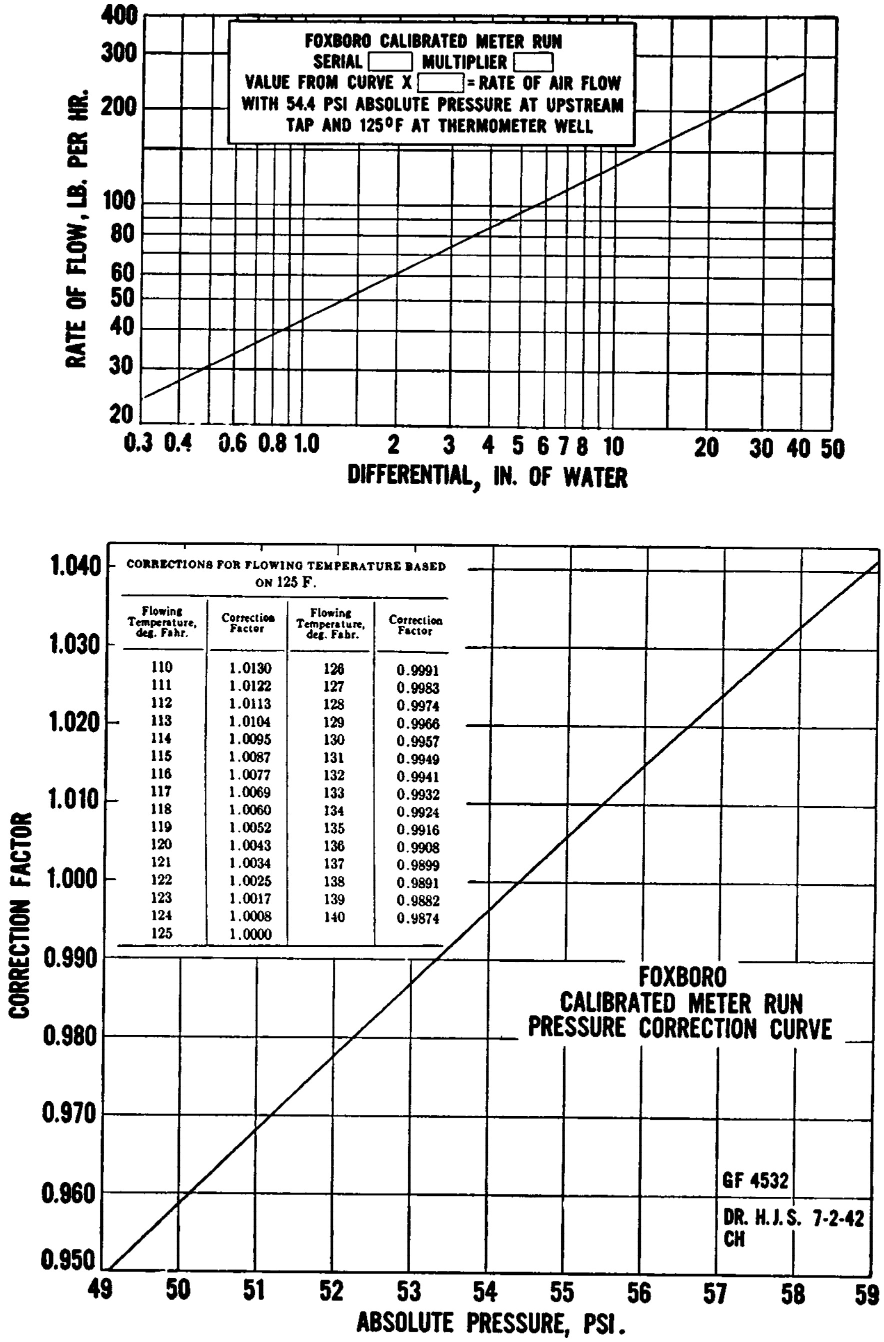
A—3000-W heater
B—Manifold pressure regulating valve
C—Atmospheric bleed valve
D—Main junction box
E—Safety relief valve
F—Coolant safety shutoff thermostat
G—Coolant condenser filler cap
H—Orifice tank heater thermostat
I—Coolant condenser
J—Orifice pressure regulating valve
K—Water cooled exhaust manifold
L—Air supply blow-off valve
M—Mercury manometer for manifold pressure
N—Ignition switch
O—Fuel injection pump controls
P—High pressure air control valves
Q—Oil heater switch
R—Fuel supply valves
S—Adjustment for barometeric pressure
T—Dynamometer locking handle
U—Oil level sight gage
V—Oil heater plug
W—Spark quadrant
X—Fuel supply pump
Y—Fuel cooler
Z—Fuel injection pump
AA—Fuel control quadrant
BB—Fuel injector in manifold
CC—Bellows guard on surge tank
DD—Surge tank thermometer and magnifying glass
EE—Surge tank thermostat

FIG. A1.10 Operating View of 60-Hz Supercharge Unit



A—Surge Tank Heater.
B—Atmospheric Bleed Valve.
C—Air Adjusting Valve.
D—Safety Valve.
E—Orifice Air Thermometer.
F—Water Manometer.
G—Calibrated Orifice.
H—Air Pressure Gage on Control Panel.
J—Air Heater.
K—Air Heater Thermostat.
L—Orifice Pressure Control Valve.
M—Air Filter.
N—Air Supply Valve.
P—Main Air Supply Valve.
Q—Condensate Bleed Valve.
R—Pressure Line to Control Panel.
S—Pressure Line from Panel.
T—Air Bleed Valve on Panel for Adjusting Orifice Pressure Valve.
U—Air Pressure Valve on Panel for Adjusting Orifice Pressure Valve.
V—Orifice Air Tank.
W—Mercury Manometer, Manifold Pressure.
X—Line from Surge Tank to Mercury Manometer.
Y—Intake Manifold.
Z—Manifold Flange.
AA—Bellows.
BB—Air Tank Flange.
CC—Intake Surge Tank Thermometer.
DD—Thermostat.
EE—Intake Surge Tank.
FF—Balance Line for Orifice Pressure Regulator.

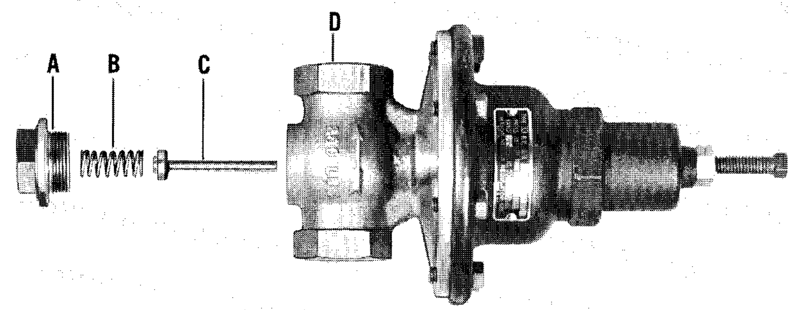
FIG. A1.11 Diagram of Induction System with Vertical Air Tanks



CORRECTIONS FOR FLOWING TEMPERATURE BASED ON 125 F.

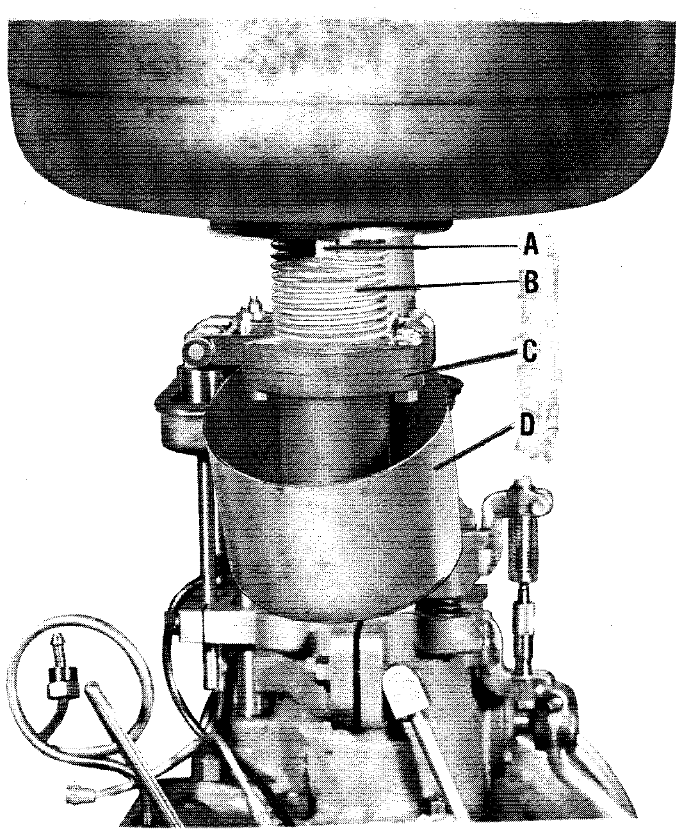
Flowing Temperature, deg. Fahr.	Correction Factor	Flowing Temperature, deg. Fahr.	Correction Factor
110	1.0130	126	0.9991
111	1.0122	127	0.9983
112	1.0113	128	0.9974
113	1.0104	129	0.9966
114	1.0095	130	0.9957
115	1.0087	131	0.9949
116	1.0077	132	0.9941
117	1.0069	133	0.9932
118	1.0060	134	0.9924
119	1.0052	135	0.9916
120	1.0043	136	0.9908
121	1.0034	137	0.9899
122	1.0025	138	0.9891
123	1.0017	139	0.9882
124	1.0008	140	0.9874
125	1.0000		

FIG. A1.12 Typical Foxboro Orifice Calibration Chart. (Not to Be Used for Calibration Purposes)



A—Cap Nut
B—Valve spring
C—Valve plunger and guide
D—Valve body

FIG. A1.13 Air Adjusting Valve



A—Capscrew
B—Bellows
C—Intake manifold flange
D—Bellows guard

FIG. A1.14 Surge Tank Bellows

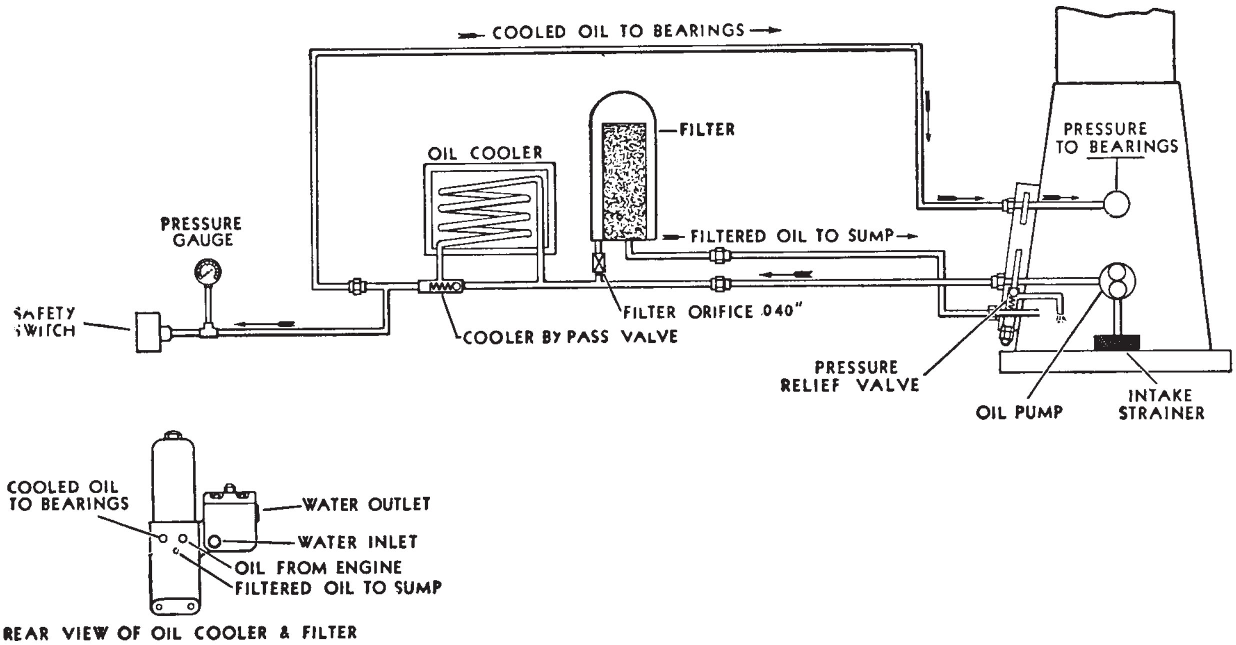
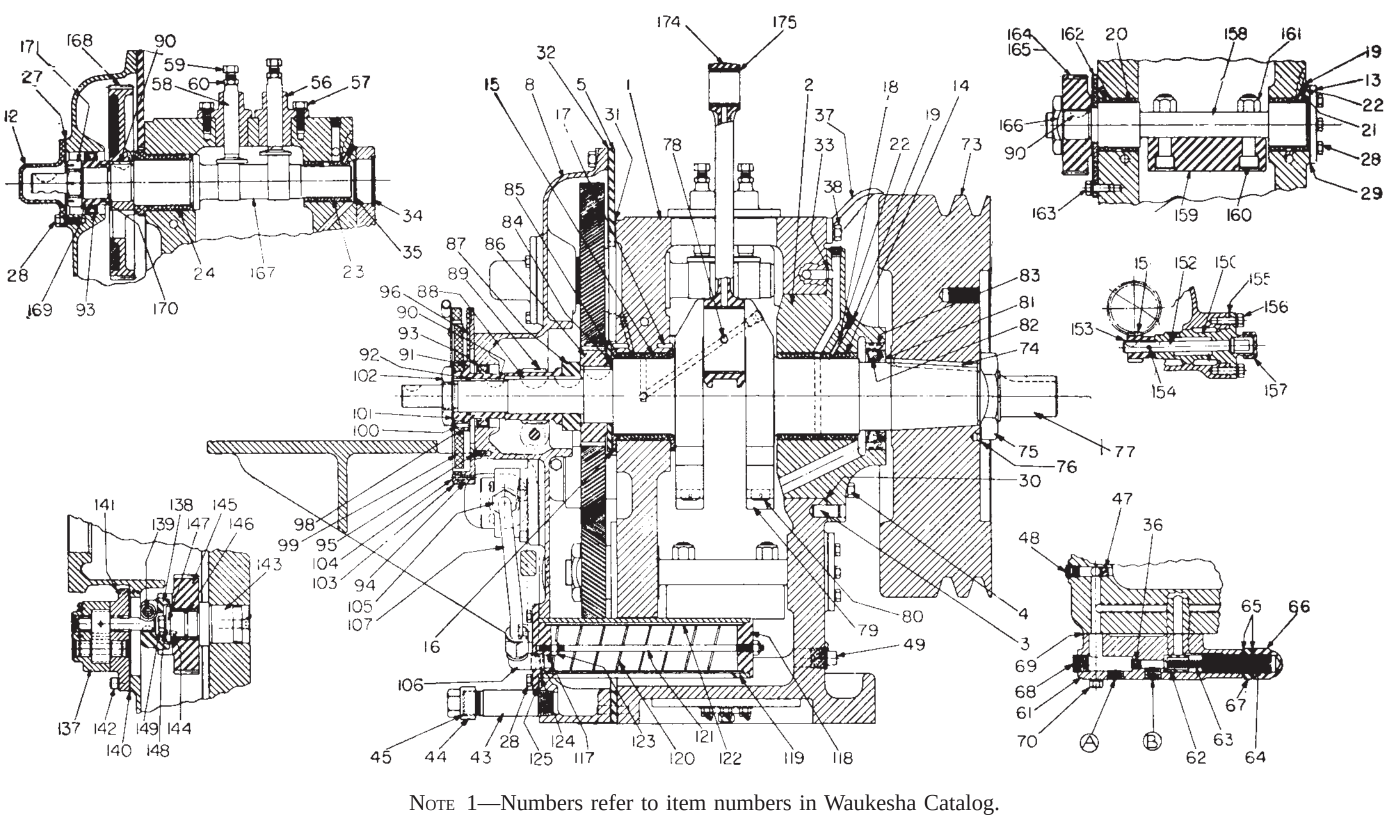


FIG. A1.15 Diagram of Lubrication System with By-Pass Type Filter



NOTE 1—Numbers refer to item numbers in Waukesha Catalog.

FIG. A1.16 Sectional View of CFR-48 Crankcase

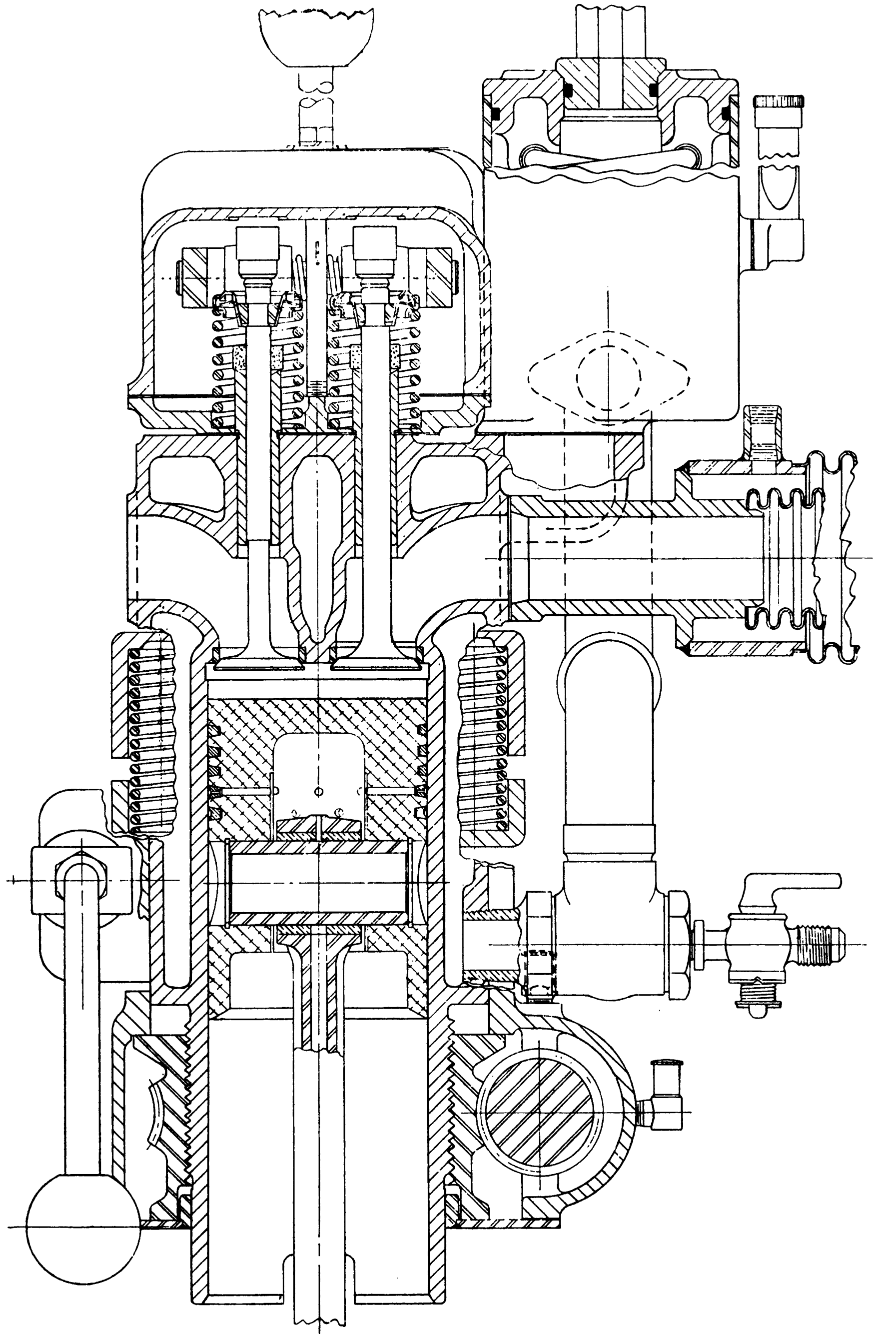


FIG. A1.17 Cross Sections of Cylinder Assembly

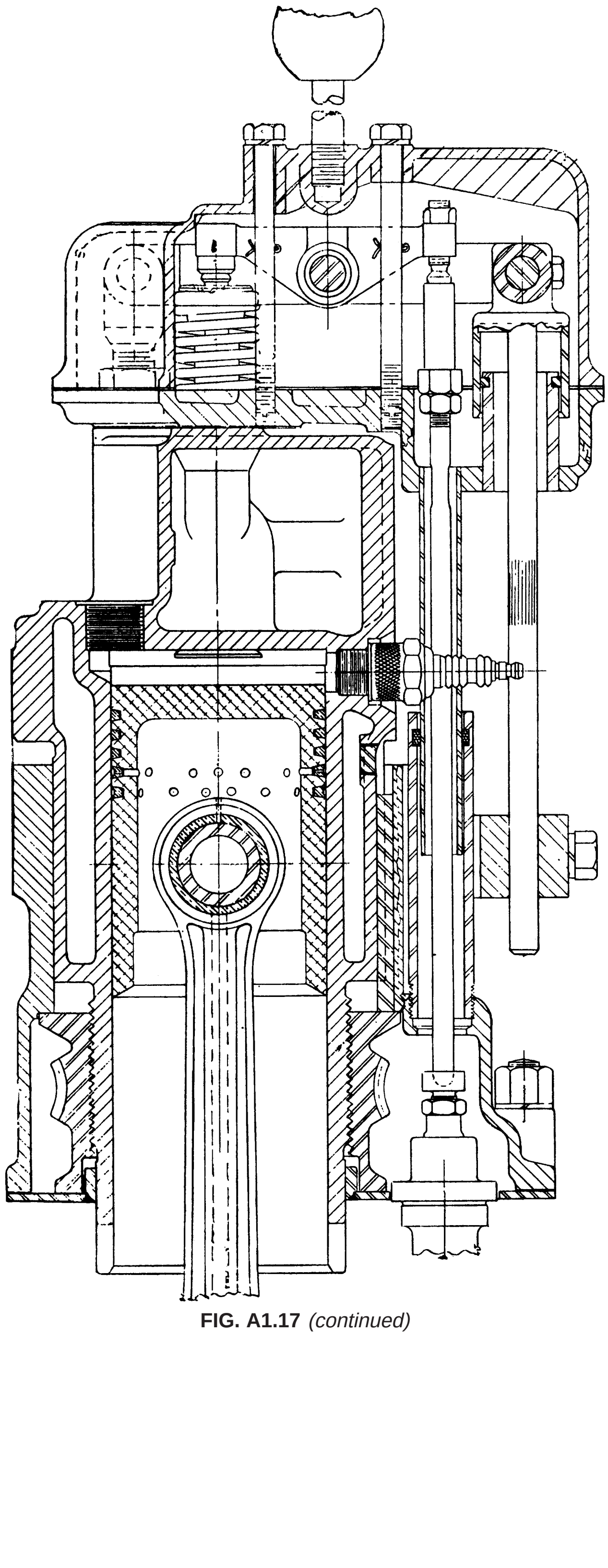
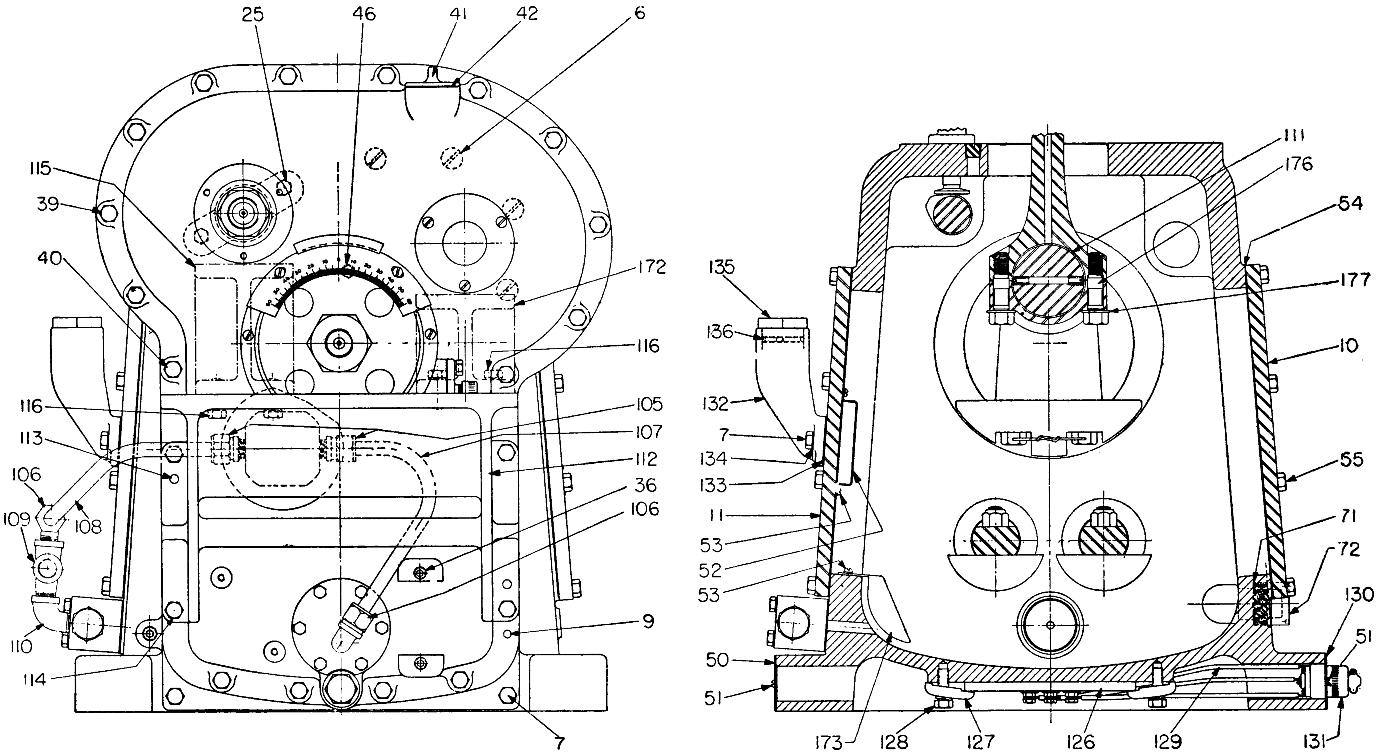
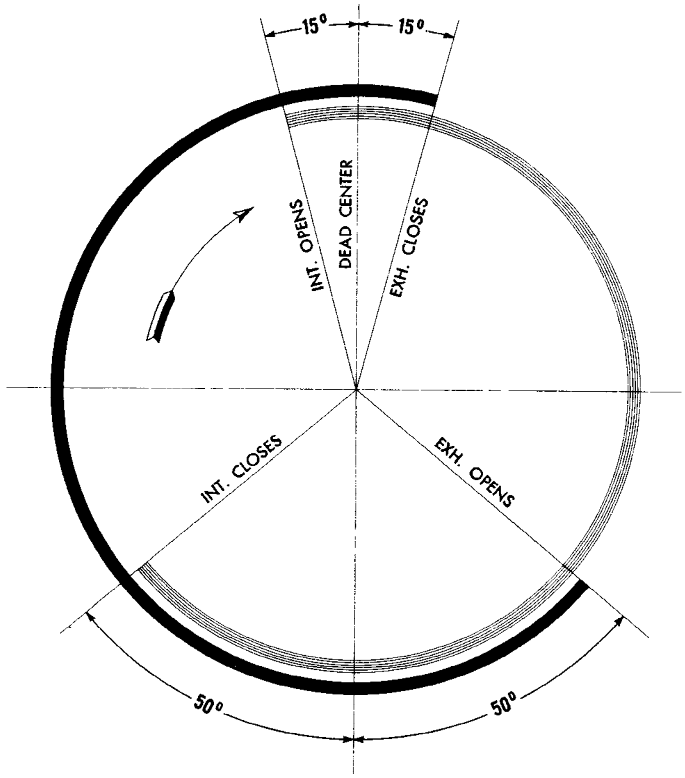


FIG. A1.17 *(continued)*



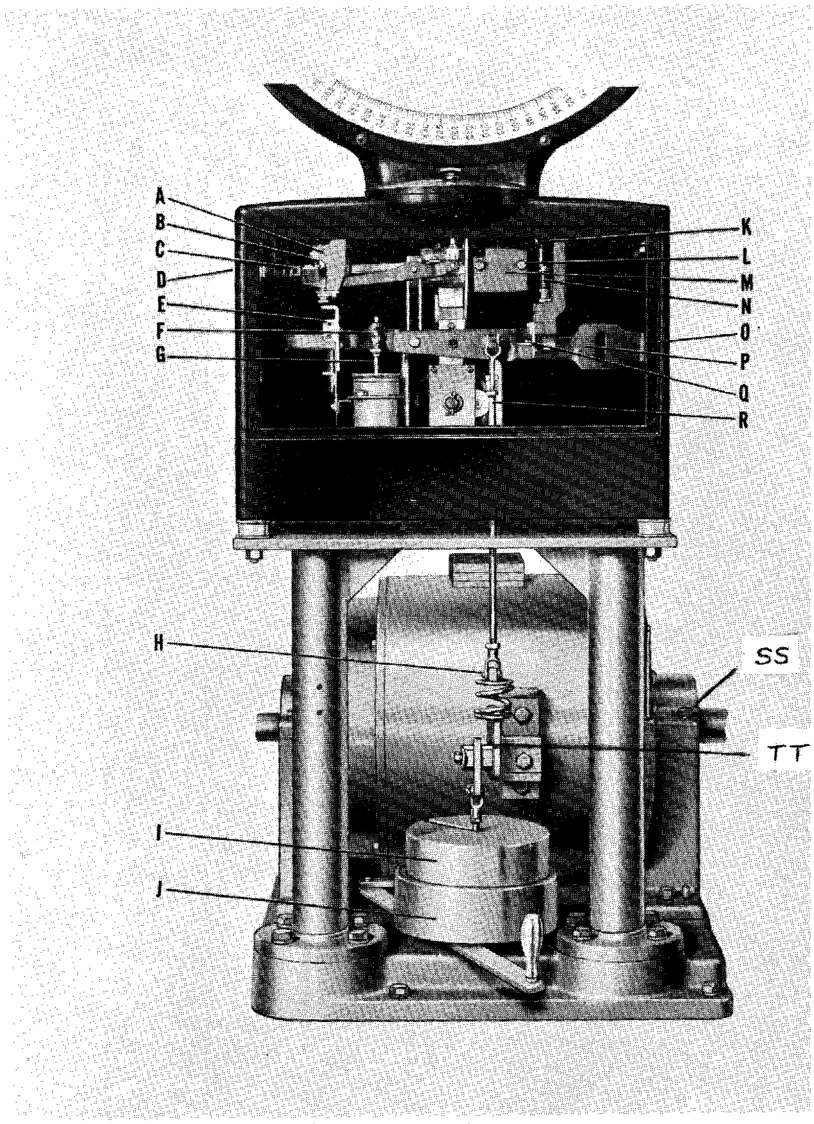
NOTE 1—Numbers refer to item numbers in Waukesha Catalog.

FIG. A1.18 Sectional View of CFR-48 Crankcase



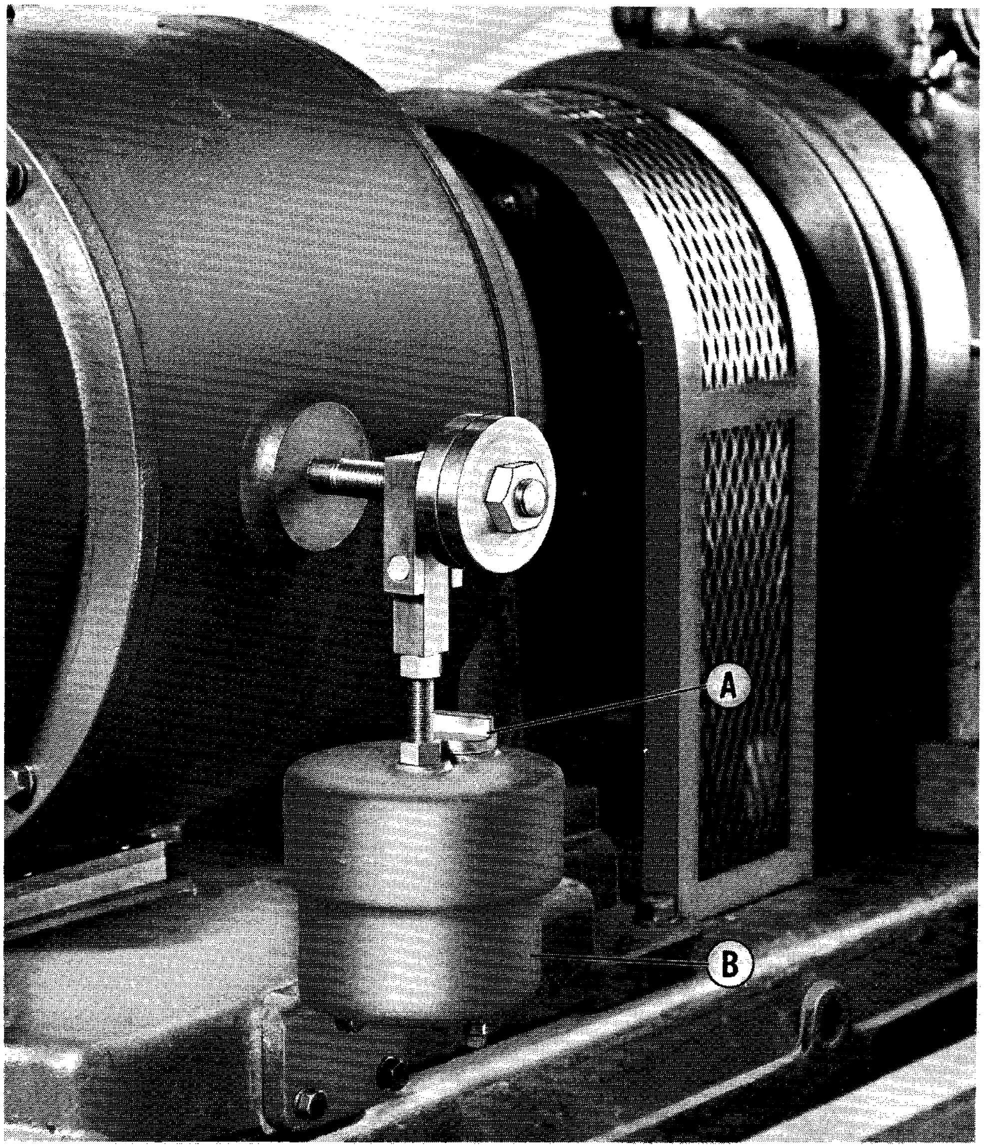
HOLD TOP EVENTS TO 2½ DEG ON FLY WHEEL
Valve clearance for timing check = 0.010 in.

FIG. A1.19 Valve Timing Diagram for Supercharge Method



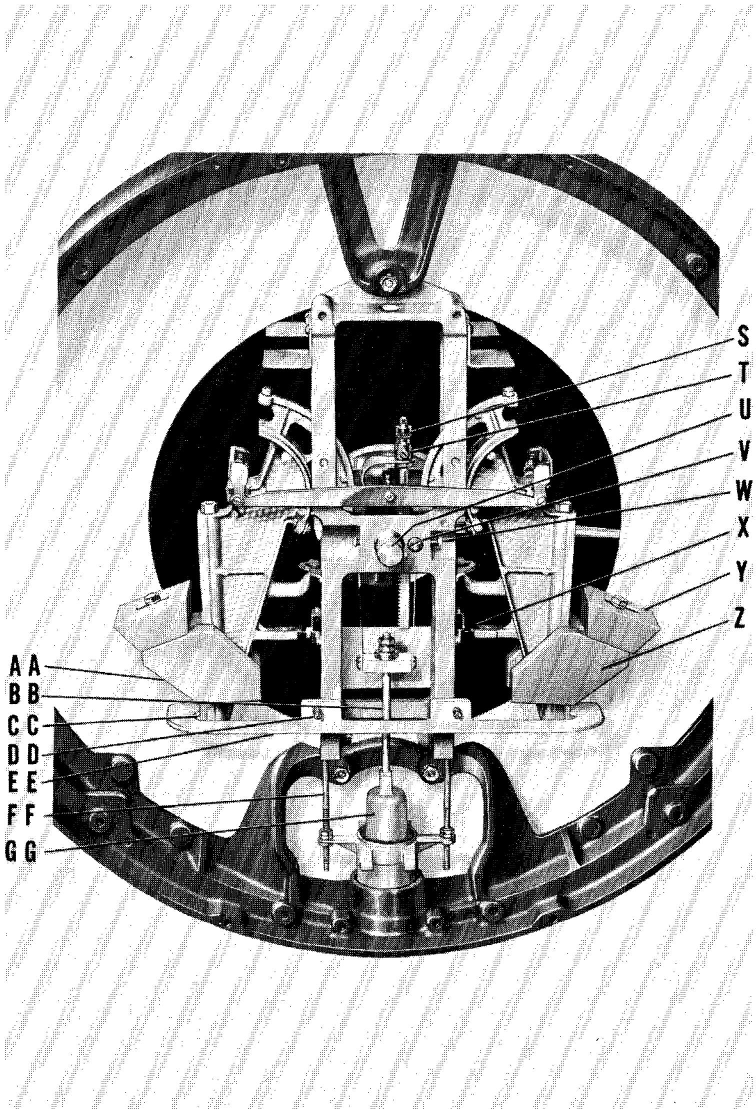
A—Pendulum lever fulcrum bracket
B—Coil spring
C—Shipping clamp
D—Zero adjustment hole
E—Shipping pin location
F—Dash pot arm
G—Dash pot plunger rod
H—Clevis pin
I—25-lb weight
J—40-lb weight
K—Fulcrum bracket stop screw
L—Shipping clamp location
M—Lever fixed weight
N—Coil spring
O—Tare beam lever clamp
P—Tare beam lever
Q—Fulcrum strip
R—Scale rod
SS—Trunnion bolt
TT—Knife edge

FIG. A1.20 Dynamometer and Scale Assembly



A—Filler cap
B—Dashpot case

FIG. A1.21 Dynamometer Dashpot



S—Rack adjuster
T—Rack locking screw
U—Indicator and pinion shaft
V—Rack guide
W—Rack guide retaining screw
X—Pendulum stops
Y—Minor weight
Z—Pendulum weight

AA—Pendulum weight lock nut location
BB—Ribbon equalizer rod
CC—Pendulum rail
DD—Rail gage clips
EE—Rail gage
FF—Pendulum locking rods
GG—Oil seal cup

FIG. A1.22 Dynamometer Scale Head

A2. REFERENCE MATERIALS AND BLENDING ACCESSORIES

A2.1 Reference Fuels

A2.1.1 The supercharge test method for determining knock ratings of aviation fuels is based on comparing a fuel in the ASTM engine under the standard test conditions with reference fuels of known ratings. The ASTM knock test reference fuels are two hydrocarbons of high and low antiknock value (and a blend thereof), which conform to the specifications in A2.9.1. These fuels can be produced as required and are available from the suppliers (see A2.10). The hydrocarbon of high antiknock value is called *iso*octane, its chemical name being 2,2,4-trimethylpentane. This fuel in its *pure* state has, *by definition*, an octane number of 100. The low antiknock fuel is *n*-heptane, which is also its chemical name. This fuel in its pure state has, *by definition*, an octane number of 0.0. A mixture of *iso*octane and *n*-heptane has an octane number that is equal to the volume % of *iso*octane in the blend of the two. Thus, a blend (by volume) of 95.0 % *iso*octane and 5.0 % *n*-heptane is defined as having an octane number of 95.0.

A2.1.2 Above 100 octane number, ratings are defined in terms of millilitres of TEL per gallon in *iso*octane. This requires the use of TEL conforming to the specifications in A2.9.4. Supercharge ratings are usually expressed in terms of performance numbers (PN) above 100 and may be expressed as PN below 100. The conversion for octane numbers to PN is shown in Table 1, and for TEL in *iso*octane to PN in Table 2.

A2.2 Standardization and Check Fuels

A2.2.1 *Aviation Standardization Fuels*—The ASTM 80 Octane Number Blend (see A2.10) containing 3.0, 4.0, and 4.6 ml of TEL per gallon has been calibrated for use as leaded standardization fuels. Calibrated ratings are as follows:

Millilitres of TEL per U.S. gallon	Supercharge PN performance number Rating at Rich Peak
3.0	87.9 ± 1.5
4.0	91.9 ± 1.9
4.6	94.8 ± 2.3

A2.2.2 *Aviation Check Fuel*—A typical aviatiaon gasoline for use in checking engine condition has been calibrated by the National Exchange Group. This fuel (Aviation Grade 100/130) with calibration data for the supercharge test method is available from the supplier (see A2.10).

A2.3 Handling Reference and Standardization Fuels

A2.3.1 *Dispensing*—Safety provisions in most laboratories are such that large quantities of fuel are not allowed in the engine room. Apparatus for dispensing reference fuels to the measuring apparatus vary considerably, some in use being gravity flow, water displacement, nitrogen pressure, and pumping. Gravity flow is a simple arrangement, particularly where there is fireproof storage above the laboratory. Water displacement is also simple and convenient if there is no freezing problem, but precautions must be used to prevent the water from entering the measuring apparatus. When the containers are subjected to nitrogen pressure, constant care is required to see that all the joints are tight or there will be loss of fuel as well as nitrogen. Transfer by means of small pumps is satisfactory.

A2.3.2 *Handling Procedures*—As the ASTM knock test reference fuels, *iso*octane and *n*-heptane, are pure stable compounds, weathering during storage is unimportant. Since these fuels have nearly the same boiling points, change due to weathering of a blend of the two compounds is greatly minimized. Weathering can occur when standardization fuels are prepared locally by blending *iso*octane and *n*-heptane with TEL. To maintain the constancy of octane numbers of reference and standardization fuels during storage and use in the laboratory, it is necessary for the user to prevent breathing and evaporation losses. The fuels, which are shipped in 55-gal drums or 5-gal containers, should be stored in a cool place and kept vapor tight. To avoid vapor loss, containers should be opened only once and then only when cool. Pouring from one container to another should be avoided; and the containers in use should be provided with check valves or liquid seals to let air in but not out, unless a pressure system is used, in which case no check valves are necessary.

A2.3.3 *Precautions*—Because all the reference and standardization materials are flammable, they must be handled with care to keep them away from any open flame. Keep containers closed when not actually pouring fuels, and avoid spilling. Prolonged or repeated breathing of vapor should be avoided. Ventilation must always be adequate to prevent accumulation of fuel fumes in any part of the laboratory. Avoid prolonged or repeated contact with the skin. See special precautions for TEL (see A2.6).

A2.4 Blending Reference and Standardization Fuels

A2.4.1 When preparing blends of reference and standardization fuels the constituents should be at the same temperature, within 5°F (3°C); otherwise an appreciable error will be caused by the relatively high coefficients of expansion.

A2.4.2 Since larger quantities of reference and standardization fuels are required, it is convenient to use 5-gal containers when making tests. The containers should, of course, be kept sealed tightly when not in actual use. Where testing is infrequent the required blends may be prepared by using accurately calibrated graduates. When the volume of testing is large, it is more convenient to prepare barrel quantities (see A2.4.3) of those blends required frequently and to withdraw small quantities as needed. Such drums should be kept vapor-tight in a cool place to eliminate loss by evaporation and breathing. Vent lines provided with check valves, or preferably liquid seals, should let air in but not out when withdrawing fuel.

A2.5 Tetraethyllead

A2.5.1 For making ratings over 100 octane number, it is necessary to use reference fuels to which TEL has been added. Also, it is frequently necessary to determine the concentration of TEL required to bring the octane number of a gasoline to a given level or standard. TEL, active ingredient of the fluid specified in A2.9.4, is available from the suppliers (see Section A2.10) in litre containers specially prepared for laboratory use. It is recommended that no more than a three months' supply be ordered at one time. For the Supercharge Method, TEL is usually added to reference fuels and samples in concentrated form (see A2.8).

A2.6 Precautions for Handling Tetraethyllead

A2.6.1 Strict precautions must be observed in handling concentrated TEL. Inhalation or contact of TEL with the skin must be avoided absolutely. Siphoning into a dispensing buret *must not*, of course, be started by mouth suction. A rubber bulb may be used satisfactorily. A beaker or porcelain dish of sufficient capacity to hold all the fluid in the container shall be kept under the dispensing buret at all times as a precaution in case the stopcock should break or become loose. Those persons who are to handle TEL should become thoroughly familiar with the instructions issued by the manufacturers of TEL (see A2.11). It is further recommended that the handling of TEL be restricted to a minimum number of people, each of whom must be thoroughly familiar with the precautions to be observed.

A2.6.2 *Safety Precautions*[10]—If it is necessary to treat batches of fuel larger than can be accommodated under the hood, it is permissible to overtreat a portion of the batch with the entire amount of concentrated TEL required and to mix this with the remainder. If this procedure is used, *avoid spilling the highly leaded fuel, breathing the fumes, or otherwise causing a health hazard*. A special pouring spout that delivers the treated portion below the surface of the untreated part is recommended. The handling of an overleaded portion can be avoided by moving the container of the entire large batch close to the hood and delivering the concentrated TEL from the buret to the fuel through an offset glass tube that ends below the surface of the fuel. The tube must be flushed with a portion of the fuel previously withdrawn. The above procedures should be used only in emergencies. If it is necessary at frequent intervals to treat larger batches of fuels than can be accommodated under the hood, it is recommended that special blending equipment (see A2.11) be installed. All batches must be very thoroughly mixed, either by shaking or other suitable means. To avoid fire hazards, a power stirrer of the enclosed type is recommended. Rolling a drum in which a mix has been made is not satisfactory.

A2.7 Apparatus for Handling Tetraethyllead

A2.7.1 The apparatus required for handling TEL and for adding it to reference fuels or samples is as follows:

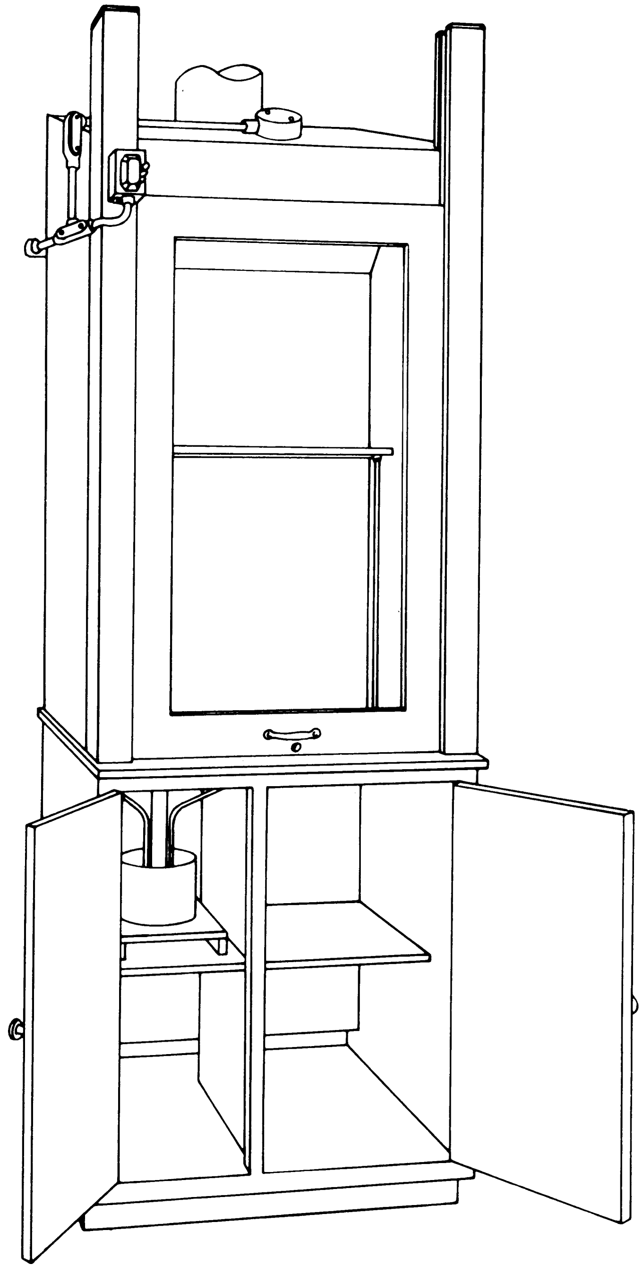
A2.7.1.1 *Blending Hood*—It is recommended that the hood shown in Fig. A2.1, or its equivalent (see A2.11), be used for all blending work.

A2.7.1.2 *Gloves, Apron, and Gas Mask*—The handling of TEL by laboratory workers in making small mixes with litre cans for experimental purposes, or in any other manner, shall be done with the same precautions as are required of workmen in mixing plants. Such activities must be confined strictly to legitimate testing and experimental procedures. In all instances, a rubber apron and rubber gloves, impervious to TEL, must be worn. If the handling of TEL is done outside a blending hood, a gas mask must also be worn (see A2.11). The mask must have a rubber face piece covering the entire face, eyes, nose, and mouth, with eyepieces of splinter-proof glass, a rubber breathing tube, and a cannister separate from the face piece, containing not less than 500 mL of high-grade activated charcoal. The apron must be of heavy rubber or rubberized cloth, while the gloves must be heavy enough to stand average use without tearing, and yet of such thinness and pliability as to permit precision in carrying out necessary manipulations. Gloves and aprons made of neoprene or synthetic rubber are permissible.

A2.7.1.3 *Measuring Burets*—Self-filling burets are recommended for use in measuring concentrated TEL (see A2.11).

A2.8 Adding Concentrated Tetraethyllead to Fuels

A2.8.1 Blends containing TEL may be prepared in several ways. Some laboratories prefer to add the necessary TEL to individual batches as required; others prefer to prepare a drum of *iso*octane with a TEL content of 6 mL/U.S. gal and then make blends of it with the corresponding clear fuel in the same manner as for blends of *iso*octane and *n*-heptane.



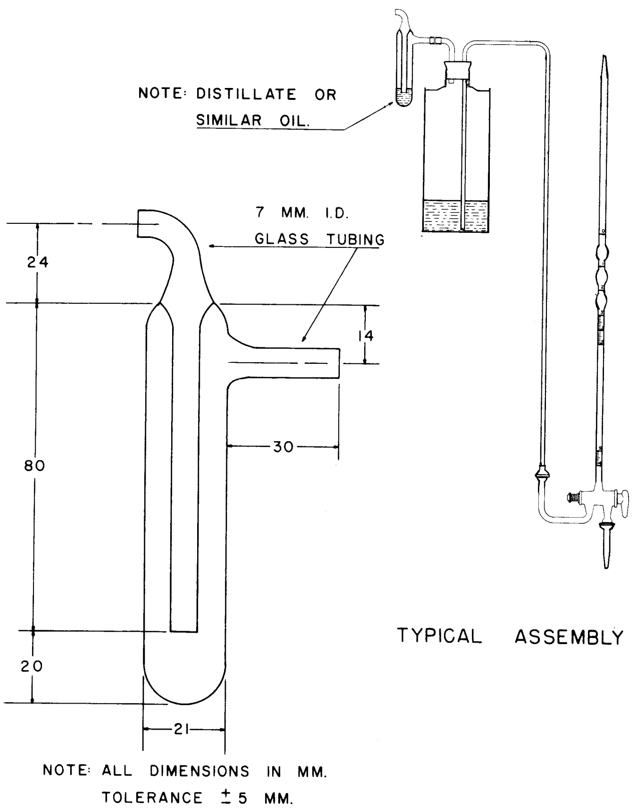
This hood to be used only for storage and handling of lead alkyls and apparatus. Blower must be kept running when any door is open.Hood must be kept locked when not in use.

FIG. A2.1 Laboratory Hood and Vapor Trap for Handling Tetraethyllead

A2.8.1.1 *Blending Hood*—It is recommended that the hood (see Fig. A2.1) be used for all blending work.

A2.8.1.2 *Blending Procedure*—Since fuel blends of several gallons will be required frequently, it is expedient to treat them with concentrated TEL rather than with the dilute fluid used in other laboratory knock testing. For convenience, and to avoid spillage, a self-filling buret (see A2.11) should be used to

[10] These safety precautions have been approved by the Safety and Medical Departments of both Ethyl Corporation and E. I. du Pont de Nemours and Co., Inc.



Hood bottom of No. 18 gage sheet metal (or other approved material) with 1 in.
wide drain pitched to left side 1 in. deep.
All joints must be tight and carefully sealed with putty-like cement (or equivalent).
Permanent baffle to be constructed of No. 18 gage steel (or other approved material). Slope as shown.
Automatic door switch for fan and light, optional.
Vapor-proof light fitting.
Blower capacity sufficient to maintain an air velocity between 125 and 175 ft/min
across front of door.
The metal drainage container must have a volume twice that of the tetraethyllead
containers in the hood, and be half filled with kerosine.

FIG. A2.1 *(continued)*

measure the quantities required. A 50-mL size is adequate for 5-gal batches at concentrations up to 6 mL/U.S. gal. For accuracy on small blends, a small buret may be more satisfactory. The tops of burets containing TEL should be connected with vapor traps as shown in the safety pamphlets of the suppliers (see A2.11). After the entrance tube of the buret has been inserted in the TEL reservoir, a ⅙-in. blanket of glycerin should be poured on top of the fluid to exclude contact with air and reduce evaporation.

A2.8.1.3 *Temperature Corrections*—For accuracy, the fuel batches must be measured carefully in standardized containers. Since a temperature correction is difficult to apply to fuels, it is convenient to adjust the quantity of concentrated TEL added. If the temperature of the fuel is below that of the TEL, the quantity of the latter is increased and *vice versa*. The coefficient of expansion of concentrated TEL may be obtained from the supplier (see Section A2.10). Computation of correction is simplified by use of Table A2.1 of the ASTM-IP Petroleum Measurement Tables (American Edition).[11]

A2.8.1.4 *Analysis for TEL*—It is recommended that each blend of fuel, particularly drum blends, be analyzed for lead content in accordance with Test Method D 2599, D 3237, or D 3341.

A2.9 Reference Materials

A2.9.1 Specifications for ASTM knock test reference fuels are given in Table A2.1.

A2.9.2 *ASTM Certification* is based on the physical properties of the sample. Engine tests are made to confirm the octane number. Suppliers are required to maintain segregated batches of *iso*octane and *n*-heptane that have been certified by the American Society for Testing and Materials as conforming to the specifications in A2.9.1. A certificate is issued to the suppliers authorizing them to guarantee that the material shipped is a part of the batch so tested and to quote the results of the tests. Maintenance of the quality of ASTM knock test reference fuels is the responsibility of the suppliers.

A2.9.3 The National Bureau of Standards has established a supply of *iso*octane and *n*-heptane of determined purity and designated them as standard reference materials (SRM). *Iso*octane (2,2,4-trimethylpentane) has been assigned SRM No. 1816 and *n*-heptane has been assigned No. 1815. The purity of *iso*octane, SRM 1816, is 99.98 % and that of *n*-heptane, SRM 1815, is 99.87 %. The principal use for these materials is in certifying the commercially produced ASTM knock test reference fuels. The SRMs are maintained by the National Bureau of Standards.

A2.9.4 *Tetraethyllead* used in primary reference *iso*octane for ratings above 100 octane number shall be in the form of a concentrated antiknock mixture (aviation mix) containing not less than 61.0 weight % of tetraethyllead and sufficient ethylene dibromide to provide two bromine atoms per atom of lead. The balance of the antiknock mixture shall be kerosine, a

[11] Available from B. G. Corp., 136 W. 52nd St., New York, NY 10019.

TABLE A2.1 Specifications for ASTM Knock Test Reference Fuels

	ASTM *Iso*octane	ASTM *n*-Heptane	ASTM 80 O. N. Blend
ASTM-IP Motor Octane No.^{A}	—	—	Nominal ± 0.1
*Iso*octane,^{B} %	not less than 99.75	not greater than 0.10	—
n-Heptane,^{B} %	not greater than 0.10	not less than 99.75	—
Lead Content,^{C} g/gal	not greater than 0.002	not greater than 0.002	

^{A} Determined in accordance with Test Method D 2700-IP 236.
^{B} Determined in accordance with Method D 2268.
^{C} To be determined in the certification test in accordance with Method D 1368.

suitable oxidation inhibitor, and an oil-soluble dye to provide a distinctive color for identification. The specifications for this material are as follows: When the concentrated antiknock mixture is added to 80.0 octane primary reference fuel at a concentration of 2.00 mL TEL per U.S. gallon at 60°F, as calculated from the volumetric dilution and the TEL content stated on the label, the blend shall meet both of the following conditions:

A2.9.4.1 The average of three analyses by either Test Method D 2599, D 3237, or D 3341 shall show 2.11 ± 0.10 g of elemental lead per U.S. gallon.

A2.9.4.2 Engine tests shall show a research octane number of 94.1 ± 0.3 by Test Method D 2699.

A2.10 Availability of Reference Materials

A2.10.1 The following information on the availability of reference materials is furnished for the convenience of users and is not intended to favor any particular supplier. Information concerning the certification of reference materials may be obtained from the President, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428–2959. Reference materials that have been certified as meeting the specified requirements are acceptable, regardless of source. Reference materials are currently available as follows:

ASTM Isooctane:
Chevron Phillips Chemical Company LP
1301 McKinney, Suite 2130
Houston, TX 77010–3030
Phillips Petroleum Co.-Latin America
Bridgestone One
2600 N. Loop West
Houston, TX 77092
Phillips Petroleum Co.-Asia
4106 Gloucester Tower
The Landmark
11 Pedder Street, Central
Hong Kong
Haltermann Gmb H
Schopenstehl 15
20095 Hamburg
Germany

ASTM n-Heptane:
Chevron Phillips Chemical Company LP
1301 McKinney, Suite 2130
Houston, TX 77010–3030
Phillips Petroleum Co.-Latin America
Bridgestone One
2600 N. Loop West
Houston, TX 77092
Phillips Petroleum Co.-Asia
4106 Gloucester Tower
The Landmark
11 Pedder Street, Central
Hong Kong
Haltermann Gmb H
Schopenstehl 15
D 20095 Hamburg
Germany

ASTM 80 Octane Number Blend:
Chevron Phillips Chemical Company LP
1301 McKinney, Suite 2130
Houston, TX 77010–3030
Phillips Petroleum Co.-Latin America
Bridgestone One
2600 N. Loop West
Houston, TX 77092
Phillips Petroleum Co.-Asia
4106 Gloucester Tower
The Landmark
11 Pedder Street, Central
Hong Kong

du Pont Tetraethyllead Compound-Aviation Mix :
E. I. du Pont de Nemours & Co., Inc.
Petroleum Chemicals Division
Wilmington, DE 19898

Pamphlet,"Regulations Governing the Handling and Blending of du Pont Tetraethyllead Compounds" :
E. I. du Pont de Nemours & Co., Inc.
Medical Director
Petroleum Chemicals Division
Wilmington, DE 19898

Aviation Check Fuel (100–130 Grade):
Chevron Phillips Chemical Company LP
1301 McKinney, Suite 2130
Houston, TX 77010–3030
Phillips Petroleum Co.-Latin America
Bridgestone One
2600 N. Loop West
Houston, TX 77092
Phillips Petroleum Co.-Asia
4106 Gloucester Tower
The Landmark
11 Pedder Street, Central
Hong Kong

Aviation Check Fuel (115–145 Grade):
Chevron Phillips Chemical Company LP
1301 McKinney, Suite 2130
Houston, TX 77010–3030
Phillips Petroleum Co.-Latin America
Bridgestone One
2600 N. Loop West
Houston, TX 77092
Phillips Petroleum Co.-Asia
4106 Gloucester Tower
The Landmark
11 Pedder Street, Central
Hong Kong

A2.11 Availability of Blending Accessories

A2.11.1 The following information on the availability of blending accessories is furnished for the convenience of users and is not intended to be a complete list or to favor any particular supplier:

Burets for Measuring Concentrated and Dilute Tetraethyllead:
Scientific Glass Apparatus Co.
105 Lakewood Terrace
Bloomfield, NJ 07003

Ace Glass, Inc.
1938 N. W. Boulevard
Vineland, NJ 08360

Core Lab Refinery Systems
19 Roszel Road
Princeton, NJ 08540

Gas Masks for Use When Handling Tetraethyllead:

Either EA 15765 or
EA 17955 Mask (G. M. A. Catalog ED 3045 cannister)

Mines Safety Appliances Co.
Braddock, Thomas, and Meade Sts.
Pittsburgh, PA 15208

4121-T Mask with Cannister OC-1 (This cannister hangs on user's back) or 4101 Mask with cannister C-1

Davis Emergency Equipment Co.
45 Halleck St.
Newark, NJ 07104

Laboratory Hood for Handling Tetraethyllead:

Core Lab Refinery Systems
19 Roszel Rd.
Princeton, NJ 08540

Partial Drum Mixing (PDM) Equipment (which utilizes 10-gal drums of concentrated Tetraethyl-lead mounted on scales):

E. I. du Pont de Nemours & Co., Inc.
Petroleum Chemicals Division
Wilmington, DE 19898

A2.12 Availability of Tables and Charts

A2.12.1 Copies of the following tables and charts are available from ASTM International Headquarters.

A2.12.1.1 *Reference Fuel Framework, Supercharge Method*, shown in facsimile in Fig. 4, has been reproduced on durable thin paper suitable for reproduction by photo-lithographing, blue-printing, or other processes and is avilable as an adjunct.[8]

A2.12.1.2 *Data Sheets, Supercharge Method*, suitable for recording test data either by the operator or a typist. A facsimile is shown in Fig. A2.3. The data sheets are available as an adjunct.[12]

[12] Available in pads of 50 sheets (8 ½ by 11 in.) from ASTM International. Request ADJD090901.

FORM NO. 909-A

DATA SHEET FOR ASTM SUPERCHARGE METHOD (D909)

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 RACE ST., PHILADELPHIA, PA. 19103

DATA SHEET NO.________
FRAME WORK NO.________

COMPANY________ DATE________ BAROM.________

ENGINE NO.________ TIME METER________ CYL. HR. SINCE OVERHAUL______ TOTAL CYL. HR.______ OPERATOR________

FUEL________

TEMP. °F: COOLANT______ AIR IN______ ORIFICE AIR______ OIL______

PRESSURE, PSI.: OIL______ FUEL______ ORIFICE______

MANIFOLD PRESSURE, IN. Hg.	MINUTES FOR 0.25 LB.			BMEP.	FMEP.	IMEP.	FUEL-AIR RATIO	REMARKS
	AIR	FUEL						

FUEL________

TEMP. °F: COOLANT______ AIR IN______ ORIFICE AIR______ OIL______

PRESSURE, PSI.: OIL______ FUEL______ ORIFICE______

MANIFOLD PRESSURE, IN. Hg.	MINUTES FOR 0.25 LB.			BMEP.	FMEP.	IMEP.	FUEL-AIR RATIO	REMARKS
	AIR	FUEL						

FUEL________

TEMP. °F: COOLANT______ AIR IN______ ORIFICE AIR______ OIL______

PRESSURE, PSI.: OIL______ FUEL______ ORIFICE______

MANIFOLD PRESSURE, IN. Hg.	MINUTES FOR 0.25 LB.			BMEP.	FMEP.	IMEP.	FUEL-AIR RATIO	REMARKS
	AIR	FUEL						

FUEL________

TEMP. °F: COOLANT______ AIR IN______ ORIFICE AIR______ OIL______

PRESSURE, PSI.: OIL______ FUEL______ ORIFICE______

MANIFOLD PRESSURE, IN. Hg.	MINUTES FOR 0.25 LB.			BMEP.	FMEP.	IMEP.	FUEL-AIR RATIO	REMARKS
	AIR	FUEL						

FIG. A2.3 Data Sheet

A3. OPERATION

A3.1 Adjusting Clearance Volume

A3.1.1 Micrometer settings are more convenient to use *than compression ratios* and, for this reason, are specified in guide curves and testing instructions. Basic settings, however, are in terms of compression ratio.

A3.1.2 To ensure the use of correct micrometer settings with relation to compression ratio, careful calibration of the combustion chamber volume is required on all new engines before use and on engines in service after each top overhaul. Only the "Bench Tilt" procedure is permissible.

A3.2 Bench Tilt Procedure

A3.2.1 *Mounting and Tilting Cylinder*—Apply a water-pump grease to the two top rings and to the surface of the piston between and above the rings. Insert the piston into the cleaned cylinder with the spark plug and valves in place. Mount the cylinder in the special jig (available from the Waukesha Engine Div.), or a similar device, which has some means of forcing the piston slowly and positively into the cylinder and of tilting the latter 15° from the vertical. Tilt the cylinder 15° so that the threaded ⅞-in. pickup hole plug will be the highest point of the combustion chamber, and move the piston within approximately 1½ in. of the top face of the hole.

A3.2.2 *Volume of Water*—Based on cylinder size and type of pickup hole plug in use, the volume of water specified in the following table should be used for measurement of combustion chamber volume in millilitres:

Cylinder Size	Waukesha Plug	Detonation Meter Pickup
Standard	108.0	106.0
0.010 in. Oversize	108.6	106.6
0.020 in. Oversize	109.2	107.2
0.030 in. Oversize	109.8	107.8

Both the cylinder and water should be at the same temperature before starting this measurement, and a clean buret should be used for the operation. Put the appropriate volume of water into the cylinder pickup hole.

A3.2.3 *Piston Position*—While the cylinder is still tilted, slowly and positively force the piston up until the pickup hole is half full of water. Then bring the cylinder to a vertical position, making certain that water remains in the hole. Place a straightedge across the spot (machined) face of the hole and force the piston up until the water just touches the straightedge. Be careful that the motion of the piston is always upward so that the rings do not change position in the grooves. If the piston is moved too far, remove it, wipe the oil and water from both piston and cylinder, and repeat the procedure.

A3.2.4 *Basic Measurement*—Remove the water from the combustion chamber with a pipet, being careful not to change the position of the piston. Measure to the nearest 0.002 in. the distance between the spot face of the pickup hole and the top of the piston, using a depth gage of the micrometer type. (A gage for this purpose is available from Waukesha Engine Div.)

TABLE A3.1 Conversion of Micrometer Reading to Compression Ratio for Supercharge Method

Micrometer Reading	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	Micrometer Reading
	Compression Ratio										
0.000	10.00	9.98	9.96	9.95	9.93	9.91	9.89	9.88	9.86	9.84	0.000
0.010	9.82	9.81	9.79	9.77	9.75	9.74	9.72	9.70	9.69	9.67	0.010
0.020	9.65	9.64	9.62	9.60	9.59	9.57	9.56	9.54	9.52	9.51	0.020
0.030	9.49	9.47	9.46	9.44	9.43	9.41	9.40	9.38	9.36	9.35	0.030
0.040	9.33	9.32	9.30	9.29	9.27	9.26	9.24	9.23	9.21	9.20	0.040
0.050	9.18	9.17	9.15	9.14	9.12	9.11	9.09	9.08	9.06	9.05	0.050
0.060	9.04	9.02	9.01	8.99	8.98	8.96	8.95	8.94	8.92	8.91	0.060
0.070	8.89	8.88	8.87	8.85	8.84	8.83	8.81	8.80	8.79	8.77	0.070
0.080	8.76	8.75	8.73	8.72	8.71	8.69	8.68	8.67	8.65	8.64	0.080
0.090	8.63	8.61	8.60	8.59	8.58	8.56	8.55	8.54	8.53	8.51	0.090
0.100	8.50	8.49	8.48	8.46	8.45	8.44	8.43	8.41	8.40	8.39	0.100
0.110	8.38	8.36	8.35	8.34	8.33	8.32	8.31	8.29	8.28	8.27	0.110
0.120	8.26	8.25	8.23	8.22	8.21	8.20	8.19	8.18	8.17	8.15	0.120
0.130	8.14	8.13	8.12	8.11	8.10	8.09	8.08	8.06	8.05	8.04	0.130
0.140	8.03	8.02	8.01	8.00	7.99	7.98	7.97	7.96	7.94	7.93	0.140
0.150	7.92	7.91	7.90	7.89	7.88	7.87	7.86	7.85	7.84	7.83	0.150
0.160	7.82	7.81	7.80	7.79	7.78	7.77	7.76	7.75	7.74	7.73	0.160
0.170	7.72	7.71	7.70	7.69	7.68	7.67	7.66	7.65	7.64	7.63	0.170
0.180	7.62	7.61	7.60	7.59	7.58	7.57	7.56	7.55	7.54	7.53	0.180
0.190	7.52	7.51	7.50	7.49	7.48	7.47	7.47	7.46	7.45	7.44	0.190
0.200	7.43	7.42	7.41	7.40	7.39	7.38	7.37	7.36	7.36	7.35	0.200

TABLE A3.1 *Continued*

Micro-meter Reading	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	Micro-meter Reading
0.210	7.34	7.33	7.32	7.31	7.30	7.29	7.28	7.28	7.27	7.26	0.210
0.220	7.25	7.24	7.23	7.22	7.22	7.21	7.20	7.19	7.18	7.17	0.220
0.230	7.16	7.16	7.15	7.14	7.13	7.12	7.11	7.11	7.10	7.09	0.230
0.240	7.08	7.07	7.06	7.06	7.05	7.04	7.03	7.02	7.02	7.01	0.240
0.250	7.00	6.99	6.98	6.98	6.97	6.96	6.95	6.94	6.94	6.93	0.250
0.260	6.92	6.91	6.91	6.90	6.89	6.88	6.87	6.87	6.86	6.85	0.260
0.270	6.84	6.84	6.83	6.82	6.81	6.81	6.80	6.79	6.78	6.78	0.270
0.280	6.77	6.76	6.75	6.75	6.74	6.73	6.73	6.72	6.71	6.70	0.280
0.290	6.70	6.69	6.68	6.67	6.67	6.66	6.65	6.65	6.64	6.63	0.290
0.300	6.62	6.62	6.61	6.60	6.60	6.59	6.58	6.58	6.57	6.56	0.300
0.310	6.56	6.55	6.54	6.54	6.53	6.52	6.51	6.51	6.50	6.49	0.310
0.320	6.49	6.48	6.47	6.47	6.46	6.45	6.45	6.44	6.43	6.43	0.320
0.330	6.42	6.42	6.41	6.40	6.40	6.39	6.38	6.38	6.37	6.36	0.330
0.340	6.36	6.35	6.34	6.34	6.33	6.33	6.32	6.31	6.31	6.30	0.340
0.350	6.29	6.29	6.28	6.28	6.27	6.26	6.26	6.25	6.24	6.24	0.350
0.360	6.23	6.23	6.22	6.21	6.21	6.20	6.20	6.19	6.18	6.18	0.360
0.370	6.17	6.17	6.16	6.15	6.15	6.14	6.14	6.13	6.13	6.12	0.370
0.380	6.11	6.11	6.10	6.10	6.09	6.08	6.08	6.07	6.07	6.06	0.380
0.390	6.06	6.05	6.04	6.04	6.03	6.03	6.02	6.02	6.01	6.01	0.390
0.400	6.00	5.99	5.99	5.98	5.98	5.97	5.97	5.96	5.96	5.95	0.400
0.410	5.95	5.94	5.93	5.93	5.92	5.92	5.91	5.91	5.90	5.90	0.410
0.420	5.89	5.89	5.88	5.88	5.87	5.86	5.86	5.85	5.85	5.84	0.420
0.430	5.84	5.83	5.83	5.82	5.82	5.81	5.81	5.80	5.80	5.79	0.430
0.440	5.79	5.78	5.78	5.77	5.77	5.76	5.76	5.75	5.75	5.74	0.440
0.450	5.74	5.73	5.73	5.72	5.72	5.71	5.71	5.70	5.70	5.69	0.450
0.460	5.69	5.68	5.68	5.67	5.67	5.66	5.66	5.65	5.65	5.64	0.460
0.470	5.64	5.63	5.63	5.62	5.62	5.62	5.61	5.61	5.60	5.60	0.470
0.480	5.59	5.59	5.58	5.58	5.57	5.57	5.56	5.56	5.55	5.55	0.480
0.490	5.55	5.54	5.54	5.53	5.53	5.52	5.52	5.51	5.51	5.50	0.490
0.500	5.50	5.50	5.49	5.49	5.48	5.48	5.47	5.47	5.46	5.46	0.500
0.510	5.46	5.45	5.45	5.44	5.44	5.43	5.43	5.42	5.42	5.42	0.510
0.520	5.41	5.41	5.40	5.40	5.39	5.39	5.39	5.38	5.38	5.37	0.520
0.530	5.37	5.36	5.36	5.36	5.35	5.35	5.34	5.34	5.34	5.33	0.530
0.540	5.33	5.32	5.32	5.31	5.31	5.31	5.30	5.30	5.29	5.29	0.540
0.550	5.29	5.28	5.28	5.27	5.27	5.27	5.26	5.26	5.25	5.25	0.550
0.560	5.25	5.24	5.24	5.23	5.23	5.23	5.22	5.22	5.21	5.21	0.560
0.570	5.21	5.20	5.20	5.19	5.19	5.19	5.18	5.18	5.17	5.17	0.570
0.580	5.17	5.16	5.16	5.16	5.15	5.15	5.14	5.14	5.14	5.13	0.580
0.590	5.13	5.12	5.12	5.12	5.11	5.11	5.11	5.10	5.10	5.09	0.590
0.600	5.09	5.09	5.08	5.08	5.08	5.07	5.07	5.07	5.06	5.06	0.600
0.610	5.05	5.05	5.05	5.04	5.04	5.04	5.03	5.03	5.03	5.02	0.610
0.620	5.02	5.01	5.01	5.01	5.00	5.00	5.00	4.99	4.99	4.99	0.620
0.630	4.98	4.98	4.98	4.97	4.97	4.96	4.96	4.96	4.95	4.95	0.630
0.640	4.95	4.94	4.94	4.94	4.93	4.93	4.93	4.92	4.92	4.92	0.640
0.650	4.91	4.91	4.91	4.90	4.90	4.90	4.89	4.89	4.89	4.88	0.650
0.660	4.88	4.88	4.87	4.87	4.87	4.86	4.86	4.86	4.85	4.85	0.660
0.670	4.85	4.84	4.84	4.84	4.83	4.83	4.83	4.82	4.82	4.82	0.670
0.680	4.81	4.81	4.81	4.80	4.80	4.80	4.79	4.79	4.79	4.78	0.680
0.690	4.78	4.78	4.78	4.77	4.77	4.77	4.76	4.76	4.76	4.75	0.690
0.700	4.75	4.75	4.74	4.74	4.74	4.73	4.73	4.73	4.73	4.72	0.700
0.710	4.72	4.72	4.71	4.71	4.71	4.70	4.70	4.70	4.69	4.69	0.710
0.720	4.69	4.69	4.68	4.68	4.68	4.67	4.67	4.67	4.66	4.66	0.720
0.730	4.66	4.66	4.65	4.65	4.65	4.64	4.64	4.64	4.63	4.63	0.730
0.740	4.63	4.63	4.62	4.62	4.62	4.61	4.61	4.61	4.61	4.60	0.740
0.750	4.60	4.60	4.59	4.59	4.59	4.59	4.58	4.58	4.58	4.57	0.750
0.760	4.57	4.57	4.57	4.56	4.56	4.56	4.55	4.55	4.55	4.55	0.760
0.770	4.54	4.54	4.54	4.53	4.53	4.53	4.53	4.52	4.52	4.52	0.770
0.780	4.52	4.51	4.51	4.51	4.50	4.50	4.50	4.50	4.49	4.49	0.780
0.790	4.49	4.49	4.48	4.48	4.48	4.47	4.47	4.47	4.47	4.46	0.790
0.800	4.46	4.46	4.46	4.45	4.45	4.45	4.45	4.44	4.44	4.44	0.800

TABLE A3.1 *Continued*

Micro-meter Reading	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	Micro-meter Reading
0.810	4.44	4.43	4.43	4.43	4.42	4.42	4.42	4.42	4.41	4.41	0.810
0.820	4.41	4.41	4.40	4.40	4.40	4.40	4.39	4.39	4.39	4.39	0.820
0.830	4.38	4.38	4.38	4.38	4.37	4.37	4.37	4.37	4.36	4.36	0.830
0.840	4.36	4.36	4.35	4.35	4.35	4.35	4.34	4.34	4.34	4.34	0.840
0.850	4.33	4.33	4.33	4.33	4.32	4.32	4.32	4.32	4.31	4.31	0.850
0.860	4.31	4.31	4.30	4.30	4.30	4.30	4.29	4.29	4.29	4.29	0.860
0.870	4.28	4.28	4.28	4.28	4.28	4.27	4.27	4.27	4.27	4.26	0.870
0.880	4.26	4.26	4.26	4.25	4.25	4.25	4.25	4.24	4.24	4.24	0.880
0.890	4.24	4.24	4.23	4.23	4.23	4.23	4.22	4.22	4.22	4.22	0.890
0.900	4.21	4.21	4.21	4.21	4.21	4.20	4.20	4.20	4.20	4.19	0.900
0.910	4.19	4.19	4.19	4.18	4.18	4.18	4.18	4.18	4.17	4.17	0.910
0.920	4.17	4.17	4.16	4.16	4.16	4.16	4.16	4.15	4.15	4.15	0.920
0.930	4.15	4.14	4.14	4.14	4.14	4.14	4.13	4.13	4.13	4.13	0.930
0.940	4.12	4.12	4.12	4.12	4.12	4.11	4.11	4.11	4.11	4.11	0.940
0.950	4.10	4.10	4.10	4.10	4.09	4.09	4.09	4.09	4.09	4.08	0.950
0.960	4.08	4.08	4.08	4.08	4.07	4.07	4.07	4.07	4.07	4.06	0.960
0.970	4.06	4.06	4.06	4.05	4.05	4.05	4.05	4.05	4.04	4.04	0.970
0.980	4.04	4.04	4.04	4.03	4.03	4.03	4.03	4.03	4.02	4.02	0.980
0.990	4.02	4.02	4.02	4.01	4.01	4.01	4.01	4.01	4.00	4.00	0.990
1.000	4.00										1.000

A3.2.5 *Installing Piston and Cylinder*—Remove the piston, wipe off the water-pump grease, and dry the cylinder wall and spark plug. Install the piston and cylinder on the engine, making sure that the nuts holding the cylinder sleeve to the crankcase are tight. Set the piston at top dead center (tdc) and raise or lower the cylinder with the crank until the distance from the spot face of the threaded ⅞-in. pickup hole to the top of the piston as measured by the depth gage is the same as the basic measurement in A3.2.4. Lock the cylinder sleeve, and set the micrometer on the side of the cylinder sleeve to read 0.250 in. Although the variable compression feature is not used, it is advisable to set the micrometer at 0.250 in. so that the cylinder height may be checked.

A3.3 Calculation of Compression Ratio

A3.3.1 Although the compression ratio is held constant (7.0 to 1), it can be varied and depends upon the cylinder position with respect to the piston. The compression ratio is the ratio of the volume of the combustion chamber when the piston is at bottom dead center (bdc) to the volume when the piston is at tdc. The piston has a stroke of 4.50 in. (114 mm) and a displacement of 37.33 in.^{3} (611.73 cm^3). This volume is the same as that of a 4.50-in. segment of the cylinder. When the piston is at tdc with the cylinder position set for a micrometer reading of 0.000 in., the volume of the combustion chamber is 4.15 in. (0.82 cm^3). This volume is the same as that of a 0.50-in. segment of the cylinder. If the clearance volume has been determined carefully and the micrometer scale has been set accurately, as described in Section A3.2, the compression ratio of the engine for any position of the cylinder may be calculated from the equation:

$$C = (4.50 + 0.50 + m)/(0.50 + m) \quad \text{(A3.1)}$$
$$= (4.50/(0.50 + m)) + 1$$

where:

C = compression ratio, and
m = micrometer reading

Values for conversion of micrometer reading to compression ratio are given in Table A3.1. The compression ratio of 7.0 to 1 specified for the test method corresponds to a micrometer reading of 0.250 in.

A3.4 Preparations Before Starting Unit

A3.4.1 Fill the crankcase with SAE 50 oil to the proper level (see A4.35.1). An additional quart is required for the first filling of engines equipped with oil filters and after the oil filters have been renewed. Operating oil levels for both types of crankcases should not exceed the mid-point of the sight glass. Too much oil in the crankcase will allow the balance weights to contact the oil and result in splashing and excessive oil consumption. On engines in service, the oil level should be checked carefully at the start of daily operations and replenished to the desired level if low. Recommendations for changing oil are given in Section A4.35.

A3.4.2 Pour SAE 30 oil into the reservoir of the injection pump through the filler opening *M* (see Fig. A1.7) until the level reaches the center of the sight glass. Remove the breather plug *R* and pour in a few millilitres of oil to ensure initial lubrication of the tappet roller and plunger. The recommended time between injection-pump oil changes is the same as that for the crankcase. If the oil acquires a strong gasoline odor or if there is a marked rise in its level, excessive dilution is indicated. When excessive dilution occurs, frequent oil changes will extend the usable life of the pump. Rather than using this means, except in an emergency, the cause of dilution should be located and corrected.

A3.4.3 *Dynamometer Dashpot*—For the dashpot, use an engine oil having a Saybolt Universal viscosity of 290 s at the *operating* temperature of the dashpot, usually 80 to 85°F (27 to 29°C). Pour 400 to 425 mL of the oil into the dashpot through the filler opening *A* (see Fig. A1.21). Be sure sufficient oil is used to keep the dashpot plunger submerged at the extreme operating positions of the dynamometer cradle. The viscosity of the oil is important; it must be high enough to give stability to the pointer of the dynamometer scale and yet low enough to permit fraction readings in 10 s. For dashpot adjustments see Section A4.56.

A3.4.4 *Fuel Transfer Pump* (**Warning**—Before starting a new or replacement transfer pump *X* (see Fig. A1.10), remove the inlet connection and prime with kerosine to avoid damaging the pump when the engine is started.)

A3.4.5 *Cooling System*—Use ethylene glycol as the coolant, with enough water added (1 to 2 %) to maintain the specified operating temperature. Twenty-one grams (1 weight %) of sodium *nitrite* or triethanolamine phosphate may be added as a corrosion inhibitor if no other inhibitor is present. Pour the coolant into the condenser through the filler opening *G* (see Fig. A1.10) until the coolant level is ½ to ¾ in. above the bottom of the sight glass. When the engine has reached operating temperature, the coolant level should be at the "operating level" mark on the side of the condenser.

A3.4.6 *Spark Plug*—Make sure that the spark plug is clean and that the gap is 0.020 ± 0.003 in. Instructions for cleaning or replacing the spark plug are given in Section A4.50.

A3.5 Setting Controls for Starting

A3.5.1 When a cold unit is to be started, perform the following operations in the order given:

A3.5.1.1 *Oil Heater*—Turn the oil-heater switch *Q* (see Fig. A1.10) to HIGH to warm the crankcase oil .

A3.5.1.2 *Water Supply*—Turn on the water supply to the condenser, exhaust manifold, spray ring, and fuel cooler (see Fig. A1.1).

A3.5.1.3 *Dynamometer*—Lock the dynamometer frame by moving the lever *T* (see Fig. A1.10) to the left. It must always be in this position for starting.

A3.5.1.4 *Manometers*—Each day, before admitting air to the induction system, adjust the water manometer *H* (see Fig. A3.1) to read zero by turning the knob at the bottom, and also adjust the mercury manometer *M* (see Fig. A1.10) to the prevailing barometric pressure by turning knob *S*.

A3.5.1.5 *Fuel Supply*—Use fuel of high enough antiknock value to give knockfree operation during the 1-h warm-up period. Check the fuel container frequently as *it must never be allowed to run dry while the engine is running*. Also, since the pump depends on fuel for lubrication and may be damaged if allowed to run dry, the engine should not be motored (driven by the dynamometer) without circulation of fuel through the pump.

A3.5.1.6 *Fuel Supply Valves*—Set both fuel valves *R* (see Fig. A1.10) in the vertical position. This permits the fuel to circulate through the supply and injection pumps when the engine is started. This is important, as explained in A3.5.1.5.

A3.5.1.7 *Fuel-Injection Controls*—Pull out the fuel-injection control knobs *O* (see Fig. A1.10) as far as they will go, to prevent fuel injection while motoring the engine. On engines that have a micrometer-fuel control mounted on the pump (not illustrated), keep the injection control lever in the OFF position while motoring the engine.

A3.5.1.8 *High Pressure Air-Control Valves*—Close the air-pressure control and bleed valves *P* (see Fig. A1.10).

A3.5.1.9 *Air Supply Condensate Valve*—Open the bleed valve *L* (see Fig. A1.10) to discharge all condensation from the air supply line. Close this valve as soon as all moisture is removed from the line.

A3.5.1.10 *Main Air Supply*—Open the main air-supply valve *N* (see Fig. A1.11) to admit compressed air into the induction system.

A3.5.1.11 *Adjusting High-Pressure Air-Control Valves*—Read the barometer and *very slowly* open slightly the left-hand air-pressure control valve, and observe the pressure gage *A* (see Fig. A3.2). Be careful not to open the valve suddenly as the liquid in the 30-in. water manometer will be blown out, and the manometer must then be refilled and the connecting lines blown dry. Close the valve when the pressure reaches that given in Table A3.2 within ±0.5 psi (3.4 kPa) for the prevailing barometric pressure. If the pressure rises too high, it can be lowered by opening the right-hand air-control valve very slightly. This reduces the pressure in the diaphragm chamber of the air-control valve *J* (see Fig. A1.10).

A3.5.1.12 *Atmospheric Bleed Valve*—Turn the bleed valve knob *B* (see Fig. A1.9) fully clockwise to close the valve.

A3.5.1.13 *Manifold Pressure Control Valve*—Turn the control knob *C* (see Fig. A1.9) counterclockwise until the adjusting screw on the valve is nearly all the way out to supply low initial manifold pressure for starting.

A3.5.1.14 *Ignition*—Turn the ignition switch *N* (see Fig. A1.10) to the ON position.

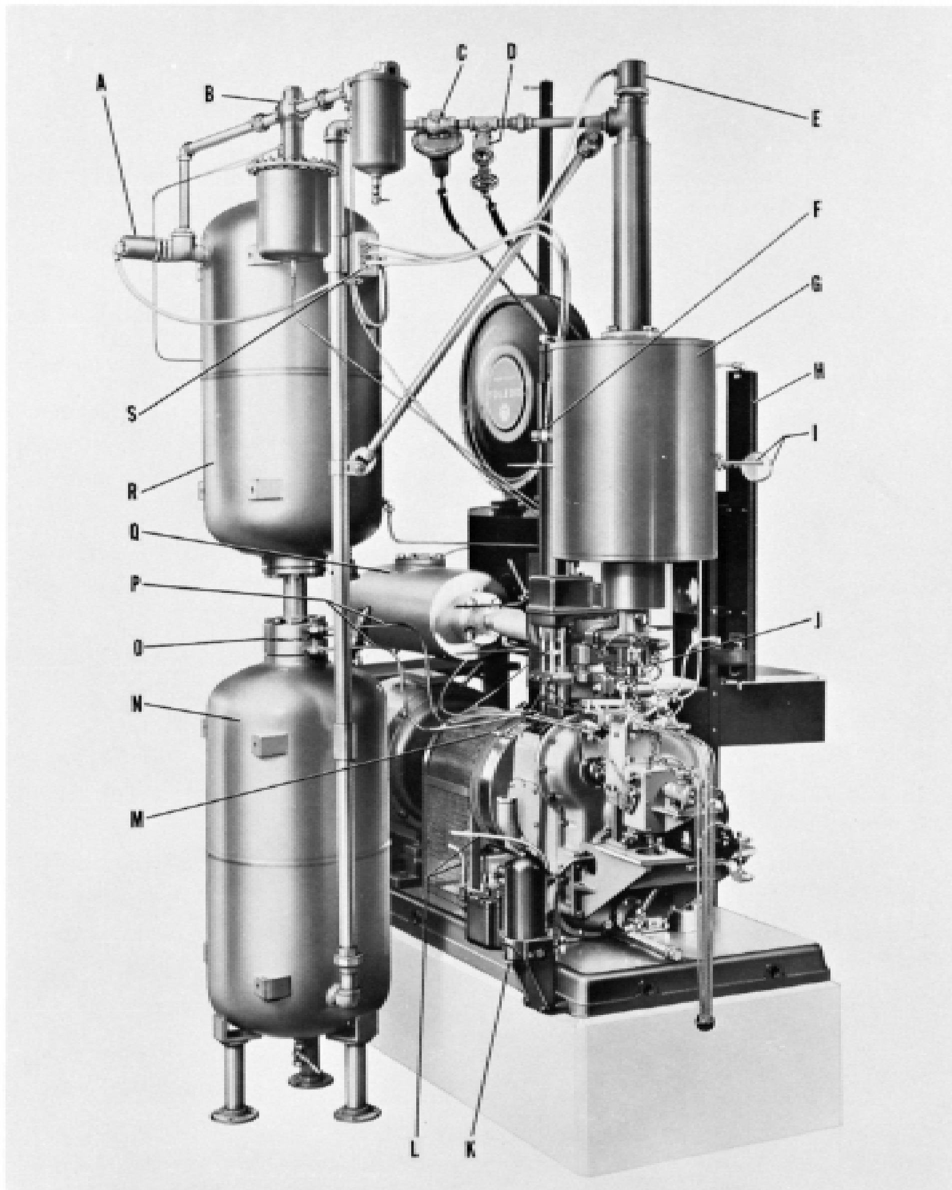
A3.5.1.15 *Oil Temperature*—When the temperature of the oil reaches 100 to 110°F (38 to 43°C) as shown by the indicator *C* (see Fig. A3.2) and the foregoing instructions have been followed, the unit may be started.

A3.5.1.16 *Coolant Thermostat—The first time the unit is started, perform the following additional operation:* Close the contacts of the thermostat *F* (see Fig. A1.10) at the top of the coolant condenser *I* by turning the slotted stem counterclockwise as far as possible. On the first start of the unit the thermostat will thus be set for a temperature higher than normal. The dynamometer circuit will not stay closed if the contacts of this thermostat are open. The thermostat *must* be reset for its normal operating temperature later, as described in A3.8.13. After this adjustment is made, overheating of the coolant will open the thermostat and stop the unit.

A3.6 Starting and Warm-Up

A3.6.1 *Motoring*—Rotate the engine by hand 3 or 4 revolutions to make sure that there is no interference, and that all parts move freely. To start the unit, follow the directions given on the starting compensator mounted on the wall (see Fig. 1). To stop the unit in an emergency, press the red STOP button on the compensator box. (**Warning**—Do not start the unit until the temperature of the oil has reached 110°F (43°C). Otherwise the oil pressure gage may be damaged by excessive pressure.)

A3.6.2 *Observations While Motoring*—While the engine is being motored by the dynamometer, observe gage *D* (see Fig. A3.2) to see that there is an oil pressure of at least 60 psi (0.41 MPa). If not, stop the unit at once to avoid damage, and investigate the trouble. (Sometimes a pressure of 80 psi (0.55

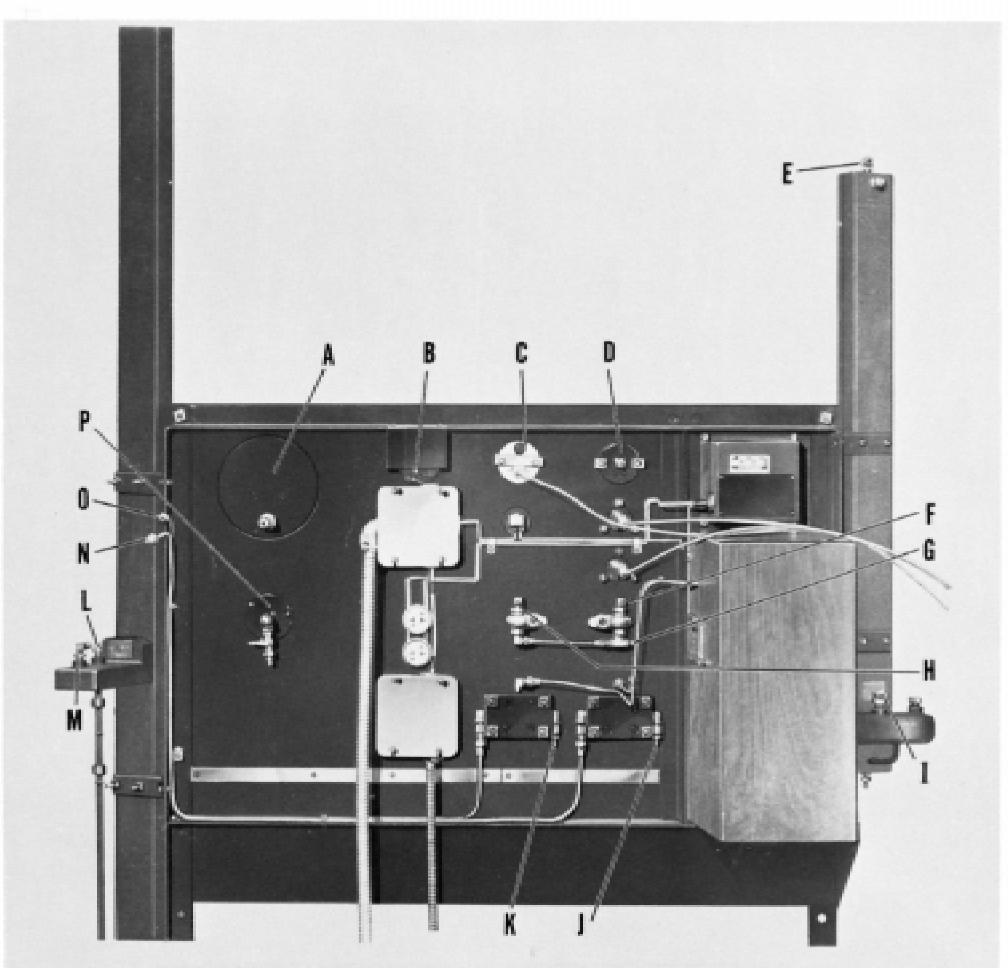


A—1500-W heater
B—Orifice pressure regulating valve
C—Manifold pressure regulating valve
D—Atmospheric bleed valve
E—3000-W heater
F—Surge tank heater thermostat
G—Surge tank
H—Water manometer
I—Surge tank thermometer and magnifying glass
J—Fuel thermometer
K—Oil filter drain
L—Water connections to oil cooler
M—Connection to oil pressure safety switch
N—Downstream orifice tank
O—Orifice plate
P—Orifice connections to water manometer
Q—Exhaust surge tank
R—Upstream orifice tank
S—Main junction box

FIG. A3.1 Rear View of 60-Hz Supercharge Unit

MPa) will be observed for a cold engine, but this is no cause for alarm.) Also observe the fuel-return line (see Fig. A1.8) (the one without the filter), to see that fuel is flowing. If not, stop the unit immediately and investigate.

A3.6.3 *Adjustment of Manifold Pressure*—Adjust the regulating valve *B* (see Fig. A1.10) until the mercury manometer shows a pressure of about 30 in. Hg (101.6 kPa), absolute. Use this pressure while warming the engine.



A—Air Pressure Gage.
B—Hour Meter.
C—Oil Temperature Gage.
D—Oil Pressure Gage.
E—Water Manometer Connection to Downstream Side of Orifice Plate.
F—Connection to Compressed Air Supply.
G—Connection to Bottom of Regulating Valve.
H—Air Bleed Valve Outlet—Leave Open.
I—Water Manometer Connection to Upstream Side of Orifice Plate.
J—Connection for Fuel Supply Pump.
K—Return Line Connection from Fuel Injection Pump.
L—Mercury Manometer Filler Plug.
M—Mercury Manometer Connection to Surge Tank.
N—Suction Line Connection to Fuel Container.
O—Fuel Return Line to Container.
P—Fuel Pressure Gage.

FIG. A3.2 Rear View of Supercharge Control Panel

A3.6.4 *Firing*—Release the vernier adjustment of the upper control knob *F* (see Fig. A1.9) and then push the knob in as far as possible. Release the vernier adjustment of the lower control knob *G* and then slowly push the knob in until the engine starts to fire. Engage the vernier and turn the injection-control knob *G* in or out until the engine fires steadily. On engines with pump-mounted micrometer controls, start fuel injection by manipulation of the fuel-injection lever and adjust the micrometer until the engine fires steadily.

A3.6.5 *Release of Dynamometer Lock and Adjustment of Fuel Feed*—Move the dynamometer locking lever *T* (see Fig. A1.10) to the right. The dynamometer scale then indicates the bmep developed by the engine. Adjust the fuel flow until the reading on the dynamometer scale reaches a maximum. Some readjustment of fuel flow may be necessary, particularly at the beginning, to keep the engine running at maximum power during the 1-h warm-up period.

A3.7 Stopping

A3.7.1 An engine that has been running at high bmep may suffer valve warpage and other damage if brought to a sudden stop, unless the following precautions are taken:

A3.7.1.1 *Fuel Supply*—Transfer the fuel intake line (see Fig. A1.8) (the one with the filter attached) from the fuel-supply can to a can of 100-octane fuel, and run the engine at maximum bmep and a boost pressure of 30 in. Hg (101.6 kPa), absolute. Place the fuel return line into another receptacle until the lines are purged of the original supply, and continue running the engine for 2 min.

A3.7.1.2 *Fuel-Injection Controls*—Shut off fuel injection by pulling the control knob *F* (see Fig. A1.9) out as far as possible. On engines equipped with micrometer controls, shut off fuel injection by manipulation of the fuel-injection lever.

TABLE A3.2 Gage Pressure Required at Various Barometric Pressures for an Absolute Pressure of 54.4 psi (380 kPa)

Barometric Pressure, in. Hg	Gage Pressure, psi (kPa)	Barometric Pressure, in. Hg	Gage Pressure, psi (kPa)
23.0	43.1 (297)	27.0	41.1 (283)
23.2	43.0 (296)	27.2	41.0 (283)
23.4	42.9 (296)	27.4	40.9 (282)
23.6	42.8 (295)	27.6	40.8 (281)
23.8	42.7 (294)	27.8	40.7 (281)
24.0	42.6 (294)	28.0	40.6 (280)
24.2	42.5 (293)	28.2	40.6 (280)
24.4	42.4 (292)	28.4	40.5 (279)
24.6	42.3 (292)	28.6	40.4 (279)
24.8	42.2 (291)	28.8	40.3 (278)
25.0	42.1 (290)	29.0	40.2 (277)
25.2	42.0 (290)	29.2	40.1 (276)
25.4	41.9 (289)	29.4	40.0 (276)
25.6	41.8 (288)	29.6	39.9 (275)
25.8	41.7 (288)	29.8	39.8 (274)
26.0	41.6 (287)	30.0	39.7 (274)
26.2	41.5 (286)	30.2	39.6 (273)
26.4	41.4 (285)	30.4	39.5 (272)
26.6	41.3 (285)	30.6	39.4 (272)
26.8	41.2 (284)	30.8	39.3 (271)

A3.7.1.3 *Dynamometer*—Lock the dynamometer by moving the lever *T* (see Fig. A1.10) to the left as far as possible, and thus be prepared for the next start.

A3.7.1.4 *Stopping the Unit*—Stop motoring the dynamometer by pressing the red STOP button on the compensator box. To avoid accidental starting, open the main powerline switch if the unit is unattended overnight or is to be shut down for any considerable time or during major servicing.

A3.7.1.5 *Atmospheric Bleed Valve*—Slowly turn the control knob *C* (see Fig. A1.10) of the atmospheric bleed valve counterclockwise as necessary to bleed the air tanks to atmospheric pressure.

A3.7.1.6 *Air Supply*—Shut off the main supply of compressed air at the service valve.

A3.7.1.7 *High Pressure Air-Control Valves*—Turn the right-hand bleed valve *P* (see Fig. A1.10) counterclockwise to reduce the pressure on the regulating valve to atmospheric.

A3.7.1.8 *Setting Engine at tdc*—Turn the engine by hand until the piston is at tdc on the compression stroke. Always do this to protect the cylinder wall, piston, valves, and rings from corrosion or damage from fumes to which they might otherwise be exposed.

A3.7.1.9 *Water Supply*—Turn off the cooling water at the main service valve *A* (see Fig. A1.1).

A3.7.1.10 *Oil Heater*—Turn off the crankcase-oil heater switch *Q* (see Fig. A1.10). This is a general rule for prolonged shutdown and in tropical climates where the laboratory temperature seldom is lower than 85°F (29°C). In temperate climates, for overnight shutdown and quick warm-up next morning, the heater switch may be left at LOW, provided the oil supply is normal.

A3.7.1.11 *Fuel Beaker*—Empty the fuel beaker *U* (see Fig. A1.9) and close any open fuel containers.

A3.8 Observations and Adjustments Before Standardizing Unit

A3.8.1 During the warm-up period, observe the various temperatures to see that they do not go higher than those specified below and that the other conditions are also met. This is particularly important the first time the engine is run, as several of the automatic controls will need adjustment. A summary of the major operating conditions is given in Table A3.3.

A3.8.2 *Crankcase Oil Temperature, 165 ± 5°F (74 ± 3°C)*—When the temperature, indicated by the oil thermometer, reaches 165°F, turn the oil-heater switch *Q* (see Fig. A1.10) to LOW. If the temperature continues to rise, turn the switch to the OFF position. A further rise in temperature will necessitate opening the oil-cooler valve *E* (see Fig. A1.1), which should be regulated (in the absence of an automatic control) to keep the oil temperature at 165± 5°F.

A3.8.3 *Oil Pressure, 60 ± 5 psi (0.41 ± 0.03 MPa)*—After the oil temperature has been stabilized at 165 ± 5°F, the oil pressure should be 60 ± 5 psi. To adjust the pressure, remove the cap nut *I* (see Fig. A1.2) from the relief valve, loosen the lock nut, and turn the adjustment screw *inward to raise* the pressure and *outward to lower* it. After making sure that the copper gaskets are in good condition, tighten the lock nut and replace the cap nut.

A3.8.4 *Orifice Air Pressure, 54.4 ± 0.5 psi (0.37 ± 0.003 MPa) Absolute*—Adjust the orifice air pressure as directed in A3.5.1.11.

A3.8.5 *Orifice Air Temperature, 125 ± 5°F (52 ± 3°C)*—Adjust the thermostat *H* (see Fig. A1.10) so that the orifice air reaches the specified temperature as indicated by the orifice air thermometer *E* (see Fig. A1.11). The right-hand pilot light on the panel board lights when current is flowing to the inlet-air heater *A* (see Fig. A1.10).

TABLE A3.3 Summary of Operating Conditions for Supercharge Method

Engine speed, rpm	1800 ± 45
Crankcase oil, SAE grade	50
Oil pressure at operating temperature, psi (MPa)	60 ± 5 (0.41 ± 0.03)
Oil temperature to oil gallery	165 ± 5°F (74 ± 3°C)
Coolant temperature	375 ± 5°F (191±3°C)
Intake air temperature, orifice	125±5°F (52 ± 3°C)
Intake air temperature, surge tank	225 ± 5°F (107 ± 3°C)
Intake air humidity, grains of water per pound of dry air (kilograms per kilogram)	70 (0.00971) max
Spark advance, degrees btdc	45
Spark plug gap, in.[A]	0.020 ± 0.003
Breaker point gap,[B] in.	0.020
Valve clearance,[C] in.:	
Intake	0.008
Exhaust	0.010
Fuel to air ratio	varied from 0.08 to 0.12
Fuel supply pressure, psi (kPa)	15 ± 2 (103 ± 14)
Injection pressure, psi (MPa):	
Bosch	1200 ± 100 (8.2 ± 0.69)
Excello	1450 ± 50 (10 ± 0.34)

[A] Metric equivalents may be found in the back of this manual.
[B] Breakerless ignition system basic setting for transducer to rotor (vane) gap is 0.003 to 0.005 in.
[C] Measured with the engine hot and running. See A3.8.8 for details.

A3.8.6 *Surge-Tank Air Temperature, 225 ± 5°F (107 ± 3°C)*—Adjust thermostat *EE* (see Fig. A1.10) so that the surge-tank air reaches the specified temperature as indicated by thermometer *DD*. The left-hand pilot light on the panel board lights when current is flowing to the surge-tank heater *A*.

A3.8.7 *Coolant Temperature, 375 ± 5°F (191 ± 3°C)*—Coolant temperature is dependent upon the boiling point of the coolant. Since the coolant used in the Supercharge engine is ethylene glycol which is hygroscopic (water absorbent), it is necessary to readjust the coolant mixture periodically to keep coolant temperature within the specified limits, 370 to 380°F. This is done by removing the cooling-condenser filler cap *G* (see Fig. A1.10), shutting off the water supply to the condenser, and boiling off some of the water while the engine is running. (**Warning**—*Do not breathe coolant vapors as they are toxic*.)

A3.8.7.1 When the coolant temperature reaches 375 to 380°F, turn on the water supply valve and replace the condenser filler cap. For altitudes where the specified temperature cannot be reached, add glycerin to raise the boiling point. For adjustment of the coolant safety thermostat, see the instructions in A3.8.13.

A3.8.8 *Valve Clearances: Intake 0.008 in., Exhaust 0.010 in.*—Valve clearances must be measured under the following conditions because clearances may change with different fuels and boost pressures:

Engine	hot and running
Boost pressure	30 in. Hg (101.6 kPa), absolute
Fuel-air ratio	for maximum bmep
Fuel	*iso*octane

A3.8.8.1 *Measurement*—Use the 0.008-in. feeler gage furnished with the tools to check the clearance of the intake valve, and the 0.010-in. gage for the exhaust valve. To determine whether the clearance is correct, insert the proper feeler gage between the rocker-arm button and the tip of the valve stem, and slide the feeler to determine whether there is drag or resistance to movement. If the feeler slides too easily or cannot be inserted at all, adjustment of the rocker-arm screw is necessary and then the clearance must again be checked with the feeler gage under the same operating conditions.

A3.8.8.2 *Adjustment*—Clearances cannot be adjusted satisfactorily with the engine running. After stopping the engine, adjust the valve clearance by loosening the lock nut and turning the adjusting screw on the end of the rocker arm a *slight amount clockwise* to *reduce* the clearance, or *counterclockwise* to *increase* the clearance. Since one revolution of the adjusting screw changes the clearance 0.036 in., only a slight change in the setting is required for most readjustments. Tighten the lock nut after each readjustment, and check the clearance again under equilibrium operating conditions as described in A3.8.8.1. After the specified valve clearances have been obtained, replace the rocker-arm cover and be sure to open the oil-supply valve on a high-speed crankcase not equipped with intermittent oiling of the valves.

A3.8.9 *Spark Advance, 45° Before Top Dead Center*—The spark advance is indicated on the graduated quadrant *W* (see Fig. A1.10) by the flash of the neon tube. To adjust the spark advance, loosen the distributor lock screw and rotate the distributor to obtain the specified timing. If the neon tube produces a multiple flash, the left-hand flash indicates the spark advance.

A3.8.10 *Injection-Pump Gallery Pressure, 15 ± 2 psi (103 ± 14 kPa)*—Injection-pump gallery pressure is indicated by a gage on the panel. Pulsations of the injection pump may make the gage reading fluctuate, but the average pressure can be assumed to be the mean between the maximum and minimum.

A3.8.11 *Exhaust Cooling Temperature*—To avoid lime deposits in the jacket of the water cooled manifold, it is desirable to keep the water outlet temperature below 125°F (52°C) by adjusting supply valve *C* (see Fig. A1.1).

A3.8.12 *Speed, 1800 ± 45 r/min*—Measure the speed occasionally with a revolution counter or tachometer after removing the cap from the extension of the dynamometer shaft. Check the speed under both motoring and firing conditions, and correct any deviation from the standard speed.

A3.8.13 *Adjustment of Coolant Safety Thermostat*—To set the coolant thermostat for protection, the engine must be running with the supply of cooling water turned off. When the boiling coolant has given off vapors for 1 min from the vent hole of the thermostat standpipe with the condenser filler cap in place, and the coolant thermometer indicates a temperature of 375 to 380°F, slowly turn the slotted stem of the thermostat clockwise until the unit stops due to breaking the control circuit. While the absorbed water is being boiled off, as directed in A3.8.7, the safety thermostat will not operate since the condenser cap is removed.

A3.8.14 *Injector Opening Pressure, Bosch Nozzle 1200 ± 100 psi (8.2 ± 0.69 MPa)*—Follow instructions for periodic checks of fuel-injection opening pressure shown in A4.43. The opening pressure for the Excello Nozzle is set at the factory for 1450 ± 50 psi (10 ± 0.34 MPa).

A3.9 Measurement of Fuel Consumption

A3.9.1 *Weighing the Fuel*—In the Supercharge method, knock-limited power is measured over a range of fuel-air ratios. Therefore, it is important that accurate measurements of fuel and air consumption be obtained. Instructions for checking the accuracy of the fuel-weighing system are given in A4.41. Fuel consumption is determined with a fuel-weighing device, which measures the time required for the engine to consume definite weights of fuel. The weighing system (see Fig. A1.9) consists of beam scales for holding balancing weights and a beaker of fuel. It is equipped with automatic electrical starting, holding, and stopping circuits that start and stop an elapsed-time electric clock. The scale and clock measure the time required for the engine to consume a predetermined weight of fuel. The electrical system and the flow of fuel to the engine, either from the supply can or the weighing system, are controlled by manipulating two valves, two preset switches, and a scale-weight lever, all mounted on the panel board, as shown in Fig. A1.9. The sequence for manipulating the fuel scale controls is as follows:

A3.9.1.1 Reset the stop clock by pressing lever *D*.

A3.9.1.2 Raise chain lever *N* which lowers the 0.25-lb (113.4-g) (or 0.125-lb (56.7-g)) weight *V* onto the left-hand platform of the scales. Leave the chain hook *W* inside the loop on the weight.

A3.9.1.3 Turn switches *P* and *Q* to the OFF position. These are preset switches and the electric clock is started and stopped by a double-acting mercury switch attached to the scale and actuated by platform movement.

A3.9.1.4 Turn the right-hand fuel-selector valve *L* to the horizontal position, and observe the filling of beaker *U* through window *K*. When the beaker fills and over-balances the weight on the opposite platform, it will move down.

A3.9.1.5 Turn the left-hand fuel-selector valve *M* to the horizontal position, and at the same time turn on the right-hand switch *P*. This presets the starting circuit.

A3.9.1.6 When the beaker rises, it will automatically start clock *E*, and begin measurement of the time required to consume 0.25 lb (or 0.125 lb) of fuel.

A3.9.1.7 Turn on the left-hand switch *Q*, which presets the stopping circuit. Move weight lever *N* to the lower position, thus lifting the weight from the platform and causing the beaker platform to drop to its lower position.

A3.9.1.8 Turn off the right-hand switch *P* so that the clock will stop automatically as the beaker rises again when the measured quantity of fuel has been consumed.

A3.9.1.9 After the clock has stopped, restore both fuel-selector valves *L* and *M* to the vertical position. This reconnects the fuel system to the main supply can. *Do this at once to prevent the injection system from running dry*.

A3.9.1.10 Read the electric clock and record the time required to consume 0.25 lb (or 0.125 lb) of fuel.

A3.9.1.11 Repeat the cycle for each measurement of fuel consumption.

A3.9.2 *Buoyancy Correction*—The fuel in the beaker of the fuel-weighing device has a buoyancy effect on the immersed portions of the fuel filling and return tubes. This buoyancy effect changes with the depth of immersion.

A3.9.2.1 The fuel level in the beaker is higher when the clock starts timing the consumption of 0.25 lb (or 0.125 lb) of fuel than when the clock stops. Therefore the buoyancy effect on the tubes in the beaker changes during measurement of fuel consumption. This is compensated for in the design by a slight increase in the weight of the nominal 0.25 lb (or 0.125 lb) weight. The weight correction is proportional to the relative cross-sectional areas of the tubes and beaker.

A3.9.2.2 Each glass tube has a diameter of $^{17}/_{64}$ in. and the standard beaker, a diameter of 3½ in. (89 mm). The cross-sectional area of one tube is 0.58 % of the area of the beaker. The weight is increased by that percentage with one tube immersed and by 1.16 % with both tubes immersed. Thus, a nominal 0.25-lb (113.4-g) weight actually weighs 114.7 g with the buoyancy correction. The nominal 0.125-lb weight (56.7 g) weighs 57.36 g with the buoyancy correction.

A3.9.3 *Safety Precautions*:

A3.9.3.1 Fuel weighing cabinets were originally equipped with a glass door on the front to enclose the weighing device. *Discard the door* because its use results in the accumulation of fuel fumes from the open beaker inside the cabinet, thus creating a fire hazard.

A3.9.3.2 Both supply and return tubes must always *extend below* the surface of the fuel to prevent building up static electricity. If the tubes are of unequal length, change to the latest type.

A3.10 Calculation of Fuel-Air Ratio

A3.10.1 Air consumption is measured with a water manometer connected to an orifice meter in the air supply line. The average air-flow curves and formulas at various manifold pressures shown in Fig. A3.3 are useful for checking the accuracy of the orifice.

A3.10.1.1 For convenience the manometer is calibrated in terms of minutes required for the engine to consume 0.25 lb of air. Since the fuel weighing system is arranged to give consumption time for 0.25 lb of fuel, the calculation of fuel-air ratio (in terms of pounds of fuel per pound of air) is simply a matter of dividing the air time by the fuel time.

A3.10.1.2 When the 0.125-lb weight is used on the fuel scale, double the fuel consumption time as read from the clock (to put it on the standard 0.25-lb basis) before dividing the air time by the fuel time.

A3.11 Air Humidity

A3.11.1 If compressed air from the plant supply is used, be certain that it is free of any entrained lubricant and that anti-freeze agents are never used in the system.

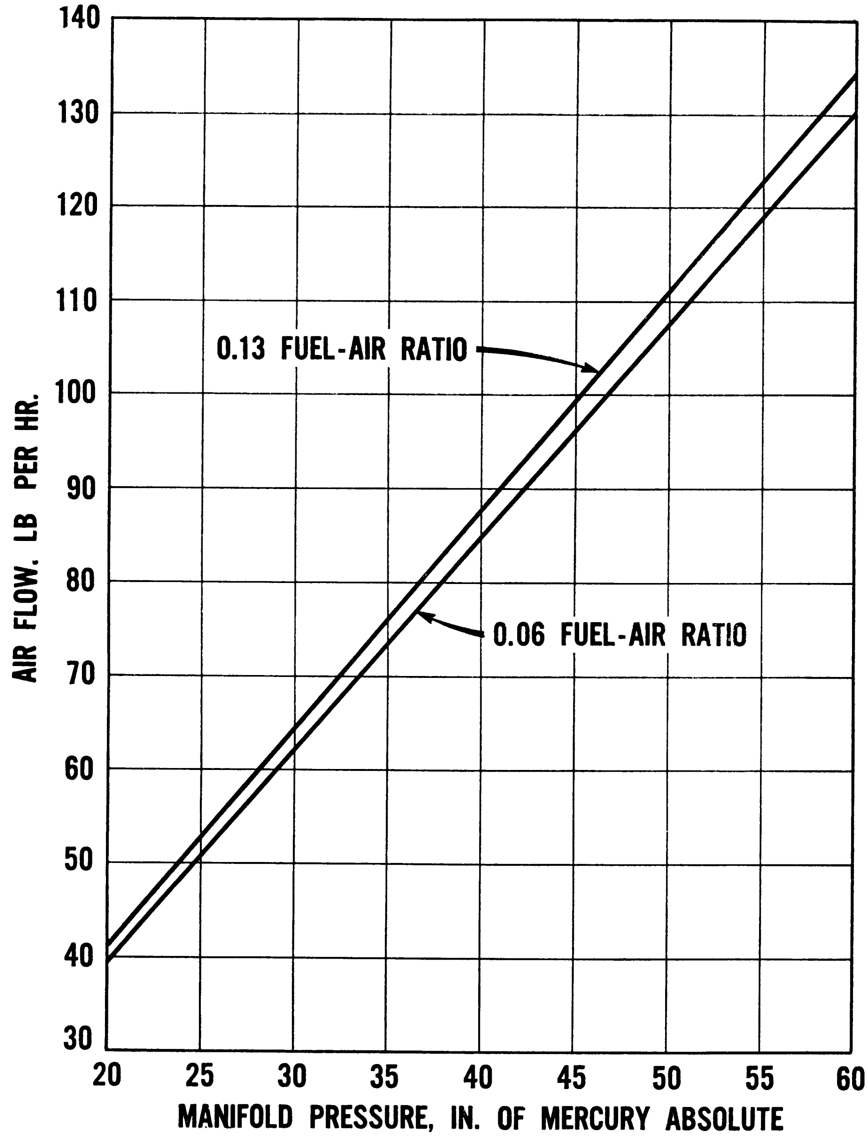
A3.11.2 The maximum permissible humidity of the intake air is 70 grains of moisture per pound (0.00997 kg/kg) of dry air. Unless the compressor supplying the high-pressure air automatically keeps the moisture below the permissible maximum, the humidity of the air supply must be measured *daily*. This may be done by bleeding air from the supply line *ahead* of the high-pressure regulating valve and passing it over a set of wet- and dry-bulb thermometers at a velocity of at least 600 ft/min. The moisture content of the air may then be read from a psychrometric chart using the wet- and dry-bulb temperatures.

A3.11.3 An alternative method of measuring the humidity may be more convenient. It consists of bleeding air from the air supply and directing it onto the side of a bright tin can without a top and filled with water. Add ice *slowly*, and constantly stir the contents of the can. Read the thermometer (graduated from 0 to 120°F) the instant that dew forms on the side of the can where the compressed air strikes it. This is the dew point which is used to determine the air moisture from a psychrometric chart.

A3.11.3.1 Precautions to observe in using this method are: (*1*) *add the ice slowly* so that the thermometer will give the correct reading, (*2*) *stir constantly* to ensure uniform temperature, and (*3*) *have the air velocity low enough* to avoid the evaporation of moisture as it forms on the can. Air velocity may be reduced by connecting the small end of a 4-in. funnel to the air-supply bleed with rubber tubing and directing the air onto the side of the can from the large end.

A3.12 Checking Operating Conditions (Table A3.4)

A3.12.1 *Power Curve*—After each top overhaul and about every 25 h between overhauls, obtain a power curve as follows:



Fuel-Air Ratio	Formula	Fuel-Air Ratio	Formula
0.06	*A* = 2.27 *P* − 6.0	0.10	*A* = 2.31 *P* − 6.0
0.07	*A* = 2.28 *P* − 6.0	0.11	*A* = 2.32 *P* − 6.0
0.08	*A* = 2.29 *P* − 6.0	0.12	*A* = 2.33 *P* − 6.0
0.09	*A* = 2.30 *P* − 6.0	0.13	*A* = 2.34 *P* − 6.0

A = air flow in pounds per hour.
B = manifold pressure in inches of mercury absolute.
Observed air flow rates should not deviate by more than 1.5 lb/h from values calculated from these formulas.

FIG. A3.3 Air Flow Curves and Formulas

With the engine at standard operating conditions, and using *iso*octane plus 6.0 mL of TEL per U. S. gal as the fuel, adjust the manifold pressure (boost) to 40 in. Hg (135 kPa) absolute. Adjust the fuel flow through successive points from lean to rich and at each point record the bmep and fmep (dynamometer scale readings). Measure and record the fuel and air consumptions, using the procedure described in A3.14. The power curve plotted from these data should peak at 164.5 ± 3 imep. Average power curves for several constant manifold pressures are shown in Fig. 2. For convenience in checking not only power output but also fuel and air consumptions, these average power curves are shown in Fig. 3 with the corresponding average curves for fuel flow and air flow. An average fmep curve for various manifold pressures is shown in Fig. A3.4.

A3.12.2 *Knock-Limited Power Curves*—After each top overhaul, obtain several knock-limited power curves using the standard blends of reference fuels. These curves should extend from 0.08 to 0.12 fuel-air ratio to be certain that the engine is conforming within ±5 % to the corresponding curves in the reference fuel framework, Fig. 4. The tolerances in 9.1.2 of the test method for spread between adjacent reference fuels must also be met.

TABLE A3.4 Recommended Torque Values for Supercharge Method

Item	Torque, lbf·ft
Cylinder clamping sleeve:	
Long studs	42
Short studs	83
Cylinder clamping cam	20[A]
Crankshaft balancing weights (CFR-48)	100
Balancer shaft weight bolts (CFR-48)	100
Balancer shaft bolt locknuts	75
Balancing rod bolts (high-speed crankcase)	100
Connecting rod	104
Spark plug	25 to 30
Pick-ups for Detonation Meters:	
External type for GPI or Sperry	10
Internal type D-1 for Model 102-A	30 max

[A] With clamp handle in locked position, tighten hexagon nut on the cylinder clamp cam bolt to this value. (Do not exceed 25 ft-lb as cylinder distortion may result.)

A3.12.2.1 It is not necessary to determine all of the knock-limited power curves in the framework, but enough of them must be obtained to cover the range of samples to be tested. The procedure to follow in determining each curve is the same as that given in Section A3.14 for rating samples.

A3.12.2.2 It is not necessary to obtain knock-limited power curves for reference fuels independently each day since they must be obtained anyway when rating samples. This affords a continuous check of the knock-limited performance of the engine on the reference fuels.

A3.12.3 *Standardization Fuel Check*—As a daily check on the operating condition of the engine, test a standardization fuel blend in the range of the samples to be tested. A description of the preparation and handling of standardization fuels is given in Sections A2.2-A2.4. Rate standardization fuel blends or check fuels in the same manner as samples, as described in Section A3.14.

A3.13 Standard Knock Intensity

A3.13.1 A description of the standard knock intensity to be used in establishing knock-limited power curves for all fuels is given in A8.1.17 of the Supercharge method. Since the method depends upon audible knock, differences in hearing ability, operator fatigue, acoustical properties of the room in which the engine is located, and the general noise level affect the sound of the knock as heard by the operator.

A3.13.2 The fact that the engine does not knock steadily, but occasionally produces loud knocks and very light knocks, adds to the difficulty of maintaining standard knock intensity. These cyclic variations also change with mixture ratio, with the steadiest knocking occurring in the vicinity of 0.09 fuel-air ratio. Both the occasional loud knocks and very light knocks should be disregarded in establishing standard knock intensity.

A3.13.3 It is recommended that new operators practice adjusting the engine to standard knock intensity (light knock) at different fuel-air ratios and at different imep levels for some time before attempting to rate samples. Skill in adjusting the engine to a constant level of knock intensity is essential to obtain good reproducibility of ratings.

A3.13.4 A detonation meter (see Section A1.15) is a useful aid to the ear in obtaining standard knock intensity. For adjustment and use of the detonation meters, refer to the manufacturers' instructions.

A3.14 Rating Samples

A3.14.1 When the operating conditions are within the specified tolerances and the engine has been checked on a standardization fuel blend as described in A3.12.3, rate samples as follows:

A3.14.1.1 Using a manifold pressure that does not produce knocking, operate the engine on the sample for about 10 min to purge the pumps and lines of the previous fuel.

A3.14.1.2 Adjust the fuel flow until the maximum bmep is obtained on the dynamometer scale. If knock occurs, reduce the manifold pressure until the knock disappears and readjust the fuel control for maximum bmep.

A3.14.1.3 Without changing the position of the fuel-injection control, gradually increase the manifold pressure until standard knock intensity is obtained (see Section A3.13). Allow the engine to reach equilibrium. During this period make minor adjustments to keep operating conditions within the specified limits and, if necessary, readjust the manifold pressure to maintain standard knock intensity.

A3.14.1.4 Using a data sheet, such as that illustrated in Fig. A2.3, record the bmep indicated on the dynamometer scale, the manifold pressure, the pressures of the oil and orifice air, and the temperatures of the coolant, inlet air, orifice air, and oil.

A3.14.1.5 Measure fuel consumption as described in A3.9.1.1-A3.9.1.11. Record the time required for the consumption of 0.25 lb of fuel and the water manometer indication of air consumption.

A3.14.1.6 Quickly move the fuel-injection control to the cut-off position and observe the friction load (fmep) indicated by the dynamometer scale. Do this within 10 s and return the fuel control to its previous position so that the engine resumes firing.

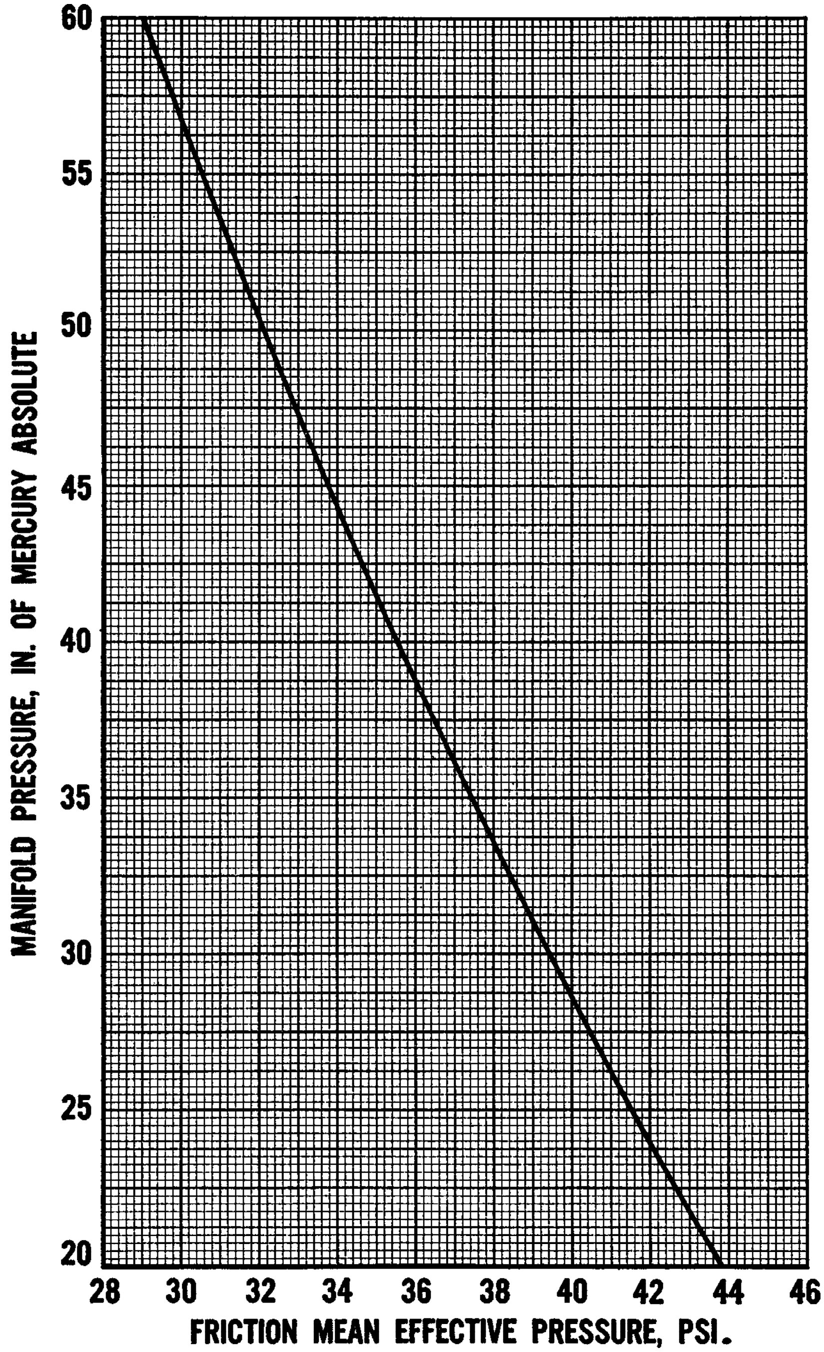
A3.14.1.7 Record the fmep, add to it the bmep obtained in A3.14.1.4, and record the sum as the imep.

A3.14.1.8 Calculate the fuel-air ratio by dividing the time required for the engine to consume 0.25 lb of air by the time for 0.25 lb of fuel.

A3.14.1.9 Plot the imep *versus* the fuel-air ratio on the framework graph paper illustrated in Fig. 4. This is the first point on the knock-limited power curve and it should be at the lean end.

A3.14.1.10 Determine a minimum of five additional points at other fuel-air ratios to define the knock-limited power curve. For each new point, enrich the fuel-air ratio by changing the fuel-injection control, increase the manifold pressure an arbitrary amount, and then lean the fuel-air ratio until standard knock intensity is obtained. Follow the procedure described in A3.14.1.3-A3.14.1.8 and plot each successive point on the graph paper used in A3.14.1.9. Draw a smooth curve through the plotted points with the aid of a French curve or flexible rule. If any of the points are obviously off the curve, redetermine as many of them as necessary to define the curve accurately.

(a) The purpose of enriching the mixture before increasing the manifold pressure (boost) and then leaning the mixture afterward is to keep the engine out of the zone of heavy knock.



Any observed fmep should not deviate from this curve by more than 3.0 psi.

FIG. A3.4 Average Friction Mean Effective Pressure Curve

If the manifold pressure were increased without first enriching the mixture, the engine would knock excessively. However, near the *peak* of the knock-limited power curve, it is more convenient to enrich the mixture in arbitrary amounts and adjust the manifold pressure to standard knock intensity.

(b) In operating a Supercharge engine, the object should be to adjust it to standard knock intensity from the non-knocking side rather than from a heavy knock intensity. This is easier on both engine and operator.

A3.14.1.11 While obtaining knock-limited power curves, occasionally check the engine for misfiring, particularly under rich mixture conditions, by opening the exhaust cutout valve and listening to determine whether the engine fires regularly without missing. Also with the valve open check for“ afterfiring” by cutting the ignition to determine whether firing stops instantly. If either misfiring or after-firing is occurring, the engine must not be used for rating samples. Check its mechanical condition.

A3.15 Bracketing Reference Fuel Blends

A3.15.1 Select the two *adjacent* standard reference fuel blends from the ones shown in the framework (see Fig. 4), which bracket the rich-mixture peak of the sample, that is, the blend that peaks immediately above the sample and the next one below it. Determine the knock-limited power curve for each reference fuel using the procedure described in Section A3.14, and plot the imep values and fuel-air ratios on the same framework sheet used for the sample.

A3.15.2 If the last reference fuel blend used is one of the pair that brackets the next sample to be tested, it is not necessary to determine again the knock-limited curve for this blend, provided the next sample is tested immediately. Time can thus be saved by grouping the samples to be tested so that a minimum number of curves for reference blends is required. However, this should *not* be interpreted to mean that several samples may be bracketed with the same two curves for reference fuel blends. Rather, the curves for both bracketing blends may be obtained after the curve for the sample; or the curve for one bracketing blend may precede that for the sample in which case the curve for the other bracketing blend must be obtained after that for the sample.

A3.16 Calculating Rating of Sample from Knock-Limited Power Curves

A3.16.1 Read the imep and the fuel-air ratio for the *lower* bracketing reference fuel b;-2q at the peak of its curve.

A3.16.2 Read the imep for the *upper* bracketing reference fuel at the same fuel-air ratio as that for the peak of the lower bracketing reference fuel.

A3.16.3 Read the imep for the sample at the same fuel-air ratio as that for the peak of the lower bracketing reference fuel.

A3.16.4 Using the imep values observed in A3.16.1-A3.16.3, determine by interpolation the equivalent reference fuel blend to match the sample.

A3.16.5 Normally the feel-air ratios at which adjacent reference fuel blends peak are approximately the same. If they differ substantially the curve for the sample may be above that for the "upper" bracketing reference fuel at the fuel-air ratio for the peak of the "lower" bracketing reference fuel. When this occurs the curves for one or both of the reference fuels should be checked carefully. If the check tests confirm the original results, draw a straight line between the peaks of the upper and lower bracketing reference fuels. Make the interpolation, using the peak imep of both reference fuels and the imep at the intersection of the curve for the sample and this straight line.

A3.17 Trouble Shooting Guide

A3.17.1 If the engine fails to conform to the imep power curve or to the reference fuel framework within the expected tolerances, or fails to give the correct standardization fuel rating (see Section A3.12), the cause should be investigated and the condition corrected. The following items are possible sources of trouble, those of a maintenance character being discussed in detail in Annex A4:

A3.17.1.1 Faulty adjustment of compression ratio. See Section A3.2 for the complete procedure for adjusting the clearance volume by the bench tilt method.

A3.17.1.2 Incorrect spark advance.

A3.17.1.3 Faulty adjustment of manifold pressure. Mercury manometer should first be adjusted for barometric pressure.

A3.17.1.4 Incorrect air temperature at orifice or surge tank.

A3.17.1.5 Faulty measurement of fuel or air flow. Water manometer should first be adjusted to zero, see A3.5.1.4.

A3.17.1.6 Faulty fuel injection. Check the fuel injection system for nozzle spray pattern, nozzle opening pressure, fuel pump timing, and so forth, as described in Sections A4.42-A4.48.

A3.17.1.7 Leaking or sticking valves.

A3.17.1.8 Sticking or broken piston rings.

A3.17.1.9 Faulty valve timing or clearance.

A3.17.1.10 Failure of piston cooling spray.

A3.17.1.11 Deposits in the cylinder coolant jacket.

A3.17.1.12 Leakage in the induction system.

A3.17.1.13 Resonance in exhaust system.

A3.17.1.14 Excessive back pressure or excessive water level build-up in surge tank, check drainage.

A3.17.1.15 Faulty adjustment of dynamometer scale.

A3.17.1.16 Binding of the dynamometer trunnion bearings.

A3.17.1.17 Incorrect coolant temperature.

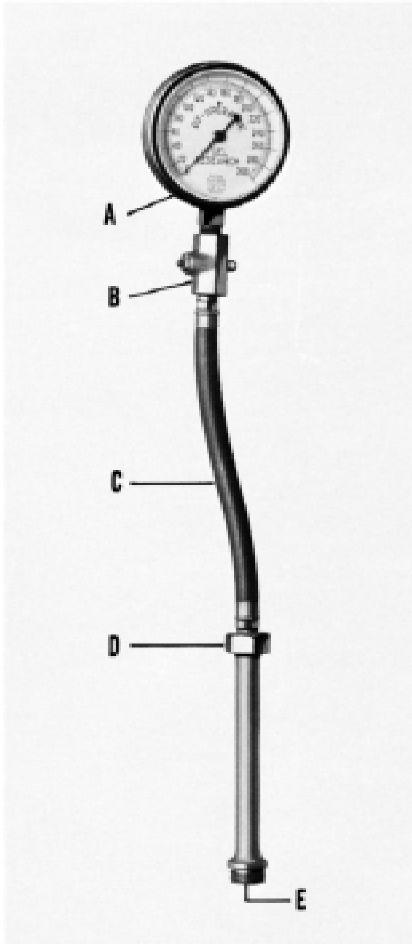
A3.17.1.18 Engine not at equilibrium temperature.

A3.17.1.19 Compression pressure. Although not a precise check, compression pressure is a useful indication of engine condition and should be determined occasionally as follows: Use the compression pressure gage (see Fig. A3.5) supplied for the purpose.

(a) Before using the gage, moisten the check valve at the bottom of the adapter with SAE 10 motor oil to ensure its proper action. To moisten, put a drop of oil in the hole at the end of the cylinder adapter. Run the engine long enough to establish equilibrium operating temperatures and then stop it. Remove the dummy plug or pickup and screw the gage into the engine. Determine the compression pressure while the engine is being motored, *without fuel injection* at an absolute pressure of 45 in. Hg (152 kPa) in the manifold, with the coolant temperature at 325 ± 10°F (163± 6°C) and with all other operating conditions standard.

(b) To obtain the absolute pressure, atmospheric pressure must be added to the gage reading. At the specified compression ratio of 7.0 to 1 and with the above engine conditions, the compression pressure should be 280 to 300 psi (1.93 to 2.06 MPa) absolute.

(c) While the cause of any abnormal compression pressure should be investigated and corrected, conformance of the engine to the power curve and reference fuel framework is a more precise indication of engine condition.



A —Pressure gage C —Flexible hose connector
B —Release valve D —Cylinder adapter fitting
E—Check Valve

FIG. A3.5 Compression Pressure Gage

A4. MAINTENANCE

A4.1 Importance of Maintenance

A4.1.1 The need for proper maintenance of fuel-testing units cannot be overemphasized if reliable fuel ratings are to be obtained. Aside from the necessity for maintaining the standard operating conditions specified in the methods, proper maintenance of the engine and the test unit as a whole is very important for obtaining reliable data and permitting longer periods of operation between overhauls. The care used in the inspection, adjustment, and overhaul of the test unit is a major factor in achieving these aims.

A4.2 Type of Maintenance

A4.2.1 Maintenance may logically be divided into three general categories:

A4.2.1.1 Daily checks, which may be considered as part of the normal operating procedure.

A4.2.1.2 Top overhaul, which is necessary at frequent intervals.

A4.2.1.3 Periodic maintenance at longer intervals.

A4.2.2 All three types are for the purpose of preventing operational difficulties. While no definite inspection periods can be prescribed to meet all operating conditions, the following is a suggested schedule for the maintenance operation.

A4.3 Daily Inspection

A4.3.1 *Fuel Induction System*—Inspect fuel line connections for leakage.

A4.3.2 *Lubrication*:

A4.3.2.1 Check crankcase oil level and add required amount of SAE 50 grade of motor oil.

A4.3.2.2 Check valve gear lubrication.

A4.3.2.3 Lubricate cylinder worm shaft.

A4.3.3 *Ignition*:

A4.3.3.1 Check condition of the breaker points and reset the clearance if necessary.

A4.3.3.2 Check ignition timing.

A4.3.4 *Valves*—Check valve clearances.

A4.4 Top Overhaul Inspection (See Section A4.7)

A4.4.1 *Cylinder*:

A4.4.1.1 Examine cylinder wall for scratches or pits.

A4.4.1.2 Check valve guides and replace them if necessary.

A4.4.1.3 Examine valve-seat inserts and if worn or damaged, replace them.

A4.4.1.4 Replace the cylinder if worn or damaged.

A4.4.2 *Valves*:

A4.4.2.1 Examine and check the valve stems for wear.

A4.4.2.2 Reface valves.

A4.4.3 *Piston and Rings*:

A4.4.3.1 Examine piston for scuffing or ring-groove failure and check for carbon deposits under the crown.

A4.4.3.2 Check rings and replace them if necessary.

A4.4.4 *Induction System*:

A4.4.4.1 Empty the air tanks of condensate.

A4.4.4.2 Clean the pressure reducing valves and air filter.

A4.4.4.3 Check the induction system for leaks.

A4.4.5 *Cooling System*—Inspect the condenser for deposits. Clean, and repair any leaks.

A4.4.6 *Breather Valve*—Clean and inspect, on high-speed crankcase only.

A4.4.7 Remove the element, clean the filter case, and install a new element.

A4.4.8 *Repeat* the items in Section A4.3.

A4.5 Periodic 500- to 800-Hour Inspection

A4.5.1 *Rocker-Arm Assembly*:

A4.5.1.1 Check rocker arm and shaft for wear.

A4.5.1.2 Check rocker-arm carrier joints for fit.

A4.5.2 *Cylinder*:

A4.5.2.1 Remove plugs and clean the cooling jacket.

A4.5.2.2 Check cylinder for wear.

A4.5.3 *Ignition System*—Check general condition.

A4.5.4 *Oil Cooler*—Clean and inspect.

A4.5.5 *Dynamometer and Scale*—Inspect for binding.

A4.5.6 *Dynamometer Dashpot*—Check oil level.

A4.5.7 *Fuel Nozzle*—Check the opening pressure, timing, and spray pattern.

A4.5.8 *Fuel Weighing System*—Test for accuracy.

A4.5.9 *Gages and Thermometers*—Clean and test for accuracy.

A4.5.10 *Injection-Pump Delivery Valve*—Inspect valve and seat.

A4.5.11 *Piston Pin*—Examine for wear.

A4.5.12 *Connecting Rod*—Check alignment.

A4.5.13 *Repeat* the items in Sections A4.3 and A4.4.

A4.6 Periodic 2000-Hour Inspection

A4.6.1 *Bearings*:

A4.6.1.1 Check connecting rod bearings.

A4.6.1.2 Check crankshaft end-play, thrust, and wear.

A4.6.1.3 Check valve timing, cam contour, and camshaft bearings.

A4.6.2 *Instruments*:

A4.6.2.1 Check oil pressure and temperature gages.

A4.6.2.2 Examine and check thermometers.

A4.6.2.3 Check pressure gage of the fuel-pump gallery.

A4.6.3 *Ignition System*:

A4.6.3.1 Recondition breaker points of distributor.

A4.6.3.2 Check connections and ignition cable.

A4.6.3.3 Check coil.

A4.6.3.4 Lubricate distributor cam.

A4.6.4 *Dynamometer*:

A4.6.4.1 Clean bearings and repack with grease.

A4.6.4.2 Inspect windings and coat with electrician's shellac if necessary.

A4.6.4.3 Check coupling.

A4.6.4.4 Rotate trunnion bearings.

A4.6.5 *Repeat* the items in Sections A4.3-A4.5.

A4.7 Recognizing Need for Top Overhaul

A4.7.1 Top overhaul is the generally accepted term used to describe valve reconditioning and cleaning of the combustion chamber, piston, and piston rings. Many other parts are also given attention during a top overhaul. The interval between top overhauls varies and depends primarily upon the quality of the maintenance work and the severity of the conditions under which the unit is operated. The average interval between top overhauls at present is 100 to 150 h. The need for a top overhaul usually can be determined by checking the performance of the engine as required and as described in detail in Annex A3 on Operation.

A4.8 Characteristic Engine Operating Faults

A4.8.1 *Lack of Compression*—Compression pressure is a rough check of general engine conditions. Marked deviation (±5 %) from normal pressure indicates that maintenance is necessary. Lack of compression pressure may be caused by:

A4.8.1.1 Leaking or sticking valves.

A4.8.1.2 Leakage past the piston caused by a sticking ring, a scored cylinder wall, or a worn cylinder, piston, or rings.

A4.8.1.3 Restriction in the exhaust system.

A4.8.1.4 Restriction in the air induction system.

A4.8.2 *Engine Misfire*—The usual causes for irregular engine operation are:

A4.8.2.1 Valves that are stuck, warped, or dirty.

A4.8.2.2 Incorrect valve clearances.

A4.8.2.3 Weak or broken valve springs.

A4.8.2.4 Spark plug that is fouled, cracked, or improperly adjusted.

A4.8.2.5 Poor contacts in ignition system.

A4.8.2.6 Insufficient ignition voltage.

A4.8.2.7 Leaky ignition condenser.

A4.8.2.8 Grounded primary or secondary wire.

A4.8.2.9 Incorrect ignition timing.

A4.8.2.10 Dirty or defective breaker points.

A4.8.2.11 Air leak in the induction system.

A4.8.2.12 Incorrect fuel injection timing.

A4.8.2.13 Faulty injection equipment.

A4.8.3 *Mechanical Engine Noise*—Operate the engine occasionally on a nonknocking fuel at a compression ratio that will enable the operator to detect mechanical noise. A suitable fuel is *iso*octane plus 6.0 mL of TEL per U.S. gal at a compression ratio of 7 to 1, and manifold pressure of 40 in. Hg (135 kPa), absolute. Mechanical noise may be caused by any of the following:

A4.8.3.1 A loose piston pin bearing.

A4.8.3.2 Excessive piston skirt clearance.

A4.8.3.3 A loose connecting rod bearing.

A4.8.3.4 A loose crankshaft bearing.

A4.8.3.5 Flywheel not securely fastened to the shaft.

A4.8.3.6 Excessive play or back lash between the teeth of the timing gears.

A4.8.3.7 Excessive end play of the camshaft.

A4.8.3.8 Slap from a loose belt (50 Hz unit).

A4.8.4 *After-firing in the Exhaust System*—This condition may result in rupturing part of the exhaust system and should be corrected immediately. It is usually caused by one of the following:

A4.8.4.1 Malfunctioning ignition system.

A4.8.4.2 Misfiring engine.

A4.8.4.3 Exhaust valve not closing properly.

A4.8.4.4 Retarded spark timing.

A4.8.4.5 Incorrect valve timing.

A4.8.4.6 Too rich a fuel-air ratio.

A4.8.5 *Excessive Oil Consumption*—Keep oil consumption at a minimum as the mixing of oil with the fuel charge may affect ratings. Excessive consumption is usually due to one or more of the following:

A4.8.5.1 Worn piston, rings, or cylinder.

A4.8.5.2 Scored piston, rings, or cylinder.

A4.8.5.3 Stuck, weak, or broken piston ring.

A4.8.5.4 Clogged oil-ring drain holes.

A4.8.5.5 Incorrect grade of oil.

A4.8.5.6 Too high an oil level.

A4.8.5.7 Oil leaks.

A4.8.5.8 Loose connecting rod bearings.

A4.8.5.9 Connecting rod improperly aligned.

A4.8.5.10 Oil pressure too high.

A4.8.5.11 Worn valve guide.

(a) Crankcase leaks are largely prevented by the breather valve which maintains a vacuum in the crankcase. To prevent sticking, this valve should be cleaned frequently.

(b) Oil leaks may also develop from other causes at the front or rear main bearing, or at the camshaft. Methods for remedying these faults are described in Section A4.33.

A4.8.6 *Excessive Carbon Formation*—The operating conditions of the test engines are not conducive to the formation of appreciable amounts of carbon in the combustion chambers. However, such carbon as is formed acts as an insulating coating, thereby causing a different heat condition from that in a clean engine. The resulting change in thermal condition appreciably affects the accuracy of ratings. Rapid formation of carbon in the combustion chamber is caused by:

A4.8.6.1 Operation at rich mixtures during idling and warm-up.

A4.8.6.2 Faulty valve condition.

A4.8.6.3 Excessive operation on untreated fuels.

A4.8.6.4 Excessive oil consumption (see A4.8.5).

A4.9 Cylinder Removal

A4.9.1 Remove the cylinder (see Fig. A1.17) (with clamping sleeve as a unit if desired) and mount it on a jig (see Fig. A4.1) or prop it in a position for overhaul. The stationary valve-linkage support may be unbolted and swung to the opposite side to give free access to the valve springs.

A4.10 Cylinder Maintenance Procedure

A4.10.1 *Cleaning Combustion Chamber*—Remove the deposits in the combustion chamber and valve ports by scraping, followed by the use of fine steel wool. Carefully remove deposits in the valve ports and engine end of the exhaust pipe since particles loosened during this operation may find their way into the valve port and be pounded into the valve seat. In addition, clean thoroughly the entire cylinder assembly with a solvent, such as kerosine, before reassembly.

A4.10.2 *Checking Cylinders for Wear*—Cylinders should be checked for wear at intervals of about every 500 h. Replace the cylinder when the wear becomes 0.0045 in., or the taper becomes 0.004 in., or the cylinder is "out of round" by 0.0025 in. Give particular attention to the wear at the top of the ring travel as it is normally greatest at this point.

A4.10.2.1 Cylinders of standard bore are preferred equipment, but rebored cylinders up to a maximum of 0.030 in. oversize may be used. In calculating the amount of wear, be sure to use the actual diameter of standard and oversize cylinders before placing them in service rather than their nominal standard and oversize diameters.

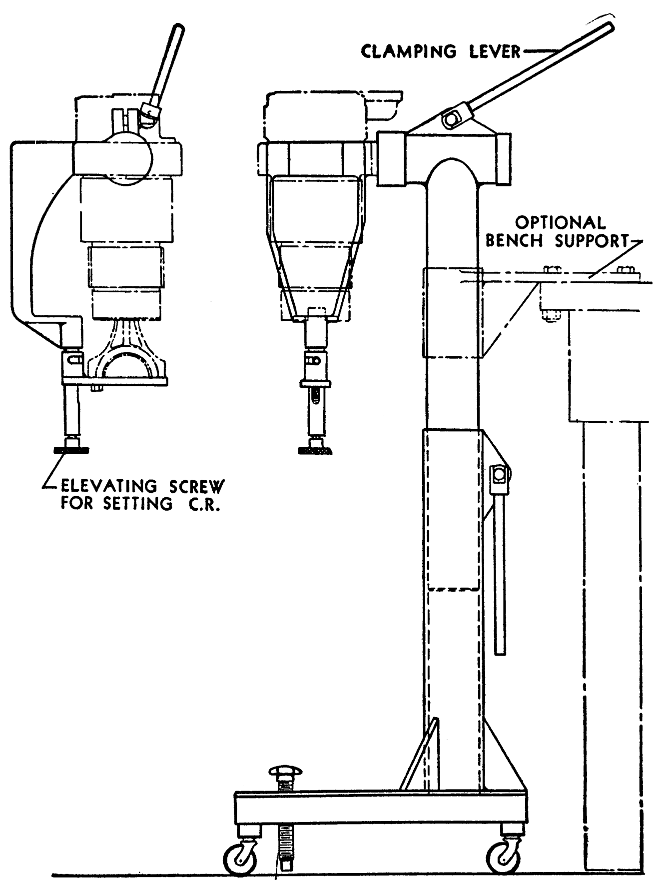


FIG. A4.1 Cylinder Servicing Stand

A4.10.2.2 The amount of wear, taper, and "out of round" permitted on oversize cylinders is the same as for cylinders of standard bore.

A4.11 Replacing Valve Guides

A4.11.1 At each overhaul the valve guides should be cleaned with a guide-cleaning tool and solvent to remove gummy deposits. The specified clearances (difference in diameters) between the valve stem and guide are:

Valve	Intake	Exhaust
New	0.002 to 0.003 in.	0.0035 to 0.005 in.
Replacement	0.0035 in.	0.0055 in.

A4.11.2 Experience has shown that misalignment may result unless these clearances are maintained. Side thrust may cause elliptical wear and the clearance along a portion of the perimeter to become greater than the above limits. When replacing a guide, it is advisable to drive the old one out with a long rod, and to chill the new guide with dry ice before tapping it into position. The shoulder on the guide should not quite touch the cylinder to prevent guide distortion. Although valve guides are hardened and cannot be reamed successfully, it often happens that the pressure may distort a new guide when it is installed, or a burr may form at one end. Check for both conditions. Then check for eccentricity with the valve seat, and correct by the procedure described in A4.15.4 and A4.15.5.

A4.12 Valve Cleaning

A4.12.1 Remove carbon with a soft wire brush and gummy deposits with a solvent. Valve stems should be examined for signs of scuffing and excessive wear resulting from rocker arm thrust. If the stem diameter in any direction is less than 0.3705 in. for the intake valve or 0.432 in. for the exhaust valve, discard the valve. Use caution in the disposal of sodium-cooled exhaust valves. If a valve of this type is cracked or broken in such a way that the sodium in the hollow stem and head is exposed, it is important that the sodium be kept away from any contact with water because the chemical action between sodium and water is extremely violent. It is recommended that any sodium that has dropped out of the valve be destroyed by throwing it on an oily rag fire out of doors. It is also recommended that all used sodium-cooled valves be disposed of by burying them in the ground rather than by putting them with other scrap metal. This precaution is necessary because an explosion is likely to occur if sodium in any quantity is dropped into a melting pot of scrap metal.

A4.13 Valve Seat Inserts

A4.13.1 *Checking and Removing*—Inspect cylinder valve-seat inserts at each top overhaul for wear, pitting, and warpage. The inserts are made of stellite, requiring methods other than lapping to center the valve seat with respect to the guide and to ensure proper valve seating.

A4.13.1.1 If worn so that the surface of the valve head is below that of the combustion chamber, replace the insert. If a cylinder is serviceable in other ways, it may be returned to the Waukesha Engine Division for replacement of valve-seat inserts and general reconditioning.

A4.13.1.2 Inserts of the chamfered type, that is, inserts having a 45° chamfer on the inner edge directly opposite the valve seat, may be removed by using the tool shown in Fig. A4.2 (Waukesha tool No. 0-109405). Place the split head of the tool in the insert after thoroughly removing the carbon deposit from the recess under the insert. The tool is a press fit in the insert. Thus, by carefully feeling as the tool is pushed through the insert, the operator can detect when the wedge lip on the tool head springs into the recess under the insert. At this point, expand the wedge into the recess by lightening the small inner nut at the opposite end of the tool. Fit the T-bar over the tool so that the arc grooves rest on the base of the cylinder supporting the tool vertically. Next, pull the insert out by threading the large nut on the external threads of the tool above the T-bar and tighten the nut against the T-bar.

A4.13.1.3 Thoroughly clean the valve-seat recess, removing all carbon and sealing compound but no metal, and coat the recess with a suitable liquid valve-seat packing material.

A4.13.2 *Installing*:

A4.13.2.1 Valve seat inserts are obtainable from the manufacturer in standard size, and 0.005, 0.010, 0.015, and 0.020-in. oversizes. The insert should be 0.007 in. larger in diameter than the cylinder recess to make a gas-tight joint and prevent loosening during operation. Chill the new insert with dry ice, liquid air, or liquid nitrogen, before driving it into place. To facilitate driving the insert into position, the cylinder may be heated by placing it in boiling water; however, that is usually unnecessary if the inserts are well chilled.

A4.13.2.2 It is helpful to have a guide fixture that will hold the insert in proper position so that a minimum of time is lost

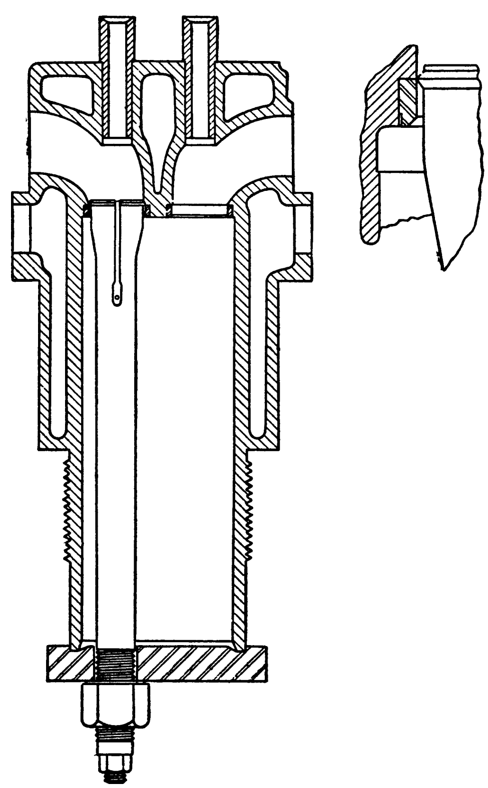


FIG. A4.2 Tool Position for Removing Valve Seat Inserts before the insert is in place after removing it from the chilling bath, thus preventing expansion, which will cause excessive interference.

A4.13.2.3 A simple fixture for replacing inserts (see Fig. A4.3) can be made easily. Place a valve stem in the valve guide from outside the cylinder and use it to guide the fixture. Press the new valve-seat insert onto the end of the brass holder so that the external step cut will face the combustion chamber. Use a piece of thread under the insert to prevent it from dropping off. Thoroughly chill the entire assembly, and then quickly remove and guide it into the cylinder recess. Sharply tap the extension rod of the fixture several times to seat the insert securely. Old cylinders will usually require oversize inserts, as the recesses in the head will have expanded so that proper fit cannot be obtained with a standard-size insert.

A4.13.2.4 Light peening of the cylinder head around the insert may also be necessary for old cylinders. Peening should be done carefully to prevent a rough surface. Eroded heads can be smoothed by peening. After the new insert is in place, it should be machine ground, lapped, and tested for leakage.

A4.14 Valve Seat Overhaul Apparatus

A4.14.1 Experience has shown that a machine grinder, using a grinding stone rotated on an arbor by a high-speed electric motor, is necessary to recondition stellite valve-seat inserts. This equipment must be handled with care. Keep the apparatus clean and well oiled. Check the parts frequently as wear will reduce the accuracy obtainable. The apparatus consists of the following:

A4.14.1.1 Electric motor, driving linkage, and grinding stone assembly (see Fig. A4.4).

A4.14.1.2 Tapered arbors in increments from 0.375 to 0.378 in. and from 0.437 to 0.439 in.

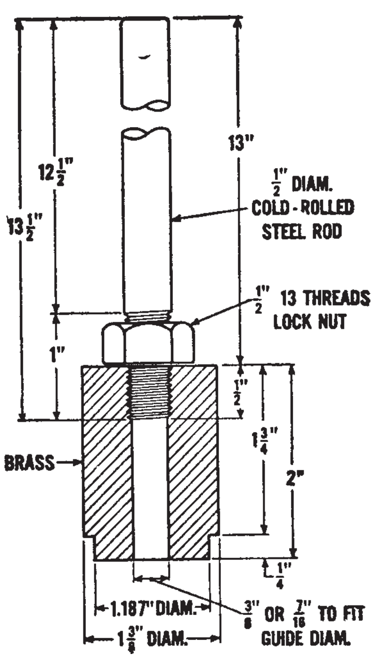
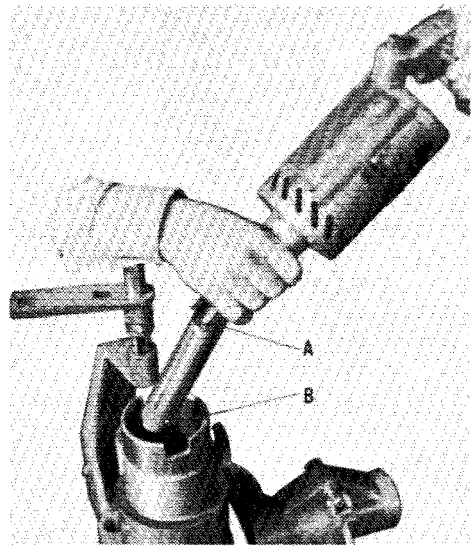


FIG. A4.3 Tool for Installing Valve Seat Inserts

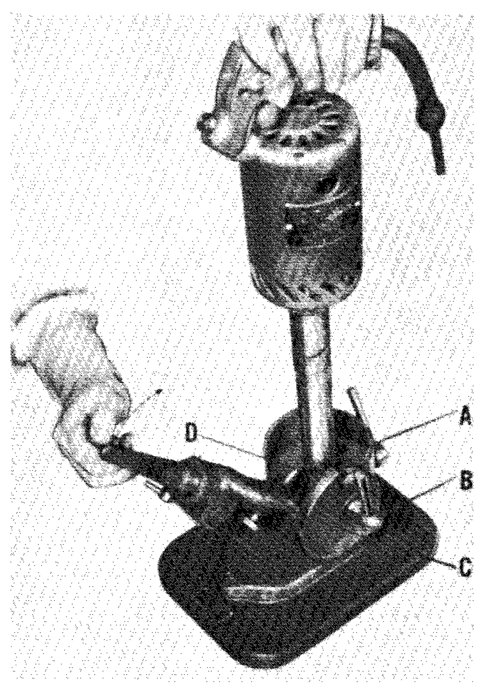


A—Flexible joint B—Grinding stone

FIG. A4.4 Grinder for Valve Seats

A4.14.1.3 Grinding stones having 45° faces: Extra stones may be dressed to 15 and 75° angles, if desired.

A4.14.1.4 A stone dressing unit adjustable to different angles (see Fig. A4.5).



A—Grinder stone to be dressed
B—Lock screw for setting dressing angle
C—Dressing angle quadrant
D—Diamond dressing tool

FIG. A4.5 Tool for Dressing Valve Seat Grinder

A4.14.1.5 An eccentrimeter or valve-seat run-out gage with special extension for use in ASTM engine cylinders (see Fig. A4.6).

A4.15 Valve Overhaul Procedure

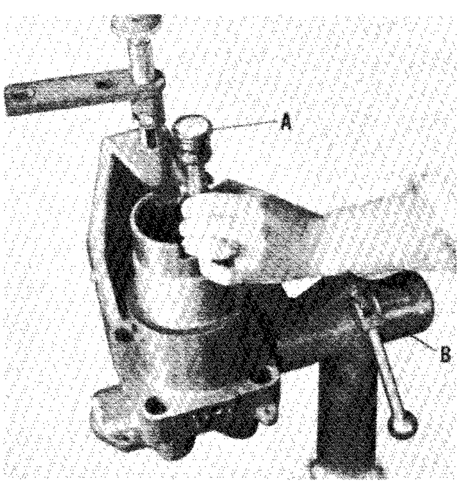
A4.15.1 Remove the valves from the cylinder and clean the combustion chamber, ports, valves, and valve guides as directed in Sections A4.10-A4.12.

A4.15.2 Examine the valve seats for incomplete or uneven seating, pits, or scores, and incorrect seat width. Both seat and valve should be ground to 45° and the seat should be 0.05 to 0.07 in. wide unless an interference angle is used. An interference angle is obtained by maintaining a 45° face on the valve but grinding the cylinder seat to 46 or 47°. This difference of 1 to 2° causes the valve to contact the cylinder seat at the area nearest the combustion chamber. The effect is to increase the unit pressure against the cylinder seat.

A4.15.3 Install the largest diameter arbor that, when drawn snugly into the guide, will permit proper operation of the stone while not allowing the spindle to strike the shoulder of the arbor.

A4.15.4 Install the run-out gage on the arbor as shown in Fig. A4.6, and adjust the rider so that contact is made with the center of the seat. Adjust the rider and dial gage with respect to the extension barrel so that the plunger of the dial gage has moved sufficiently to remove all backlash. Rotate the assembly and observe the amount of run-out and the position of the high point. Rotate the arbor one quarter of a turn in the guide and recheck the run-out. A corresponding shift in the position of the highest point indicates that the valve guide may contain dirt or that the arbor may be damaged. If the high-point position is unchanged and an eccentricity with the guide exceeding 0.0015 in. is observed, grinding is necessary (see A4.15.5-A4.15.7). If grinding is not needed, proceed as described in A4.15.8 and A4.15.9.

A4.15.5 After making several contacts with the valve insert, the grinding stone should be replaced in the dressing unit at a setting of 45° as shown in Fig. A4.5. If an interference angle is used, the stone is dressed to 46 or 47°. As working clearances in the cylinder are close, grinding stone diameters should be not greater than 1.375 in. *New stones must be cut to this diameter.*



A—Dial indicator
B—Cylinder servicing stand

FIG. A4.6 Dial Indicator for Valve Seats

A4.15.5.1 Apply a small amount of oil on the arbor and place the grinding unit on it, as shown in Fig. A4.4. Hold the unit so that the stone does not rest on the seat. Start the motor and when it has reached speed, touch the stone to the seat with a few light, jabbing motions. *Be careful not to touch the seat with the stone either too heavily or too long* since insert life may be shortened unnecessarily if excess material is removed. Remove only enough material to reach the bottom of pits or imperfections in the seat.

A4.15.5.2 Stop the motor, *but do not remove the assembly from the arbor until the stone has come to rest*, as the uncontrolled rotating flexible shaft will score the cylinder. Wash both arbor and seat thoroughly with solvent. Examine the seat to see whether pits have been removed and whether the surface is now in good condition. Check the total run-out, and if it is greater than 0.002 in., redress the stone and repeat the procedure.

A4.15.6 Reface the valve if its run-out is more than 0.0015 in., if the cylinder seat has been machine ground, or if there is a contact groove on the face of the valve. Run-out may be determined by suitably mounting a dial gage in a fixture equipped with two short V-blocks to support the valve stem, and then rotating the valve. A stop must be provided at the tip of the valve stem against which the valve is pressed while it is being rotated. The valve should be discarded if refacing results in a sharp edge at the top. Apply a very light film of bluing on the valve face, insert the valve in the guide, and rotate it about one fourth of a turn on the seat. Remove and examine the face for seat width and location of contact. Correct improper seat width or seat location on the valve face by using the 75 or a 15° grinding stone on the cylinder seat. The top edge of this contact area on the valve should not be closer than 0.03 in. to the top edge of the faced portion of the valve.

A4.15.6.1 Caution is necessary when using a 15° stone for narrowing seats, as repeated grinding with it may result in the removal of some material from the cylinder head.

A4.15.7 When the cylinder seat is ready, the valves may be lapped in the following manner: Apply a light film of fine lapping compound (300 to 600 grit) to the valve face. Next, attach the valve to the lapping tool and insert it in the guide. With a light tapping action, alternately touch the cylinder seat and raise the valve off the seat. Slowly rotate the valve while it is *off the seat*. Remove the valve, wash both valve and seat with solvent, and inspect the surface.

A4.15.8 Before assembling, *thoroughly wash* the valves, ports, and cylinder with solvent to remove all traces of grinding compound and particles of stone abrasive. Oil the valve stems and guides when assembling.

A4.15.9 After assembly, check the valves for leakage as follows: Place the cylinder on its side with a port upwards and fill the port with solvent. Inspect through the bore for seepage. Turn the cylinder over and repeat for the other port. If leakage is observed, open and close the valve several times. If leakage persists, repeat the procedure in A4.15.5-A4.15.9.

A4.16 Piston and Rings

A4.16.1 *Removing Piston*—Remove the piston from the connecting rod by first taking out the piston pin retainers with a pair of pliers or the tool provided for this purpose, and then pushing out the piston pin. If the pin is a tight fit, the piston should be heated, preferably by placing an electric hot plate upside down on top of the piston. Then the pin can be removed freely.

A4.16.1.1 Dismantling the engine while it is still hot makes removal of the piston pin easier. Use the tool supplied with the engine, or a piece of wood or soft metal to avoid damaging the piston. Never use heavy pressures, which may bend the connecting rod or distort the piston.

A4.16.2 *Removing Rings*—After removing the piston from the engine, take the rings off with the proper tool. Expand each ring just enough to remove it from the piston and release the tension immediately to avoid distortion. Observe the same precaution in reassembling used or new rings on the piston after cleaning.

A4.16.3 *Cleaning Piston*—Carbon should be removed from the rings and grooves and from both sides of the piston crown. Since scraping is poor practice, the following procedure is suggested for removing deposits: The aluminum piston can be cleaned by heating it in sodium nitrate at 900 to 930°F (482 to 499°C) or in triethanolamine at 250 to 300°F (121 to 149°C). The piston must be dry before immersion to avoid splattering. Pistons should be heated under a laboratory hood. When the piston surface appears clean, examine the ring grooves to be sure that no deposits remain; otherwise, serious damage may result to the engine. A new piston should be installed when the skirt clearance exceeds 0.013 in.

A4.16.4 *Checking Piston Rings*—Before reinstalling, piston rings should conform to the following measurements:

Aluminum Pistons	Inch[A]
Gap Clearance:	
New compression rings	0.015 to 0.020
New oil rings	0.010 to 0.018
Gap Clearance, replacement limits:	
Compression rings	0.035[B]
Oil rings	0.030

[A] Metric equivalents may be found in the back of this manual.
[B] Or when the surface shows signs of scuffing or scoring.

A4.16.4.1 Aluminum pistons are fitted with wedge-type rings. For a new ring, the distance between the piston and ring surfaces should be 0.000 to 0.004 in., with the ring resting in its groove under its own weight (see Fig. A4.7). Check the dimension shown with a dial indicator, and when it exceeds 0.006 in. replace the ring.

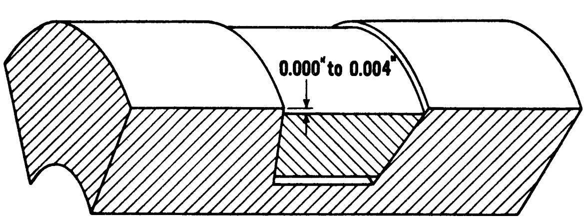


FIG. A4.7 Fit of Wedge Ring in Aluminum Piston

A4.16.4.2 The piston ring grooves wear also, and when a new ring rests deeper than 0.006 in. below the ring land surface, a new piston is needed. It is advisable to change the rings when the gap clearance exceeds 0.035 in. for compression rings and 0.030 in. for oil rings.

A4.16.4.3 To measure gap clearance, the ring should be placed in the cylinder barrel and the gap measured with feeler gages. To ensure correct alignment, the ring should be pushed into the cylinder with the piston to a depth of 1½ in.

A4.16.5 *Reassembling*—In reassembling, the rings must first be compressed and oiled before insertion of the piston in the cylinder. The use of a piston ring compressor is advisable.

A4.17 Piston Pins and Retainers

A4.17.1 *Piston Pin Retainers*—The aluminum pistons are machined for piston pin retainers. When assembling these pistons to the connecting rod, the retainers that hold the piston pin in place must rest securely in their grooves. Occasional checks should be made of the retainer tension as continued use reduces it. This is done by closing the tangs with a pair of pliers until they touch. Upon release the maximum diameter of circlips should be no less than 1.390 in.; that of Truarc retainers should be no less than 1.340 in. It is important that this requirement be met. Otherwise the retainers will vibrate and wear loose in their grooves, which may result in scoring of the cylinder wall.

A4.17.2 *Piston Pin*—The piston pin should fit snugly (push fit) in the piston. After operation, it may be difficult to remove the pin from the aluminum piston. It is advisable to heat the piston with an inverted hot plate set on the crown rather than to drive the pin out. Connecting rod alignment should be checked when new pistons or piston pin bushings are installed.

A4.18 Cylinder Clamping Sleeve

A4.18.1 The worm and gear assembly requires periodic cleaning. Deposits accumulate in the gear teeth and worm, and should be removed with solvent. Leakage of ethylene glycol from the condenser is likely to drip on the gear assembly and form a hard, crusty deposit which prevents turning. Deposits also accumulate on the outside of the cylinder and in the keyway.

A4.19 Rocker Arm Assembly

A4.19.1 Periodic inspections of the rocker-arm assembly should be made, as excessive clearances will impair proper valve action. These inspections should include the carrier joints as well as the bearings of the rocker arm. The latter are needle bearings. If the bearings need to be replaced, they should never be forced into the rocker arm by tapping or pounding directly on the shell of the bearing. The shell is thin, and if hit locally, serious damage may result. The bearing should be pressed into place with an arbor which bears uniformly on the shell.

A4.19.2 The rocker-arm, push rod, and valve ball-ends become worn or distorted through use. As this may affect valve action and clearance measurement, replacement should be made as soon as there is evidence of appreciable wear.

A4.20 Cooling System

A4.20.1 Deposits accumulate in the cylinder jacket and condenser. It is obvious that those in the jacket will affect the heat transfer from the cylinder and may lead to the formation of a hotspot condition, which will have an appreciable effect on fuel ratings. Two types of deposits are present in the cooling system, the most troublesome one being deposits formed by the decomposition of ethylene glycol. Iron rust is usually found in small amounts and may at times be a source of trouble common to all systems. Ethylene glycol deposits should be removed before each over-haul. Removal of rust and scale is required only occasionally, every five to ten overhauls. The inhibitor specified in A3.4.5 for the coolant is to prevent corrosion of the metals by the coolant; it does not inhibit the ethylene glycol against decomposition. Consequently, the coolant should be discarded or reclaimed by distillation after 250 h of use.

A4.20.1.1 *Removal of Ethylene Glycol Deposit*—Drain the cooling system and flush with water. Fill the system with a water solution containing 8 oz of cleaner (Oakite 24 is recommended) per gallon. Operate the engine at a manifold pressure of 30 in. Hg (101.6 kPa) absolute, and at the fuel-air ratio for maximum power. For systems that have not been cleaned this way before, the engine should be run for 2 or 3 h, allowing the solution to boil. After the first thorough cleaning, 30 to 60 min operation will be sufficient.

(a) Drain the cleaning solution, and flush the system with hot water. If possible, this should be a pressure stream to remove the scale broken loose during the cleaning run. Having the cylinder inverted during flushing helps remove the loosened deposits. Although this is the best cleaning procedure developed so far, it may not remove carbonaceous deposits completely. Therefore, periodic inspection should be made by removing the Allen plugs in the outer wall of the cylinder. If a plug is too tight, it should be removed by drilling and replaced with a new one. Any deposits remaining should be removed by scraping tools.

(b) Particular care should be used to ensure that there are no deposits in the cylinder jacket between the valve seats. It is suggested that the Allen plugs be removed on receipt of a new cylinder and replaced, using either graphite grease or mica lubricant, such as B. G. mica lubricant for spark plugs[13] on the threads, and tightening the plugs just enough to prevent leakage of coolant. The plugs should be removed frequently thereafter to prevent seizing.

A4.20.1.2 *Rust Removal*—The cooling system (see Fig. A1.10) should be drained, and a mixture of clean water and acid cleaner circulated through the jacket at high velocity. Recommended acid cleaners are: Permatex radiator cleaner (25 % solution in water), sodium bisulfate (8 oz/gal of water), or Magnus D Scale-R (8 oz/gal of water). The temperature of the cleaning solution should be between 180 and 200°F (82 and 93°C), but not higher than the latter limit. Circulate the solution for 30 min, then drain and flush with hot water.

(a) If a high-velocity circulating system is not available, the next best method is to put the acid cleaner in the cooling system and run the engine for a few minutes to bring the temperature of the solution to 180 to 200°F (82 to 93°C). The solution should be kept at this temperature for approximately 30 min and then drained. The system should be flushed with clean hot water, or steam and water. Having the cylinder inverted while flushing helps remove the loosened deposits.

[13] Available as a separate publication from ASTM and the Institute of Petroleum, 61 New Cavendish St., London, W1, England.

A4.21 Main Bearings

A4.21.1 The main bearings of the engine should be checked for wear if excessive clearance is suspected. When the maximum clearance between the bearing and crankshaft is reached (see Table A4.1), install new bearings.

A4.21.1.1 For an approximate check of clearances, remove the flywheel, mount a dial indicator on the crankshaft adjacent to the bearing to be tested, lift the shaft, and record the change in dial reading; this change will give an approximate indication of the clearance.

A4.21.1.2 To obtain an accurate measurement of clearance or to inspect the main bearings, the crankshaft must be removed. This requires complete disassembly of the engine and needs to be done if there is evidence of failure. Indications of failure of the main bearing are:

(a) Excessive bearing clearance.
(b) Mechanical noise.
(c) Small pieces of bearing material in the crankcase.
(d) Difficulty in maintaining oil pressure.

A4.21.2 *CFR-48 Crankcase*—If main-bearing replacement is necessary, it can be done at the laboratory. Remove, in sequence, the following:

A4.21.2.1 Connecting rod.
A4.21.2.2 Magneto.
A4.21.2.3 Spark-indicator neon tube, carrier disk, and collar.
A4.21.2.4 Oil pump and its connecting lines.
A4.21.2.5 Injection pump.
A4.21.2.6 Tachometer-drive body assembly.
A4.21.2.7 Camshaft nut.
A4.21.2.8 Gear cover and camshaft.
A4.21.2.9 Tachometer-drive gear, crankshaft-gear spacer, and crankshaft gear (puller required).
A4.21.2.10 Flywheel nut, flywheel, and key (puller required).
A4.21.2.11 Rear oil-seal carrier assembly (puller required).
A4.21.2.12 Rear main-bearing adapter and crankshaft. To renew main bearings, remove the bearing locating screws (see Fig. A1.18, Item 19) and push the bearings from the crankcase. Push new precision inserts into place by hand, aligning the drilled hole in the bearing with the locating screw. No line boring or reaming is required.

A4.22 Crankshaft and Flywheel

A4.22.1 Journals should be checked for wear if excessive clearance is suspected.

A4.22.1.1 *CFR-48 Crankcase*—Crankshaft end-play is listed in Table A4.1. End thrust is absorbed by the thrust plates, (see Fig. A1.18, Item 16) and mounted on either end of the front main bearing. These are separate from the main bearing and are slipped over the locating dowels (see Fig. A1.18, Item 17) in the crankcase. When end play exceeds 0.010 in., it is

TABLE A4.1 Manufacturing Tolerances and Replacement Limits for Crankcases of Supercharge Engine

All dimensions not otherwise indicated are in inches. Metric equivalents may be found in the back of this manual.

Item	CFR-48 Crankcase		High-Speed Crankcase	
	Manufacturing Tolerances	Replacement Limits	Manufacturing Tolerances	Replacement Limits
Oil Lines	should pass ¼ rod	...	should pass ¼ rod	...
MAIN BEARINGS:				
Rear journal	0.0035 to 0.0049	0.006	0.0035 to 0.0038	0.005
Front journal	0.0035 to 0.0049	0.006	0.0035 to 0.0038	0.005
End-play	0.006 to 0.008	0.010 (adjustable)	0.006 to 0.008	0.010 (adjustable)
Bearings to case	0.0005 to 0.002	...	pressure fit	Loose in retainer
CONNECTING ROD BEARINGS:				
End-play	0.008 to 0.014	0.016	0.008 to 0.014	0.016
Diameter	0.0011 to 0.0036	0.005	0.0011 to 0.0036	0.005
Rod end clearance on piston bosses, min	⅙	...	⅙	...
Pin to bushing fit	0.0005 to 0.0010	0.0015	0.0005 to 0.0010	0.0015
Pin to piston fit	0.0000 to 0.0002	0.0015	0.0000 to 0.0002	0.0015
FLYWHEEL:				
Face runout	0.005 max	0.007	0.005 max	0.007
Rim eccentric	0.003 max	0.005	0.003 max	0.005
CAMSHAFT BEARINGS:				
Front	0.0015 to 0.003	0.004	0.0015 to 0.0025	0.0035
Rear	0.002 to 0.0035	0.004	0.002 to 0.003	0.0040
End-play	0.002 to 0.005	0.007	0.002 to 0.004	0.007
Front bearing to case	0.0005 to 0.002	...	0.0005 to 0.0025	...
Rear bearing to case	0.0005 to 0.002	...	pressure fit	loose in retainer
BALANCING SHAFTS:				
Bearings to case	0.0005 to 0.002	0.0025	...	...
Bearings to shafts	0.0015 to 0.003	0.004	...	...
End-play	0.002 to 0.006	0.010	...	...
GEARS:				
Idler end-play	0.002 to 0.004	0.008	...	...
Idler bearing	0.0015 to 0.003	0.004	...	...
Backlash	0.002 to 0.004	0.006	0.000 to 0.002	0.006
TAPPET GUIDE CLEARANCE	0.0005 to 0.002	0.003	0.0005 to 0.002	0.003
GUIDE PLATE CLEARANCE ON CYLINDER	0.002 to 0.004	0.006	0.002 to 0.004	0.006
NEON TUBE DISK CLEARANCE ON QUADRANT SCALE	0.008 to 0.015	0.018 (adjustable)	0.008 to 0.015	0.018 (adjustable)
VALVE TIMING WITH 0.010 IN. CLEARANCE:				
Inlet valve opens	15° btdc ± 2½ °	...	(same as for CFR-48)	...
Inlet valve closes	50° abdc ± 2½ °	...		...
Exhaust valve opens	50° bbdc ± 3°	...		...
Exhaust valve closes	15° atdc ± 3°	...		...
BALANCING ROD:				
End-play	...	...	0.003 to 0.009	0.011
Balancing rod clearance, dia	...	...	0.003 to 0.005	0.006
Pin end clearance on piston bosses	...	...	⅙	...
Pin to bushing fit	...	...	0.0000 to 0.0005	0.002
Pin fit in balancing piston	...	...	0.0002 to 0.0004	0.001
BALANCING WEIGHTS:				
Clearance in sleeve after clamping	...	...	0.005 to 0.0075	0.009
Each balancing weight, including pin and lock screw, must weigh 0.900 of engine piston, rings, and pin	...	...	±¼ oz	...
Weight of balancing piston (Part No. 105965-A piston and No. 105533-B pin)	...	...	36.6 oz ± ¼ oz	...

adjusted by shims (see Fig. A1.18, Item 84) placed between the crankshaft shoulder and the steel thrust washer (see Fig. A1.18, Item 85) to give the proper end play.

A4.22.1.2 *High-Speed Crankcase*—Crankshaft end-play is listed in Table A4.1.

A4.22.2 *Flywheel*—Check the accuracy of the position of the flywheel pointer with a dial gage mounted so that an extension attached to its plunger and extending through the opening for the combustion pickup unit in the top of the cylinder will reach to the top of the piston. Rotate the flywheel until the dial gage indicates true tdc. If the tdc setting is incorrect, reset ignition timing indicator quadrant so that at true tdc the zero mark on the quadrant aligns with the indicator slot in the rotating disk. Also reset the flywheel pointer so that it aligns with the tdc mark on the flywheel. Be sure the flywheel nut is securely locked.

A4.23 Connecting Rod

A4.23.1 *Big-End Bearing*—The big-end bearing of the connecting rod should be examined every 2000 h. The specified connecting rod clearances are listed in Table A4.1. To measure the bearing clearance, place a thin strip of virgin lead or other suitable material[14] 1 in. long and 1⁄16 in. wide between

[14] Plastigage, available from the Perfect Circle Co., Hagerstown, IN, is suitable for this purpose. If it is used, the flattened strip is placed on the calibration chart supplied with it and the clearance is read therefrom.

the bearing cap and the journal, with the long dimension parallel to the centerline of the journal, and tighten the bearing bolts securely. Be sure that the rod cap is firmly seated and that there is a slight bind of the bearing. If the lead strip is used, remove and measure its thickness with a micrometer. This is the bearing clearance. Excessive clearance can be reduced only by the installation of a new set of bearing shells.

A4.23.2 *Piston-Pin Bushing*—The bronze piston-pin bushing should be inspected every 2000 h and replaced when the clearance exceeds that listed in Table A4.1. The oil hole in the bushing must be in alignment with the oil passage in the rod. There must be an oil groove to connect this hole with the small oil passage in the top end of the connecting rod. Replacement bushings must be fitted to the piston pin after installation.

A4.23.3 *Alignment of Connecting Rod*—The connecting rod should be checked periodically for alignment. This can be done with any of the alignment jigs available in automotive service stations. When the connecting rod is properly aligned, the following conditions are met:

A4.23.3.1 The piston wall is perpendicular to the axis of the journal within 0.003 in.

A4.23.3.2 The piston pin is not twisted more than 0.002 in. in the length of the big-end bearing.

A4.23.3.3 The centerline of the connecting rod is perpendicular to the axis of the bearings within 0.003 in.

A4.24 Camshaft

A4.24.1 *CFR-48 Crankcase*—The camshaft is supported by precision-type sleeve bearings at both ends. It is not interchangeable with the camshaft of the high-speed crankcase. The flanged bearing at the timing gear end controls the end-play. The camshaft with timing gear may be withdrawn after stripping the front end of the engine and removing the front bearing retaining screws (see Fig. A1.16, Item 25). It is good practice to remove the valve lifters (see Fig. A1.16, Item 58) and guides (see Fig. A1.16, Item 56) before removing the camshaft. If end-play is over 0.007 in., the front camshaft bearing should be replaced to give a total end-play of 0.002 to 0.005 in. when the gear is again drawn into position. The running clearances of the front camshaft bearing should be 0.0015 to 0.003 in., and of the rear bearing 0.002 to 0.0035 in. Install new bushings when clearances of 0.004 in. are exceeded, aligning the locating screw hole in the rear bushing with the location screw. No line boring is required. When reassembling, make sure the gear teeth mesh at the "X" marks so that the valve timing will be correct.

A4.25 Valve Timing Procedure

A4.25.1 Checking the valve timing should not be necessary except in cases of complete disassembly and overhaul. When doing so always turn the flywheel forward to avoid errors due to backlash in the timing gears.

A4.25.2 *High-Speed Crankcase*:

A4.25.2.1 Before moving the cam gear, check the accuracy of the position of the flywheel pointer with a dial gage mounted so that an extension attached to its plunger and extending through the opening for the knock pick-up unit or plug in the top of the cylinder will reach to the top of the piston. Rotate the flywheel until the dial gage indicates true tdc. Reset the flywheel pointer if necessary. If the tdc setting is incorrect, reset the spark quadrant so that at true tdc the zero mark aligns with the neon-tube indicator slot in the rotating disk. Also reset the timing of the fuel-injection pump, as described in A4.46.

A4.25.2.2 Before moving the cam gear, it is necessary to disconnect the fuel-injection pump, pump drive and bracket, magneto and drive coupling, shaft nut and spark advance indicator. The gear cover may then be removed, exposing the timing gears.

A4.25.2.3 The cam gear has four keyways, each of which produces a change in valve timing of approximately 2½ °. One keyway will give timing within the specified limits. After reassembling the parts, check the timings of the fuel injection pump and the spark as outlined in Sections A4.46 and A4.49. Set the engine at tdc on the *firing stroke* and adjust the valve clearances to be exactly 0.010 in. for each valve. Then set the engine at tdc on the *exhaust stroke* and rotate the flywheel again until the clearances for both valves are equal. Mark this position on the flywheel. It should be within 2½ ° of tdc. If it is not, move the cam gear on the camshaft until the position of equal clearance is within 2½ ° of the tdc mark.

A4.25.2.4 Reset the valve clearances for standard engine operation. The valve timing is shown in Fig. A1.19 and is as follows:

Valve	Opens	Closes
Intake	15° btdc	50° abdc
Exhaust	50° bbdc	15° atdc

The contour of the valve cam may be checked in a similar manner and should be within the limits shown in the timing diagram.

A4.25.3 *CFR-48 Crankcase*—A4.25.1 and A4.25.2 are generally applicable to the CFR-48 crankcase except for the following: The camshaft gear has 76 teeth, whereas the high-speed gear has 68 teeth. Thus, shifting the timing one full gear tooth will make 1.320 in. change on the flywheel. The extra keyways in the gear permit adjustment of the timing by 0.330-in. increments on the flywheel, or within 1°, 11 min of a given fixed mark.

A4.26 Valve Tappets

A4.26.1 The mushroom valve tappets are assembled in cast iron guides, and should just drop by their own weight when new. When a clearance of 0.003 in. develops, replace the guides. Do not use a tappet that shows signs of excessive wear. Discard any tappet that has a groove on the cam contact face, as this interferes with rotation and affects the valve clearance.

A4.27 Balancing Systems

A4.27.1 *CFR-48 Crankcase*:

A4.27.1.1 The rotating balance system should be inspected when trouble is suspected. The two shafts are carried in four identical precision-type bushings (see Fig. A1.16, Item 20) held in the crankcase by locating screws. Balancing shaft running clearance should be 0.0015 to 0.003 in.

A4.27.1.2 When running clearance exceeds 0.0035 in., new bearings should be installed. Line boring is not required when bearings are replaced. End thrust is absorbed by the thrust plates (see Fig. A1.16, Item 162) and end-play should be 0.002 to 0.006 in.

A4.27.1.3 If end-play exceeds 0.010 in., new thrust plates should be used. The gears are installed with the flat faces to the front and must be timed to the engine so that both eccentric weights are at bdc when the engine piston is at tdc.

A4.27.1.4 The full engine gear train is marked at assembly with "X" and "C" marks at gear-timing points, but service replacement gears are not so marked. The solid steel weights are used in pairs to balance the aluminum piston. Tightening torque on the nuts holding the weights to the balance shafts is 100 ft-lb. Remove the weights and thrust-plate cap screws (see Fig. A1.16, Item 163) to withdraw shafts from the crankcase.

A4.28 Idler Gear

A4.28.1 *CFR-48 Crankcase*—The idler gear (see Fig. A1.16, Item 145) is retained on the stub shaft by a thrust washer and cap screw and drives the oil pump as well as the balancing shafts. The running clearance of the bushing is 0.0015 to 0.003 in. and end-play is 0.002 to 0.004 in. Replacement should be made when running clearance exceeds 0.004 in., or end-play exceeds 0.008 in. Replacing the gear bushing requires machine reaming concentric with the outside diameter.

A4.29 Lubrication System

A4.29.1 *CFR-48 Crankcase*—The oil pump is mounted externally on the gear cover and draws oil through an external line from the sump oil screen. The oil screen is easily removed through the gear cover opening for cleaning. Oil is delivered to an external oil-pressure relief valve, and then to the crankshaft, camshaft, balancing shaft, idler shaft, connecting rod, and piston-pin bearings under full pressure. The timing gears are oiled by an intermittent spray jet controlled by holes in the front camshaft bearing.

A4.30 Oil Pressure Adjustment

A4.30.1 Oil pressure should be adjusted to 60 psi (0.41 MPa).

A4.30.1.1 *CFR-48 Crankcase*—The oil pressure relief valve is mounted horizontally below the crankcase side door on the camshaft side of the engine. Oil pressure is adjusted by means of the screw under the cap-nut on the valve body.

A4.30.1.2 *Low Oil Pressure*—If the specified pressure cannot be maintained with the proper grade and quantity of oil in the system, it may be due to clogging of the strainer screen or to foreign matter on the relief-valve seat, holding the relief valve open. The drilled oil passages in the crankcase are closed at the outside end by screw plugs. Whenever the camshaft, crankshaft, or oil pump is removed, the oil passages should be opened and any obstructions removed with compressed air and a stiff brush. Do not apply air to any passage without removing the shafts as this will blow the dirt into the bearings.

A4.31 Valve Lubrication

A4.31.1 On all CFR-48 and late high-speed crankcases equipped with the enclosed valve gear, the amount of oil fed to the valve mechanism is controlled by the intermittent registry of the passages at the front camshaft bearing. Early high-speed crankcases used full-pressure oil with an orifice of 0.030-in. diameter in the oil line and a valve at the rear of the cylinder to turn the oil supply on or off. In assembling the mechanism, be sure that the shafts are in proper position as a rotation of 180° will block the oil passages.

A4.32 Oil Cooler and Filter

A4.32.1 The oil-filter has a replaceable element, which should be replaced at least every 50 h after draining the filter by removing the drain plug. Inspect the oil cooler and water passages for free flow and clean if required.

A4.33 Crankcase Oil Leaks

A4.33.1 *CFR-48 Crankcase*—If an oil leak develops, replace the faulty oil seal. The front seals are pressed into the gear cover to seal around the front of the camshaft and the crankshaft. The camshaft seal, Item 93 (All item numbers in A4.33.1 refer to Fig. A1.16.) rides on a sleeve, Item 169, which is held in place by the camshaft nut and is sealed to the camshaft by an internal O ring, Item 170. The crankshaft front seal rides on the ignition-indicator disk spacer, Item 91, which is sealed to the crankshaft by an internal O ring, Item 92. The rear oil seal, Item 82, is pressed into a stationary carrier, Item 81, which is sealed to the main-bearing adapter by two external O rings, Item 83. The rear main-bearing adapter is sealed to the crankcase by an O ring, Item 30. An O ring, Item 33, seals the oil-pressure transfer passage to the rear main bearing. No relative motion occurs at O rings in operation. All the rotating shaft seals are of the synthetic-rubber lip type and are installed with the sharp edge of the lip toward the crankcase. Make sure that the lip runs on a clean polished surface.

A4.34 Crankcase Breather Valve

A4.34.1 The function of the breather valve is to maintain a vacuum in the crankcase. The valve should be removed, cleaned, and inspected to see that it is seating properly at each top overhaul. The vacuum should be at least 1 in. of water. If the breather vent line is so long that the required vacuum cannot be obtained a small blower may be used in the line, but it should not create a vacuum of more than 10 in. (254 mm) of water.

A4.35 Oil Change Procedure

A4.35.1 *Crankcase*—Oil should be changed frequently enough to prevent excessive lacquering or gumming of engine parts. The oil-change interval is dependent entirely upon the oil performance. It is suggested that the oil be changed at least every 50 h. The CFR-48 crankcase requires 3.5 qt (3 L) of oil, the high-speed crankcase, 3 qt (2.8 L). An additional quart is required if the oil filter has been repacked. The oil level should be kept halfway up the sight glass, but not above that point. On the CFR-48 crankcase the sight glass is a transparent plastic plug (see Fig. A1.18, Item 72). It should not be tightened excessively as its expansion, when hot, will seat it very firmly on its gasket to prevent leakage.

A4.35.2 *Fuel Injection Pump*—SAE 30 oil is specified for the fuel injection pump. The level should be kept halfway up the sight glass *K* (see Fig. A1.7) and the oil should be changed at 50-h intervals. It is expedient to change it at the same time the crankcase oil is being changed; but if excessive dilution of this oil occurs prior to the end of the 50-h period, it should be changed more frequently.

A4.36 Engine Break-In

A4.36.1 Following the installation of a new cylinder or piston and rings, operate the engine for approximately 8 h before attempting ratings. Use atmospheric pressure 30 in. Hg (101.6 kPa) in the intake manifold at the beginning of this period and gradually increase it to 40 or 45 in. Hg (135 or 152 kPa). Use a fuel having sufficient antiknock value to prevent knocking and adjust the fuel-air ratio for maximum power.

A4.36.2 Stop the engine periodically, remove the cylinder plug, and inspect the piston for signs of oil pumping. The piston top must be dry before proceeding with ratings. If oil pumping cannot be eliminated after 16 h of running, carefully check the rings, cylinder, and piston, and remove and check the connecting rod for alignment and twist.

A4.36.3 After a top overhaul, the engine often knocks irregularly and imeps for the reference fuels may not conform to the framework. This is usually caused by oil pumping. In such cases the engine should be run as above until operation is satisfactory.

A4.37 Induction System Heaters

A4.37.1 The inlet air heater *J* (see Fig. A1.11) and the surge-tank air heater *A* should be inspected and cleaned periodically.

A4.38 Air Induction System

A4.38.1 Before working on the air induction system, turn off the air supply *P* (see Fig. A1.11) and relieve the pressure through the atmospheric bleed valve *B*. Open this valve slowly; otherwise, the sudden change in pressure will force the water out of the manometer.

A4.38.2 *Testing for Leaks*—At every overhaul, or more frequently if necessary, the air-induction system must be checked to see that leakage at a pressure of 90 in. Hg (304 kPa) does not give a pressure drop of more than 0.1 in. Hg (0.34 kPa) per minute. The procedure is as follows:

A4.38.2.1 Disconnect the fuel-injector line (see Fig. A1.8) and loosen the intake manifold at the engine, leaving it firmly connected at the bellows (see Fig. A1.14).

A4.38.2.2 Insert a blank metal plate to block the outlet of the intake manifold. Restore the manifold to its original position with a regular manifold gasket on each side of the metal plate, and pull the flange nuts tight.

A4.38.2.3 Remove the large capnut (see Fig. A1.13) from the pressure regulating valve. After removing the spring *B*, and the valve plunger and guide C, replace and tighten the nut. The valve is then inoperative so that pressures throughout the system equalize.

A4.38.2.4 Close the atmospheric bleed valve *D* (see Fig. A3.1).

A4.38.2.5 Attach a rubber tube to the outlet at the top of the 100-in. manometer and lead it into an empty flask or bottle to provide for recovering the mercury in case the air pressure should increase suddenly and blow the mercury out of the manometer tube.

A4.38.2.6 Close both valves *H* and *J* (see Fig. A1.9).

A4.38.2.7 Open the condensate-drain valve *Q* (see Fig. A1.11) to drain moisture from the compressed air lines. When the moisture has been cleared, close the drain valve and open the main valve *P*.

A4.38.2.8 Open very slightly valve *J* (see Fig. A1.10) as in preparation for starting, but permit the pressure to rise until the mercury column reaches the 90-in. mark. Then tightly close the valve.

A4.38.2.9 Immediately close the air valves *P* and *N* (see Fig. A1.11). Open the condensate drain valve *Q* so that in case of a leak in the air valve *N* the induction system cannot take in more air from the compressed air line.

A4.38.2.10 During the first few seconds after the pressure has been raised to 90 in. Hg (304 kPa), the mercury will bounce up and down as the pressure equalizes in the various portions of the induction system. When the mercury comes to rest, observe the rate of pressure drop using a reliable watch. If the mercury drops faster than 0.1 in./min, the system is not tight enough and must be explored for leaks.

A4.38.2.11 Brush a tacky soap solution or SAE 10 oil around the fittings and joints. Bubbles will appear wherever there are leaks. Inspect all joints in this manner and do not overlook the thermostat, thermometer, and manometer connections. Lower the bellows guard *D* (see Fig. A1.14) and check the entire bellows, as well as the upper and lower flange connections.

A4.38.2.12 If repairs are required at any of the joints and connections, open very slightly the atmospheric bleed valve *D* (see Fig. A3.1) and gradually release the pressure in the system to prevent the water manometer from losing its liquid. Make whatever repairs are required and repeat the test.

A4.38.2.13 Replace parts *B* and *C* (see Fig. A1.13) that were removed from the pressure regulating valve.

A4.38.2.14 After removing the blank metal plate and fastening the intake manifold to the engine, check this joint to make sure it does not leak.

A4.38.3 *Cleaning*—Every effort should be made to keep the inlet air clean. The filter *M* (see Fig. A1.11) and the two air tanks in the air system should be drained at every overhaul to prevent entrained moisture or rust from entering the engine. To do this, disconnect the two lines at the water manometer to prevent blowing water out of the manometer when the drain valves are opened and closed. Then open the drain valves at the bottom of the filter and of each air tank. Turn on the air and allow it to flow at high velocity through the valves and manometer lines. Also remove the two plugs adjacent to the air orifice to disperse any moisture collected at these points. Occasionally the internal surfaces of the pipes of the intake system should be examined, and replaced with new ones if they show evidence of rust formation.

A4.38.4 *Air Filter*—Due to the variation in the purity of the air in different laboratories, no definite periods for cleaning the air filter *M* (see Fig. A1.11) can be stated, but it should be examined periodically and cleaned if dirty. To inspect the filter element remove the strap bolts and cover, which will allow it to be lifted out. Clean the element by rinsing in solvent, and dry thoroughly before replacing it.

A4.38.5 *Pressure Reducing Valves*—Air often contains entrained oil from the air compressor. If this condition exists, the pressure reducing valves should be taken apart and cleaned at every overhaul period.

A4.38.5.1 To clean the high-pressure valve *L* (see Fig. A1.11), remove the plug at the top and the check ball from its seat. Clean both ball and seat with a solvent, and check the plunger for freedom of movement.

A4.38.5.2 To clean the low-pressure valve *C* (see Fig. A1.11), remove the capnut *A* (see Fig. A1.13), being careful not to lose the small spring *B*. The small valve plunger and guide *C* may then be lifted out. Clean the valve and its seat with solvent and examine the stem for wear before reassembly.

A4.38.5.3 If badly worn, the valve will tend to chatter and cause undue fluctuations in the mercury manometer, an indication that it should be replaced.

A4.39 Exhaust System

A4.39.1 The specifications for the exhaust system (see A1.11) should be followed strictly. Back pressure and resonance affect engine scavenging, causing irregular cyclic variation. Consequently, they affect fuel ratings.

A4.39.2 For exhaust systems of the surge-tank type, open the surge-tank port and remove any deposits. Give particular attention to deposits at the mouth of the water drain pipe. If this drain pipe appears to be clogged, remove and clean it.

A4.39.3 Inspect exhaust systems using water injection for clogging of the spray holes in the brass ring. They may be blown with air or reamed with a piece of wire.

A4.40 Fuel Injection System

A4.40.1 The fuel system should be inspected periodically and any foreign matter in the fuel containers, lines, or pumps removed by flushing with solvent.

A4.40.2 The fuel filter (see Fig. A1.8) at the end of the line from the sample container should be blown out with air and the sintered bronze filter, in the fuel pump, cleaned or renewed at every overhaul.

A4.40.2.1 The condition of this filter is often indicated by the rate at which the beaker in the fuel weighing device fills. The cores of the three-way valves should be removed, wiped clean with a lint-free cloth, and reassembled, using graphite and oil, or any suitable commercially available valve lubricant that is not soluble in gasoline. Older units are equipped with a Bosch fuel-supply pump, and dirt sometimes lodges on its valves and seats. These parts should be removed and cleaned. Either a low rate of fuel flow to the beaker or low fuel pressure is evidence of a dirty condition. In these units, the fuel pressure is maintained by means of an orifice in the fuel line behind the injection pump. If the pressure is too high, the orifice may be dirty and should be cleaned. Later units are equipped with a gear pump and a spring-loaded check valve to maintain the fuel pressure. *This pump should never be run without fuel in the system, as the fuel acts as a lubricant.*

A4.41 Fuel Weighing System Check

A4.41.1 Disconnect the injection nozzle *A* (see Fig. A1.7) from the intake manifold and arrange it to discharge through a short rubber connection into a copper tube which in turn discharges into a 500-mL graduate placed in an ice bath.

A4.41.2 For checking purposes use ASTM *iso*octane.

A4.41.3 While motoring the engine at 1800 rpm, flush the entire fuel system with this fuel. Make sure that all lines are full and free of entrapped vapor. This may be done by actually discharging fuel from the nozzle while operating first from the supply can (see Fig. A1.8) and then from the beaker. Fill the beaker with fuel in the same manner as when measuring the rate of fuel flow.

A4.41.4 Place approximately 50 mL of fuel in the 500-mL graduate and weigh. Place the graduate in the ice bath with the copper tube installed so that it discharges below the level of the fuel.

A4.41.5 Adjust the fuel valves to draw fuel from the beaker *U* (see Fig. A1.9) in the fuel weighing device. Arrange the fuel control rack *E* (see Fig. A1.7) to open the desired amount.

A4.41.6 Simultaneously start a stop watch and fuel injection by releasing the control lever *G* (see Fig. A1.9) of the fuel rack.

A4.41.7 Operate the fuel weighing device in the conventional manner during the period that the fuel is being collected in the 500-mL graduate. Use the weight on the scale and the time recorded by the clock to calculate the fuel-flow rate in pounds per hour.

A4.41.8 After somewhat more than 0.25 lb (0.11 kg) of fuel has been collected in the graduate, simultaneously stop the watch and the fuel injection by means of the fuel-rack control.

A4.41.9 Take the 500-mL graduate with the fuel it contains out of the ice bath, thoroughly dry the outside of the graduate, and weigh it.

A4.41.10 Use the difference between the weights obtained in A4.41.4 and A4.41.9 and the time recorded by the stop watch to calculate the rate of fuel flow in pounds per hour.

A4.41.11 Using the same setting of the fuel rack, adjust the fuel valves to draw fuel from the supply can and again follow the procedure in A4.41.4, A4.41.6, A4.41.8, A4.41.9, and A4.41.10.

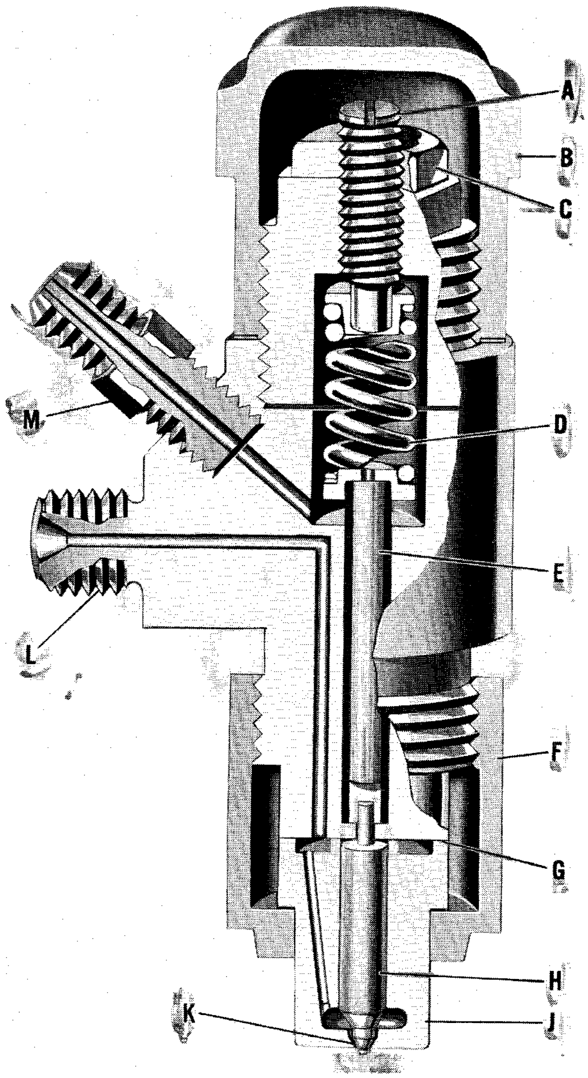
A4.41.12 The rates of fuel flow obtained in A4.41.7, A4.41.10, and A4.41.11 should agree within ± 1 %.

A4.41.13 Repeat the procedure for at least two settings of the fuel rack, covering the normal range of flow rates. It is advisable to check the determinations at each setting at least once.

A4.41.14 If the proper calibration is not obtained within ± 1 %, test the fuel lines for leaks and restrictions, and check the electric time clock, fuel-weighing scales, injection pump, and transfer pump.

A4.42 Fuel Injection Nozzle

A4.42.1 In any operations requiring the disassembly of the fuel-injection nozzle (see Fig. A4.8) scrupulous cleanliness must be observed to prevent dirt or moisture from damaging the finely finished fits.



A—Screw for adjusting nozzle pressure
B—Protecting cap
C—Locknut
D—Nozzle spring
E—Nozzle pressure spindle
F—Nozzle retaining nut
G—Lapped joint
H—Nozzle pintle
J—Nozzle
K—Nozzle valve seat
L—Fuel connection
M—Nozzle drain

FIG. A4.8 Bosch Fuel Injector

A4.42.1.1 Parts removed should be placed in a *clean* container and submerged in fuel oil or kerosine. They should be handled as little as possible with bare fingers to prevent body acids from etching lapped surfaces, and should be thoroughly cleaned and oiled before reassembly.

A4.42.1.2 To clean the nozzle assembly, first soak the barrel and plunger in solvent to remove gum or lacquer. Clean carbon from the pintle tip by forcing it into a piece of cork and rotating the plunger back and forth.

A4.42.1.3 To clean the pintle orifice and seat, work a charred match into the barrel. Rotate the stick firmly but not forcibly until the carbon is removed.

A4.42.2 *Spray Pattern*—It is important that the spray pattern from the fuel injection nozzle be of the proper shape. It is also important that the nozzle be centered in the inlet elbow so that the core of the spray impinges on the intake valve stem. At every overhaul the character of the fuel spray should be inspected by arranging the injector to spray fuel into the room, using unleaded gasoline. The seat of the nozzle plunger should be cleaned or lapped if the injection shows any of the following characteristics when the engine is rotated slowly by hand:

A4.42.2.1 A coarse stream rather than a finely divided mist.

A4.42.2.2 An asymmetrical rather than a true conical spray.

A4.42.2.3 Nozzle dripping instead of shutting off completely.

A4.42.2.4 Excessive leakage through the leak-off connection. It is comparatively easy to check the spray pattern by removing the nozzle holder and connecting it again to spray into the room. The approximate diameter of the spray at any point may be determined visually. However, it is advisable to make a series of holes of different diameters in pieces of cardboard or thin sheet metal, or from a light wire. These may be used to determine the distance from the face of the nozzle at which the spray makes contact with the periphery of the hole. Some means must be provided, or course, for centering the hole with respect to the axis of the nozzle. The fuel rack should be set to deliver approximately 10 lb (4.5 kg)/h.

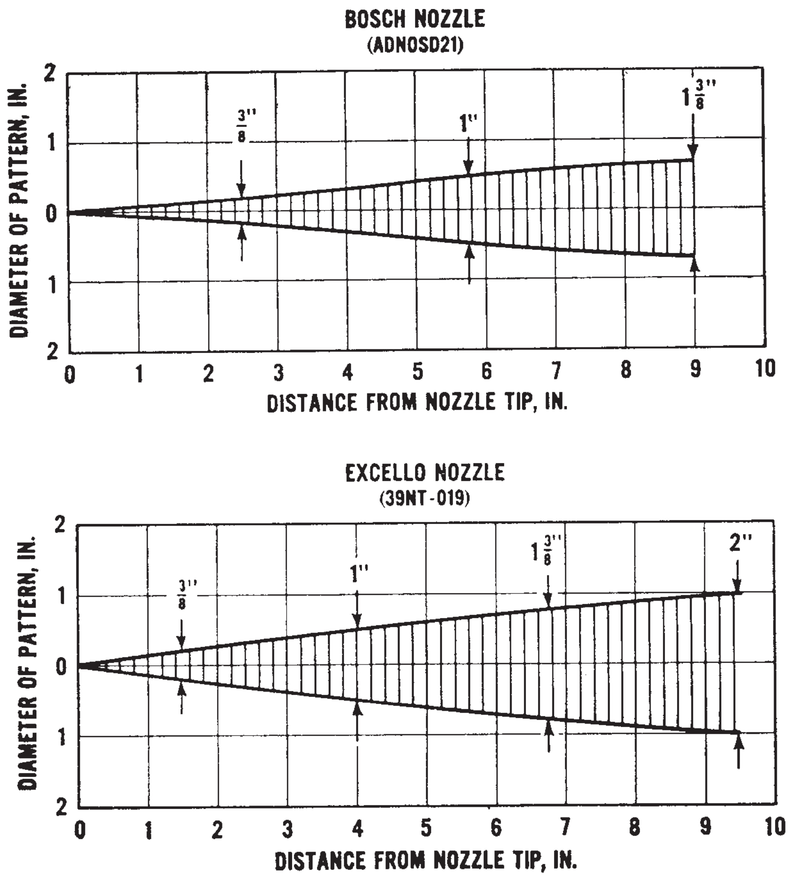
A4.42.3 *Centering the Spray*—Failure of the nozzle spray to conform within reasonable limits to the pattern shown in Fig. A4.9, or irregular distribution of the spray around its centerline, is indicative of a dirty or damaged injection nozzle. To make sure the spray is centered with respect to the intake manifold, install the nozzle in the elbow and turn the elbow so that the spray is directed into the room. If a piece of white paper is held over the end of the elbow and injection started, the center of the spray will punch a hole in the paper. Check this hole for concentricity with the elbow opening. In this test use an unleaded reference fuel with the fuel rack set to deliver approximately 10 lb (4.5 kg)/h.

A4.42.4 *Safety*—It is extremely important to provide ample ventilation when injecting fuel into the room, since the presence of any quantity of fuel vapor in the air will form an explosive mixture. *It is also extremely important that the high velocity fuel spray be kept away from contact with the skin.*

A4.43 Checking Nozzle Opening Pressure

A4.43.1 The operation of the engine is affected markedly by variance from the standard nozzle opening pressures. The specified opening pressure of the Bosch nozzle is 1200 $\pm$ 100 psi (8.2 $\pm$ 0.69 MPa) and needs to be checked only two or three times a year, or whenever the fuel injector operates incorrectly. To adjust the pressure remove the protection cap *B* (see Fig. A4.8) loosen the locknut *C*, and adjust the pressure screw *A*. The opening pressure of the Excello nozzle is 1450 $\pm$ 50 psi (10 $\pm$ 0.34 MPa) and is not adjustable. The methods described in A4.43.2 to A4.43.3 may be used to check the opening pressure.

A4.43.2 *Bacharach Tester, Model 65-0030*—This bench tester is suitable for checking such items as opening pressure, spray pattern, leakage, or dribbling before opening pressure is reached, chattering, and condition of the delivery valve. The tester consists of a high pressure pump equipped with a pressure gage, fuel reservoir, and a valve. Pressure is applied to the nozzle by a pump operated by hand. The fittings required to



Engine speed	1800 rpm
Fuel	*iso*octane
Fuel rate	10 lb/h

FIG. A4.9 Spray Patterns for Injector Nozzles

connect the nozzle to the tester can be purchased as a separate item from the supplier.

A4.43.3 *Robert Bosch Tester*[15]*, Potentiometric Type No. EFEP66A*—This is an in-line tester and is recognized as one of the most reliable for this purpose. It is usable only on engines having the earlier swage-type metric fittings and does not fit the Ermeto sleeve-type connectors currently used. To use the tester, remove the injector from the intake manifold. Arrange for it to spray into a suitable container with the tester installed in the injector supply line. Motor the engine and adjust the tester so that fuel is delivered from both injector and tester. A suitable container should also be provided to catch the fuel from the tester. Read the opening pressure for the injector valve as indicated on the tester when the quantity of fuel delivered is about equally divided between the injector and tester. If the opening pressure is not within the limits shown in the following table, adjust the tension on the injector spring until the desired opening pressure is obtained.

Fuel	Clear Reference Fuel
Injection pressure	1200 ± 100 psi (8.3 ± 0.7 MPa)
Fuel rate	4 lb/h (1.8 kg/h)

A4.44 Fuel Pump Delivery Valve

A4.44.1 The delivery valve *E* (see Fig. A4.10) of the injection pump should be inspected periodically or whenever injection is irregular to see that the valve is seating properly.

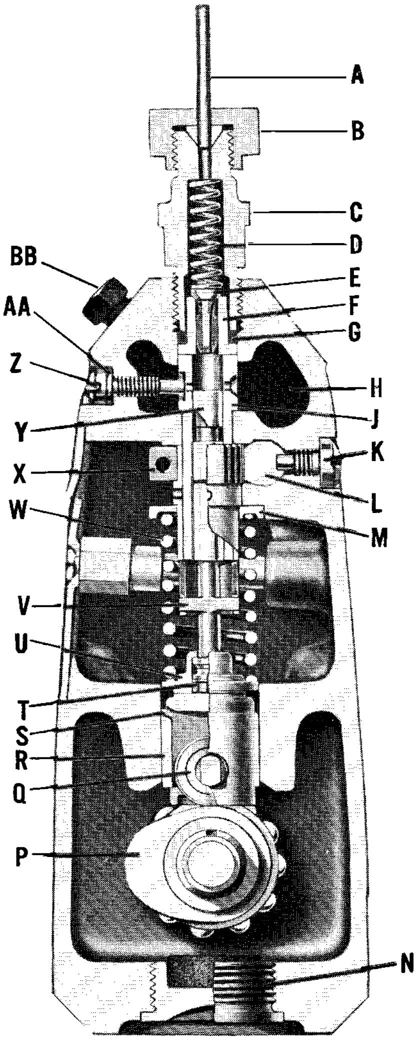
A4.44.2 To remove the valve and seat, disconnect the line to the nozzle, remove the valve holder *C* and spring *D*, and then the valve assembly *E*, *F*, and *G*. The valve seat *F* and gasket *G* must be pulled out with a special extractor tool (obtainable from American Bosch Co.). These parts should be cleaned or lapped with special rouge as required but, in general, lapping is not recommended.

A4.44.3 In reassembling, be sure that gasket *G* is put back between the valve seat and the valve holder, and that the bottom face of the seat and the mating top of the plunger barrel *J* are clean.

A4.45 Fuel Pump Barrel and Plunger

A4.45.1 The barrel and plunger of the injection pump are an individually mated assembly and seldom need replacement. When there is excessive dilution of the oil in the pump (see A4.11), the barrel and plunger should be examined for wear or replaced with a new mated assembly.

[15] These Bacharach and Bosch testers have been found satisfactory for the Supercharge method and are available respectively from Bacharach Instrument Co., AMBAC Industries Inc., 625 Alpha Drive, RIDC Industrial Park, Pittsburgh, PA 15238, and from Robert Bosch Corp., 2800 South 25th Ave., Broadview, IL 60153.



A—Fuel injection line
B—Nipple nut
C—Delivery valve holder
D—Delivery valve spring
E—Delivery valve
F—Delivery valve seat
G—Valve assembly gasket
H—Fuel gallery
J—Plunger barrel
K—Fuel rack setscrew
L—Fuel rack
M—Upper plunger spring seat
N—Base plug
P—Camshaft
Q—Tappet roller
R—Tappet body
S—Hole in tappet for disassembly
T—Tappet spacer
U—Lower plunger spring seat
V—Plunger lug with punch mark facing inspector door
W—Plunger spring
X—Clamping jaw of control sleeve and segment
Y—Pump plunger
Z—Pump barrel set screw
AA—Copper washer
BB—Fuel by-pass connection

FIG. A4.10 Section Through Bosch Fuel Injection Pump

A4.45.1.1 In disassembling the various parts of the fuel-injection system, observe the following precautions: Put all removed parts in a *clean* container immersed in kerosine or fuel oil. Keep together any mated parts, such as delivery valve and seat or barrel and plunger. *Never* interchange single units of mated assemblies; when making replacements always use a complete mated assembly.

A4.45.1.2 Do not touch lapped or polished surfaces. Wash each part in clear kerosine and wipe it with clean, lint-free cloth. Check replacement parts by number and visual inspection. Lubricate moving parts with light oil.

A4.45.2 *Removing Barrel and Plunger*—Remove the pump from the engine, the delivery valve assembly, *C*, *D*, *E*, and *F* (see Fig. A4.10) and the large inspection plate on the side, then turn the cam so that the tappet head is exposed. Remove the hairpin control spring of the pump rack. Insert a ⅛-in. rod in hole *S* of the tappet to keep it off the cam. Remove one bearing end plate and the camshaft *P*. Remove the base plug *N*. Then with a stout wooden stick, push the tappet up and remove the ⅛-in. rod. This makes it possible to remove the tappet *R*, spring *W*, plunger *Y*, upper and lower plunger-spring seats *M* and *U*, and the tappet spacer *T*. Through the inspection-plate opening, remove control sleeve *X*. Remove barrel set screw *Z*, and washer *AA*. Remove barrel *J* from the top, pushing with a fiber or brass rod if necessary.

A4.45.3 *Replacing Barrel and Plunger*—Insert barrel *J* (see Fig. A4.10) with plunger removed, into position through the top with the slot (oblong recess) line with the hole for the barrel setscrew *Z*. Replace the setscrew, making sure that the tip meshes with the slot in the barrel. Do not forget gasket *AA*, under the setscrew head.

A4.45.3.1 Place the control rod *L* in mid-position. Slide sleeve *X* over the barrel, meshing the teeth of the segment with those of the control rod so that the clamping jaws are perpendicular to the rod. Move the control rod back and forth to see that the toothed segment has full swing in both directions. If it does not, move the segment one tooth and recheck.

A4.45.3.2 The slot in the lower end of the control sleeve must align with the clamping jaws of the segment. Slide the upper spring seat *M*, and the plunger spring *W* over the control sleeve. Put the lower spring seat *U*, and the tappet spacer *T*, on the plunger *Y*, and inset the unit into the barrel so that the plunger lug *V*, with punch mark, is in line with the clamping jaw *X*, and in the slot of the control sleeve. Insert the tappet with hole *S* of its holder in front, and compress the spring with a stout wooden stick until a ⅛-in. rod can be inserted in this hole *S*. Replace the camshaft *P*, and endbearing plate. Remove the tappet holder rod. Replace the hairpin control spring of the pump rack, the inspection cover plate, the base plug *N*, and the delivery-valve assembly *C*, *D*, *E*, *F*, and *G*.

A4.45.3.3 Whenever the injection pump is removed or a new plunger and barrel installed, the pump timing must be checked, as described in Section A4.46. With a new plunger and barrel, the pump-plunger lift should also be checked as described in Section A4.47.

A4.46 Fuel Pump Timing

A4.46.1 If new parts have been installed or the plunger lift has not been checked recently, the port closing point must be checked. This procedure is described in Section A4.46. Set the Bosch nozzle for the proper opening pressure of 1200 $\pm$ 100 psi (8.2 $\pm$ 0.69 MPa). The opening pressure of the Excello nozzle is 1450 $\pm$ 50 psi (10 $\pm$ 0.34 MPa) and can be adjusted by the manufacturer only.

A4.46.2 Use the following procedure to check the timing of the fuel injector:

A4.46.2.1 Remove the delivery valve *E*, and spring *D* (see Fig. A4.10) from the pump and reassemble without these parts.

Arrange the fuel-injection line *A* so that air may be blown through it, preferably with a rubber bulb.

A4.46.2.2 Submerge the end of the fuel by-pass line *BB* in water or light oil.

A4.46.2.3 Set the flywheel on the intake stroke, and move the injection-pump rack to the position for maximum fuel delivery. While slowly rotating the fly wheel forward, blow into the rubber hose until the bubbles at the end of the fuel by-pass line disappear. When the bubbles cease, the port has just been closed by the plunger on its upward stroke. Determine the point by several trials, and note the reading on the flywheel. The port closing must occur at 50 ± 5 deg atdc on the intake stroke. If necessary adjust the coupling between the pump and the engine to get this setting.

A4.46.2.4 Replace the delivery valve and its spring.

A4.47 Pump Plunger Lift

A4.47.1 The port of the pump plunger should close when the plunger has moved up 0.100 to 0.116 in. from the base circle of the cam. This adjustment is made at the factory and should not require checking unless the barrel and plunger are renewed. If it is desired to check the plunger lift, remove delivery valve *E*, and spring *D* (see Fig. A4.10) from the top of the pump, and insert a pin in the delivery-valve hole so that the pin rests on the top of the plunger *Y*.

A4.47.2 To indicate the plunger lift, arrange a dial indicator so that it rests on the pin. With the plunger at the bottom of its stroke and the dial gage set on zero, rotate the engine forward until the port closing position is registered on the flywheel as determined in Section A4.46. The reading of the dial gage indicates the lift from the base circle at the point of port closing.

A4.47.3 On older type pumps any deviation from the specified lift cannot be adjusted and the pump should be sent to the nearest Bosch service station for repairs. However, with later type pumps equipped with adjustable tappets, the lift may be set by loosening the locknut at the top of the tappet. After making such an adjustment, the injection timing must be rechecked as outlined in Section A4.46.

A4.48 Fuel Pump Drive

A4.48.1 The fuel-injection pump on the CFR-48 crankcase is driven from the front end of the camshaft through a rubber-bushed coupling and a vernier plate assembly. This provides a means for easy adjustment of the pump timing. The accessory bracket is accurately doweled to the crankcase for proper alignment of the pump shaft with the camshaft.

A4.49 Ignition System

A4.49.1 *Breakerless System*—A unitized control unit comprising power supply, control circuitry, and capacitor is used in conjunction with a timer unit with trigger coil. The timer unit vane is driven from the front of the camshaft actuating the trigger coil to signal the control unit to fire the spark. None of the components of this system are interchangeable with those of the earlier breaker system.

A4.49.1.1 If system failure occurs, it may be due to inadvertent grounding of the electrical circuit between the control unit and the trigger coil, a defective trigger coil, or a defective control unit. Check that all leads are connected and if operation is not restored, component replacement is recommended. (**Warning**—Electrical continuity or resistance checks of the control unit are not recommended.)

A4.49.2 *Breaker System*—A coil and distributor ignition system is used. The primary circuit for the coil is taken from the ignition power supply. Negative polarity at the spark plug terminal produces highest spark efficiency. Be sure the *plus* terminal of the coil connects to the distributor. The primary d-c supply should be positive and connected to the *minus* terminal of the coil. The ignition system should be thoroughly inspected at each overhaul and any faults should be corrected. Coils should be tested at 2000-h intervals. Due to the wide variety of testing equipment in service, however, it is not feasible to specify a detailed procedure.

A4.49.2.1 *Coil and Distributor Timing*—The steps for timing the ignition system are as follows:

A4.49.2.2 Set the piston at tdc on the compression stroke as indicated on the flywheel and then make sure the spark indicator scale is set with the zero mark accurately in line with the neon-tube slot. If the indicator is wrong, adjust the position of the scale, *W* (see Fig. A1.10).

A4.49.2.3 Rotate the flywheel backward so that the neon tube slot is opposite the spark advance mark of 45 ± 1 deg before tdc. Lock the distributor in place with the knurled lock screw.

A4.49.2.4 Adjust the distributor cam to make contact at the specified setting indicated in A4.49.2.3 by loosening the nut that holds the cam to the shaft, moving the cam to its proper position, and then tightening the nut.

A4.49.2.5 Run the engine and make the final adjustment by rotating the distributor body to give exactly the specified spark advance.

A4.50 Spark Plugs

A4.50.1 Spark plugs are very often the cause of poor engine operation. When the condition of a plug is doubtful, it should be replaced. (**Warning—**To *prevent personal injury, be sure to shut off the air supply to the induction system and open the atmospheric bleed valve before removing the spark plug.*) The porcelain should be inspected carefully for cracks and blisters. Set the spark-plug gap cold with a wire feeler gage at 0.020 ± 0.003 in. When installing a spark plug, use a 3⁄32-in. solid copper gasket. It is also good practice to put a small amount of suitable lubricant, such as graphite grease or mica lubricant, on the threads of the plug. Tighten the plug with a torque wrench set for 25 to 30 lb·ft.

A4.51 Breaker Points

A4.51.1 A gap of 0.020 in. is specified, even though the name plate on some of the older units may state differently. The surface of the cam should be given a very light coating of petrolatum.

A4.52 Condenser

A4.52.1 Failure of the 4-µF condenser results in no ignition spark and replacement is necessary.

A4.53 Neon Spark Indicator

A4.53.1 Neon tubes gradually diminish in brilliancy with use and occasionally the flash becomes dull and hard to distinguish. The tube and the connections grounding it to the crankshaft should be cleaned. Occasionally the ignition wire may be at fault and should be replaced. If the flash does not improve, the tube should be replaced. The flash indication will be brighter if observed while fuel is shut off. A check should be made occasionally to ensure that the slot in the rotating disk of the spark-advance indicator points to zero when the crankshaft is at tdc. If not, adjust the protractor scale until the slot coincides with the zero mark.

A4.54 Dynamometer and Scale

A4.54.1 Every 500 h, or more often if necessary, it is advisable to check for binding or sticking in the dynamometer and scale assembly (see Fig. A1.20). To detect this, operate the dynamometer 1 h to warm the bearings and bearing lubricant adequately, then push the dynamometer frame by hand, first in one direction and then in the other. Binding is indicated if the scale pointer fails to return to its original position.

A4.54.2 Although the trouble is likely to be in the trunnion bearings, the following procedure is advisable: first disconnect the dashpot plunger from the dynamometer (see Fig. A1.21) and repeat the binding test. The removal of the dashpot affects the scale reading and also decreases considerably the damping of the scale pointer. If the binding is eliminated, the trouble is in the dashpot and probably is due to misalignment of the plunger.

A4.54.3 If the trouble is not in the dashpot, disconnect the scale from the dynamometer by removing the knife-edge *TT* (see Fig. A1.20). In dynamometers with the new style knife-edge that has independent links for the scale and weight rods, suspend the weights from the bottom of the scale link, using the hole provided for this purpose. To maintain the original complete weight of the linkage on the scale rod, place the extra links on the weights. Now alternately lift and depress the weights and observe whether the scale binds. Failure of the scale pointer to return to a constant reading indicates binding.

A4.54.4 While the scale is disconnected, it is convenient to make the preliminary accuracy check described in Section A4.57. If binding in the dashpot, scale, or scale linkage is not indicated, the trouble must be in the dynamometer. Make sure there are no external causes of friction, such as lead wires not being free and flexible, frame touching another object, or the rotor touching the frame; and then examine the trunnion bearings.

A4.54.5 If the trunnion bearings are causing the difficulty, examine them thoroughly and eliminate the cause of the difficulty.

A4.54.6 If the dynamometer scale vibrates excessively, adjust the capscrews holding the scale to the pedestal either by tightening or loosening as required. However, do not loosen them so much that tension is not exerted by the lock-washers.

A4.55 Rotation of Trunnion Bearings

A4.55.1 To distribute wear evenly around the trunnion bearings, rotate them a small amount two or three times a year. Turning both the inner and outer races is preferable, but in most cases this requires complete dismantling of the dynamometer.

A4.55.2 It is recommended that the outer race be turned as follows: Remove the bolts *SS* (see Fig. A1.20) that hold the caps to the pedestals, and carefully clean all around the bearing housing so that no loose dirt may find its way into the bearings. Remove the cap, and after releasing the dynamometer locking lever *T* (see Fig. A1.22) raise the frame with a lever or jack just enough to take the load off the trunnion bearings. Carefully rotate the outer race of the bearings about 15° to bring the balls to a new area in the race; then lower the frame and replace the caps.

A4.55.3 If the grease in the bearings is caked or dirty, remove the bearings, and clean and relubricate them with high-temperature ball-bearing grease.

A4.56 Dashpot Adjustments

A4.56.1 To obtain the proper damping for the dynamometer and scale, the dashpots for each must be adjusted properly. When testing fuels, the operator is continuously checking the damping characteristics. The following procedure is recommended for adjusting the dynamometer dashpots.

A4.56.1.1 *Scale Dashpot*—With the dynamometer dashpot *B* (see Fig. A1.21) dry, adjust the scale dashpot *G* (see Fig. A1.20) so that friction readings can be taken in 4 s when the engine is operating on *iso*octane containing 6.0 mL of TEL per gallon at a manifold pressure of 60 in. Hg (203 kPa) absolute. Make the adjustment as described in Section A4.57.

A4.56.1.2 *Dynamometer Dashpot*—After making the adjustment in A4.56.1.1, fill the dynamometer dashpot *B* (see Fig. A1.21) with the oil specified in A3.4.3 to three-fourths of its capacity. The dashpot plunger clearances of some of the earlier units were less than the 0.018 to 0.020 in. now in use. With the former clearances there was a tendency to stick.

A4.57 Preliminary Scale Check

A4.57.1 The linkage and dial assemblies for the dynamometer scale are shown in Fig. A1.20 and Fig. A1.22. A preliminary check for scale accuracy can be made without removing the scale from the dynamometer.

A4.57.1.1 First disconnect the scale from the dynamometer by removing the knife-edge, which has independent links for the scale and weight rods. Suspend the weights from the bottom of the scale link, using the hole provided for this purpose. Place the extra link on top of the weights to maintain the original complete weight of the linkage on the scale rod.

A4.57.1.2 With the 40 and 25-lb counterweights in place, make sure that the scale pointer reads zero. If it does not, adjust it to zero by turning the screw in the left-hand end of the beam housing at *D*, (see Fig. A1.20). Remove the 25-lb counterweight and observe the scale reading on the minus side. If the reading is in error by more than 1 % (0.25 lb or 1 bmep), the scale is seriously out of adjustment, and must be checked and adjusted throughout its range.

A4.57.1.3 Note that on the optional dial, which is graduated in bmep instead of pounds, the minus 25-lb calibration point is indicated by a small mark near the 105 fmep point. If this check shows that the scale needs calibration throughout its range, the procedure in Section A4.58 should be followed.

A4.57.2 *Rail Gage*—Before proceeding with the complete scale calibration, Section A4.58, use the rail gage *EE* (see Fig. A1.22) to check the relationship between pendulum position and indicator, since further adjustments will be futile unless this relationship is correct. With the 40- and 25-lb weights on the dynamometer, install the rail gage across the back of the pendulum rails, flush with the lower ends, and secure it to the sector guides with the clips *DD*.

A4.57.2.1 If necessary, raise the weights *Z* enough to give room for the rail gage. Note the amount these weights are raised, since they must be returned later to their exact original positions. If the scale indicator is within ± 0.5 graduation of −25 with the gage in place, the indicator setting is satisfactory and the gage may be removed.

A4.57.2.2 If the deviation is greater, loosen the rackguide retaining screw *W* and turn screw *V* to disengage rack and pinion. Rotate the indicator and pinion assembly *U* to the −25 point on the dial (which is the scale zero) and engage the rack teeth with the pinion so as to get the closest reading to −25. Then adjust the rack guide *V* to get about 0.010 in. clearance between the back of the rack and the guide block, and tighten screw *W*. Loosen the rack locking screw *T*, and turn knurled adjuster *S* until the indicator is within ± 0.5 graduation of −25, and retighten *T*. Remove the rail gage and the 25-lb weight.

A4.57.2.3 If the pendulum weights *Z* were raised to use the rail gage, lower them to their exact original positions and proceed with the calibration after resetting the indicator to −25 through hole *D* (see Fig. A1.20). Do *not* adjust zero with nut *S*, except when the rail gage is in place as already outlined.

A4.57.2.4 Fill the dynamometer dashpot as prescribed in A5.5.1.10 and adjust the rod length as described in A5.5.1.11.

A4.57.3 Check the dashpot plunger rod in the scale head to see that it is as well centered as possible in the dashpot cap hole. Dashpot arm *F* may be adjusted to obtain this condition, with the scale loaded to read half capacity. Remove the dashpot cap and see that the oil is level with the anti-splash plate near the top. Replace the cap. To adjust the oscillation of the dial indicator turn the knurled adjusting nut on the dashpot rod to obtain the desired degree of indicator damping.

A4.57.4 With the scale loaded to dial capacity, place a sufficient quantity of light oil in the annular oil seal cup *GG* to fill it to within ⅛ in. of the top. This will prevent foreign matter from entering the dial housing from underneath. The scale has been tested prior to shipment and is now ready for use after replacing dial gass, dial back, and cabinet cover.

A4.58 Complete Scale Calibration[16]

A4.58.1 To adjust the scale, it is recommended that the manufacturer's serviceman be engaged, particularly when any major change is necessary. If this is not possible, the following procedure may be used to test and adjust the scale over its entire operating range.

A4.58.2 In checking the scale calibration, the zero, and ¼ , ½ , ¾ , and full scale readings are used as the checking points. Since the full scale deflection is 100 lb, these points come at 25-lb intervals. On the special depressed pounds dial these points are − 25, 0, + 25, + 50, and + 75 lb, respectively. On the optional bmep-fmep dial, small marks indicate the quarter points near the − 105 fmep, 0, + 105, + 211 and + 315 bmep graduations. Note that in the calibration discussion, zero scale refers in all cases to the − 25-lb mark or the mark near the − 105 fmep point on the special dial.

A4.58.2.1 Since there is insufficient space for extra test weights to be applied to the scale as mounted on the dinamometer, remove the scale head and pedestal from the dynamometer base, set the complete assembly on a level table, and brace it in a vertical position. The table should have a hole through which the weight rod can hang. Replace the scale rod links and spring with the extra-weight extension rod available for calibration purposes. When attached directly to the tare beam lever, this rod will accommodate the necessary standard test weights.

A4.58.2.2 In addition to using the 40 and 25-lb counterweights, which are a normal part of the dynamometer linkage, three additional 25-lb test weights are available for calibrating the scale. An extension rod with an eye for attachment to the tare beam lever is also available from the Waukesha Engine Division.

(a) With the scale mounted as described in A4.58.2.1 with the 40-lb counterweight hanging from the extension rod, and with all of the linkage parts except the standard weight rod added to the 40-lb test weight, adjust screw at *D* (see Fig. A1.20) to make the scale needle read − 25 lb. This is the normal zero position for the scale. Leave this 40-lb counterweight in place throughout the calibration test and do not count it as part of the measured weight hanging on the scale. It is used to preload the scale and take up all the slack in the linkage.

(b) Add the standard linkage parts, except the weight rod, to the counterweight throughout the tests, to maintain the complete standard weight on the scale. The standard rod is omitted as its weight is approximately compensated for by the special test-weight extension rod. The slight difference in weight of these parts is taken care of by a final zero adjustment of the scale when reinstalled on the dynamometer.

A4.58.2.3 With the 40-lb weight in place at all times, and with the scale zero at a − 25-lb dial reading, add four 25-lb test weights to the special rod. If the indication at full dial capacity is low, raise the pendulum weights *Z* by loosening the lock nuts *AA* on the weights and turning the hex headed screws at the top of the rails clockwise. Count the turns and raise each weight an equal amount, making sure that the lower faces of the hex headed adjusting screws seat on the top of the pendulum rails. Tighten the lock nuts, and then tighten the adjusting screws to eliminate all play. If indication was high, reverse the above procedure. Remove the 100 lb of test weights and reset to − 25 lb through hole *D*, if necessary. Repeat the procedure to get correct readings at − 25 lb and full capacity.

A4.58.2.4 Place 50 lb of test weights on the 40-lb initial weight and check half dial capacity reading. If indication is low, move the minor weights *Y* toward the faces of the vertical pendulum rails, or away from them if the indication is high. The correction ratio for the minor weights is ten to one, that is,

[16] To obtain calibration points on units equipped with the older type of Toledo Scales, refer to the 1952 ASTM manual of Engine Test Methods for Rating Fuels, pp. 268 to 272.

one graduation of error at half capacity will require a correction of ten graduations with the minor weights at half capacity. (see Note A4.1) To adjust, loosen the minor weight cap screw and move each weight equally. Then remove the 50-lb test weights, correct zero, and repeat the full, half, and zero capacity adjustments in order, if required, to obtain accuracy at these three points.

NOTE A4.1—*Example*—Scale readings at zero and full capacity are correct, but scale reading at half capacity is 1½ graduations low. To correct, move minor weights toward rails. The amount of correction is 15 graduations (1½ × 10). Correct 7½ graduations with each minor weight. With the proper correction, the indicator will read 13½ graduations high at half scale, which amount is the algebraic sum of the negative error and the positive correction.

A4.58.2.5 Place a 25-lb test weight on the rod with the 40-lb weight and check ¼ dial capacity. If in error, correct by adjusting the threaded weight on the back of the indicator-hub disc. (This weight moves parallel to the indicator pointer.)

A4.58.2.6 Place 75 lb of test weights with the 40-lb weight on the rod and check ¾ dial capacity. If in error, note, and remove 25 lb to get the indicator to half capacity. Then adjust the small threaded indicator hub weight which is at right angles to the indicator pointer until the half dial indication is in error the same amount and the same direction as was noted at ¾ dial. Remove the test weights, correct zero, and repeat the full, ½ , and ¼ capacity adjustments. If the ¾ capacity point is then still in error, repeat the sequence again until zero and all quarters are correct. If errors occur between quarters, check for friction, kinked ribbons, and dirt on ribbons or cam faces or on the rack and pinion. Use *iso*octane but *no abrasives* for cleaning. Note that zero scale in all cases refers to the −25-lb point.

A4.58.2.7 After reinstalling the scale on the dynamometer base and before connecting the dynamometer knife-edge, give the zero position of the scale a final setting with the 40 and 25-lb counterweights in place and with all of the standard linkage parts replacing the special test-weight extension rod.

A4.59 General Mechanical Scale Adjustments

A4.59.1 When the tare-beam lever-lock on the back of the cabinet is locked, the pendulums should hit the bumpers *X* (see Fig. A1.22) at the same time and the indicator should rest near the center of the ungraduated portion of the dial. To adjust, lock the tare-beam lever, loosen the bumper lock nuts, and turn the bumper screws until the indicator is centered in the ungraduated portion of the dial, the pendulums rest on the bumpers, and both strike simultaneously.

A4.59.2 There should be about 1⁄32-in. clearance between the lower nuts on the pendulum locking rods *FF*, and the lower oil-seal cup with the tare-beam lever locked. Adjust these rod lock nuts to obtain this clearance beneath the lower nut and the oil cup flange.

A4.59.3 The compression spring *N* (see Fig. A1.20) applies pressure on the fulcrum bracket for the tare-beam lever through the hex-headed hollow stud on which the spring rests. The pressure is correct when this stud is screwed into the bracket until its lower end is just flush with the underside of the bracket. Tighten the locknut to hold this adjustment.

A4.59.4 Adjust hex-headed screw *K* to give about 0.010 in. clearance between the end of the screw and the top of the cabinet with no weights at all on the dynamometer linkage. Loosen lock nut, turn screw *K* finger-tight against the top of the cabinet, back off ¼ to ½ turn and tighten the lock nut at this setting. This limits the travel of the fulcrum bracket for the tare-beam lever.

A4.59.5 Set the tension on coil spring *B*, on pendulum level fulcrum bracket *A*, by bringing the hex-headed sleeve and lock nut tightly against the underside of the fulcrum bracket.

A4.60 Alignment of Dynamometer Shaft

A4.60.1 The 60-Hz dynamometer is connected directly to the engine by a rubber disk coupling, and accurate alignment of the two shafts is essential for satisfactory operation. If either the engine or the dynamometer is moved, the shafts must be realigned. If a new crankcase or engine is installed, if may also be necessary to shim either the engine or the dynamometer, since the over-all shaft height on crankcases may vary.

A4.60.2 The following procedure is a convenient way to check shaft alignment. Attach an arm carrying a dial indicator gage to the dynamometer shaft. Slowly rotate the shaft, allowing the dial gage to run first along the outer periphery of the engine flywheel and then along its face. Be careful to eliminate end play of the dynamometer while rotating the dial gage over the face of the flywheel.

A4.60.3 It is also advisable to check the run-out of the flywheel itself before using it to set the shaft alignment. The engine shaft should be approximately 0.008 in. lower than the dynamometer shaft when the unit is cold. The engine runs appreciably hotter than the dynamometer under operating conditions, and this difference in shaft height is necessary to provide for the greater thermal expansion of the crankcase.

A4.60.4 The 50-Hz dynamometer is belt driven and may be aligned by laying a straightedge along the face of the two pulleys. The belt tightness should be adjusted so that hand pressure on the belts results in a displacement of ½ to 1 in.

A4.61 Lubrication of Dynamometer Bearings

A4.61.1 Since the movement in the trunnion bearings is very slight, the grease packed in them should last a long time. If necessary, to repack them, use a light high-temperature ball-bearing grease and fill the races about ½ full. To exclude dirt, also apply a light ring of grease at the entrance to the pedestals. The main dynamometer shaft bearings should be cleaned thoroughly, and the bearings and housings repacked after 6000 to 8000-h service. Too much grease may cause excessive bearing temperatures and leakage from the housing. The grease cups should be given a quarter of a turn at each top overhaul.

A4.62 Induction Heater Safety Switches

A4.62.1 A safety switch is provided to break the induction heater circuit when the engine stops. This is a diaphragm switch actuated by the engine-oil pressure and should open when the oil pressure falls below 15 psi (103 kPa). The diaphragm unit may have to be replaced after prolonged use.

A4.63 Electric Relays and Thermostats

A4.63.1 If the relays stick, cleaning or replacement of the contact points generally corrects the trouble. Thermostats should be removed and cleaned periodically. They should be replaced when they no longer control the temperature within the specified limits.

A4.64 Pressure Gages

A4.64.1 All pressure gages should be checked by a dead-weight tester whenever the correctness of the pressure readings is in doubt. The oil gage sometimes is affected adversely by an excessive pressure when starting the engine with cold oil. The fuel-pressure gage sometimes reads incorrectly because of pulsations in the fuel line.

A4.65 Thermometers

A4.65.1 All thermometers (see Table A2.1) should be checked occasionally to see that they read correctly and that the mercury columns have not separated. They should not be subjected to sudden shocks, and preferably should be stored in an upright position to prevent separation of the mercury column when not in use. Thermometers should be removed and the bulbs cleaned every 500 h.

A4.66 Dimensions, Replacement Limits, Recommended Torque Values

A4.66.1 To facilitate overhaul, inspection, and determination of renewal requirements, manufacturing tolerances and replacement limits are given in Table A4.1 and Table A4.2. Recommended torque values are given in Table A3.4. The replacement limits and torque values are based upon wide experience of many operators, and it is believed that in any but special cases they will be completely dependable.

TABLE A4.2 Manufacturing Tolerances and Replacement Limits for Supercharge Cylinder Assembly Parts

All dimensions are in inches. Metric equivalents may be found in the back of this manual.

Item	Manufacturing Tolerances	Replacement Limits
PISTON:		
Material	aluminum	
Land Clearances:		
Top	0.0200 to 0.0235	...
Intermediate	0.0150 to 0.0185	...
Skirt	0.0105 to 0.0115	0.0130
Alignment, max	0.001	0.0015
PISTON PIN RETAINERS:		
Free diameter after compression, min:		
Truarc	1.340	1.340
Circlips	1.390	1.390
PISTON RING SIDE CLEARANCES:		
Top Second Third Fourth Fifth	face 0.000 to 0.004 below ring land surface, with ring in groove under own weight	when face is 0.006 below ring land surface, with ring in groove under own weight
RING GAP CLEARANCES:		
Top	0.015 to 0.020	0.035
Second	0.015 to 0.020	0.035
Third	0.015 to 0.020	0.035
Fourth	0.010 to 0.018	0.030
Fifth	0.010 to 0.018	0.030
VALVES:		
Stem Diameter:		
Intake	0.3725 to 0.3720	0.3705
Exhaust	0.4345 to 0.4335	0.4320
Stem Clearance:		
Intake	0.0020 to 0.0030	0.0035
Exhaust	0.0035 to 0.005	0.0055
VALVE SPRINGS:		
Free Length, non-rotator type	2.58 to 2.61	2.45
Free Length, rotator type	2.33 to 2.36	2.20
VALVE SEATS:		
Eccentricity, seat to guide, max	0.001	...
Width	0.050 to 0.070	0.100
VALVE GUIDES (ASSEMBLED):		
Internal diameter:		
Intake	0.3740 to 0.3755	0.3765
Exhaust	0.4375 to 0.4385	0.4395
CYLINDER:		
Standard bore:		
Diameter	3.250 to 3.2515	...
Taper, max	0.0005	...
Out of round, max	0.0005	...
Quality of surface	10 to 20 µin.	Scored or pitted
Hardness, Brinell	200 to 269	...
Wall thickness:		
Spark plug side	0.250 to 0.312	...
Pickup side	0.250 to 0.312	...

TABLE A4.2 *Continued*

Item	Manufacturing Tolerances	Replacement Limits
Intake side	0.250 to 0.312	...
Exhaust side	0.250 to 0.312	...
Top	0.281 to 0.312	...
Intake port thickness:		
Spark plug side	0.188 to 0.250	...
Pickup side	0.188 to 0.250	...
Exhaust port thickness:		
Spark plug side	0.188 to 0.250	...
Pickup side	0.188 to 0.250	...
Spark plug hole depth	0.609 to 0.641	...
Pickup hold depth	0.672 to 0.703	...
Valve port: Concentricity to manifold	±0.031	...
CYLINDER SLEEVE:		
Clearance on cylinder	0.002 to 0.004	0.006
CYLINDER ELEVATING NUT:		
End clearance on sleeve	0.002 to 0.004	0.006
Thread clearance	turn freely	loose
End play:		
Thread, max	0.002	0.004
Shaft	0.001 to 0.003	0.005
ROCKER-ARM CARRIER:		
Fit of bracket pins:		
Rear	0.000 to 0.0007	0.0015
Center	0.000 to 0.0007	0.0015
Front	0.000 to 0.0007	0.0015
ROCKER ARMS:		
Bearing shaft diameter	0.5003 to 0.5005	...
Ball seats	smooth and fit ball	loose or out-of-round
INJECTOR OPENING PRESSURE, psi (MPa):		
Bosch	1100 to 1300 (7.5 to 8.9)	reset
Excello	1400 to 1500 (9.6 to 10.3)	...

A5. INSTALLATION AND ASSEMBLY

A5.1 Unpacking Precautions

A5.1.1 To prevent damage or loss of parts prior to installation, all boxes containing the ASTM engine and equipment should be stored unopened until the preparations described in Annex A6 on Building and Utility Requirements are completed. A dimensional diagram of the completed unit is shown in Fig. A5.1.

A5.1.2 The units are shipped from the factory in a large box and several smaller boxes. The large box contains the engine and its power-absorbing dynamometer mounted on the bedplate. All exposed machined surfaces or parts likely to rust are coated with a moisture-proof protective coating, and the unit itself is enclosed in a waterproof evacuated sealed bag.

A5.1.3 Other accessories and parts are packed as groups of related parts, of which there may be one or more to each box, suitably designated by group numbers. Although it is necessary to open the small boxes of loose parts to identify the individual groups for installation, it is suggested that none of the boxes be unpacked prior to the need for the contained parts. Otherwise, these parts may become lost or broken by lying around in the open.

A5.2 Installing the Unit Assembly

A5.2.1 *Unpacking*—When an overhead crane is not available, place blocks under the unopened box so that the bottom of the bedplate is about level with the prepared foundation. Remove the top boards of the box. Then remove any small parts packed individually in this box. Next, remove the sides of the box and the protective engine covering. The unit on its bedplate can now be slid out of the box either directly onto the previously prepared foundation, or onto the floor for hoisting into position on the foundation.

A5.2.2 *Installation*—After the unit has been placed squarely on its foundation, level it with metal wedges ⅜ to ½-in. thick, as shown in Fig. A5.2. It is important to use metal wedges or spacers *A* as wooden ones tend to swell and lift the bedplate from the grouting before the cement sets. To provide an opening for mounting the oil cooler and filter, place a block of wood over the space *B*. Build a temporary form around the foundation with the top edge above the rim of the bedplate, a 2-in. (50-mm) rim being sufficient. Prepare an adequate amount of a thin grout made of three parts sand and one part cement. When pouring the grout, be sure it is thin enough to flow freely under the edge of the bedplate, and puddle it thoroughly to pack it solidly under the rim. The grouting should come to the top of the bedplate rim. For greater strength the holes in the sides of the bedplate may be used to pour additional cement into the interior of the plate. The cement should be permitted to set a minimum of 48 h before work is done on the unit, and at least 72 h before the engine is started.

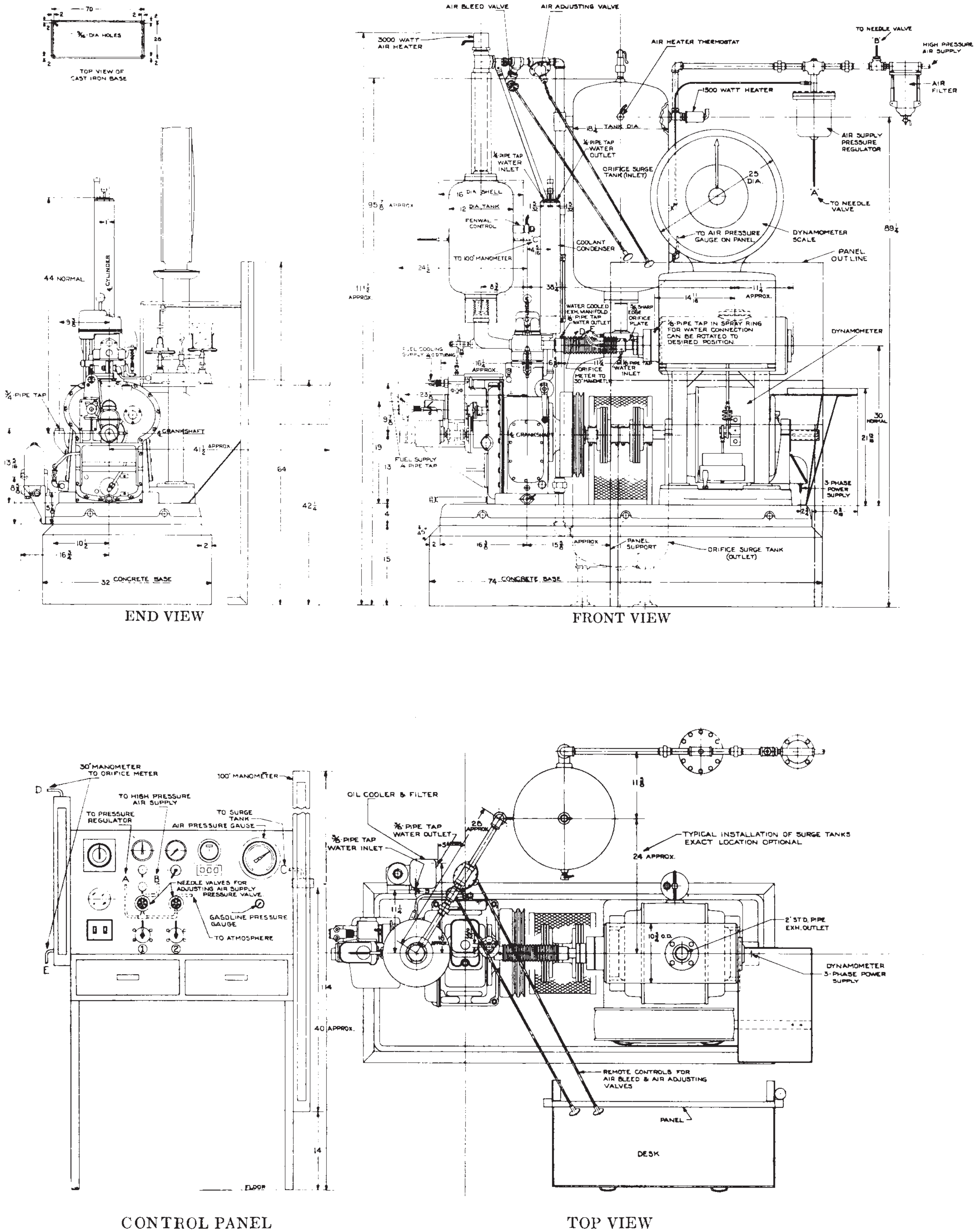
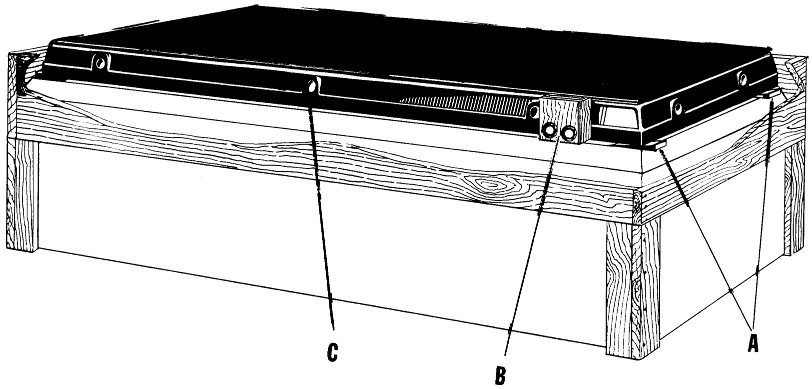


FIG. A5.1 Diagrams of 60-Hz Supercharge Unit



A—Metal Leveling Wedges at Each Corner of Bed Plate.
B—Wood Block to Provide Opening for Mounting Oil Cooler and Filter.
C—Holes Through Which Grouting May Be Puddled.

FIG. A5.2 Diagram of Bed Plate Ready for Grouting

To meet operating conditions that indicate inadequate or insecure grouting, four anchor bolts imbedded in the foundation may be used to secure the unit. A sound grouting job is in most cases adequate to withstand the vibration and keep the unit level.

A5.2.3 *Installation on Isolated Block*—It has been found satisfactory to bolt units without grouting directly to a block of cast concrete which is isolated from the floor by means of specially designed vibration-absorption pads. Such a block is shown in Fig. A5.3. The mass of this block and the cushion pads dampen the unit vibration effectively. Shims should be used when bolting the bedplate to the block, if the top of the block is not perfectly flat and level.

A5.3 Assembling the Induction System

A5.3.1 The induction system may be partially assembled while the grouting cement is setting. The system consists of orifice air tanks 1 and 2, an intake-manifold surge tank, connecting pipes, valves, and fittings. Unpack these parts and assemble them, using Fig. A1.11 as a guide. Do not bolt the tanks to the floor or make any connections to the engine until later. Use a good sealer in making all connections. A sealer (such as Permatex No. 2), which remains plastic, facilitates later adjustment or dismounting and is preferable to white or red lead or any other compound which hardens.

A5.3.2 Be sure that all connections are drawn up snugly but not so tightly that they cannot be disassembled, for it may be necessary to rearrange or move the system when connecting it to the engine. Some fittings have a directional arrow cast in or painted on the body and should be assembled in such manner that the air flow will follow the direction of the arrow.

A5.3.3 As a positive insurance against air leaks, some laboratories have found it advantageous to weld the joints of the induction system, but this should not be done at this time. More detailed instructions for assembling the induction system are given in Section A5.13.

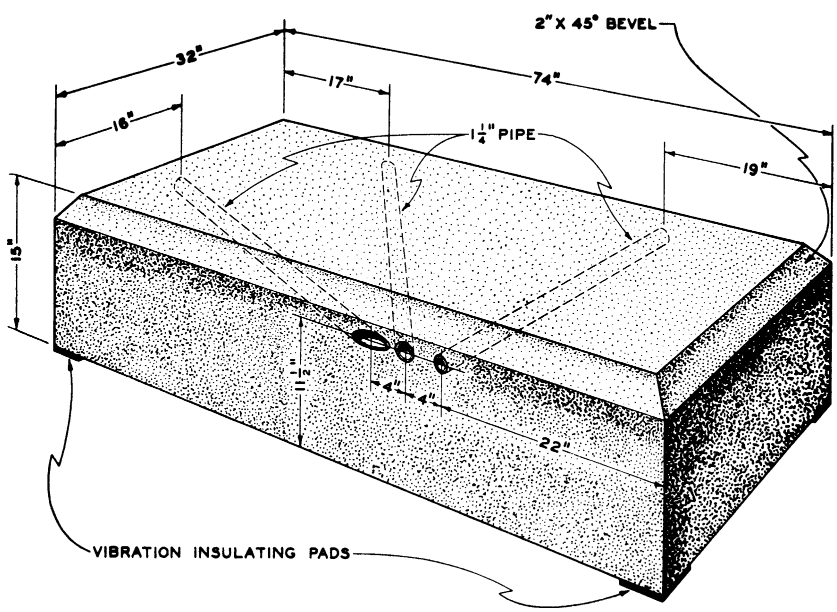


FIG. A5.3 Isolated Block Foundation for Supercharge Unit

A5.4 Mounting the Cooling Condenser

A5.4.1 The coolant condenser is packed as a separate item in the box. Remove all grease and protective coating from the mounting surfaces of both cylinder and condenser. After the concrete has set thoroughly, mount the coolant condenser on the cylinder, as shown in Fig. A1.10. No sealer or coating should be used on the gasket. To avoid breakage of the casting, tighten the mounting nuts evenly and snugly. The thermometer should not be installed at this time, as all small fragile parts and fittings should be installed only after all heavy work has been completed.

A5.5 Dynamometer Scale Head Assembly

A5.5.1 Before mounting the scale head, clean the top of the pedestal and place four flat steel washers, then the four rubber cushions, and then four more steel washers on top of them to cushion the scale at its attaching points. Carefully remove the slats from the box containing the scale head, and remove the scale. Set it on the rubber cushions and install the four bolts, lock washers, and nuts, tightening them evenly and sufficiently to put about half compression on the lock washers. *Be sure that the cabinet is level.* Then connect the scale to the dynamometer as follows:

A5.5.1.1 Remove from the dial housing both the dial glass and back cover, held in place by eight screws each, to obtain access to the interior. Support the glass, as it is not attached to the bezel ring. Then remove the front cover plate from the cabinet to expose the lever linkages, as shown in Fig. A1.20. The dial housing as illustrated in Fig. A1.22 shows the mechanism viewed from the back side. All key letters in A5.5.1.2-A5.5.1.9 refer to Fig. A1.20 and Fig. A1.22.

A5.5.1.2 Remove the shipping clamps at *C* and *L* (see Fig. A1.20) from the ends of the pendulum lever and from the cabinet. The capscrew attaching the clamp to the lever at *L* must be replaced after unclamping, as it holds the lever fixed weight *M* in place.

A5.5.1.3 Remove the clamp at *O* from both the cabinet and the tare-beam lever *P*, and do not replace the capscrews. A pin *E* secures the left end of the lever during shipment. Pull the pin out from the front and discard it.

A5.5.1.4 The top of the plunger rod *G* is screwed into the top of the dashpot to prevent oil loss during shipment. Unscrew the rod and connect it to the dashpot arm *F* in the tarebeam lever *P*.

A5.5.1.5 Working on the dial housing, remove and discard the shipping pins which are inserted through the upper section of the sector guide and the pendulums. (**Warning—**Be careful not to twist the pendulums and cause distortion of the support ribbons.) Carefully wipe any dust or dirt off the pendulum-cam faces because abrasives cannot be tolerated on these sensitive areas. If necessary, *iso*octane may be used as a cleaning agent.

A5.5.1.6 For shipment, a clamp and plate assembly is clamped to the sector guide to keep the pendulums against their stops *X*, and to hold the ribbon equalizer rod *BB*. Remove and discard the clamp.

A5.5.1.7 Unlock the scale by turning the locking handle on the back of the cabinet to a horizontal position; then depress the left end of the tare-beam lever *P* to remove the strip of manila paper from between the rack and pinion.

A5.5.1.8 Install the 40-lb (18-kg) counterweight *J*, with clevis and rod assembly on the dynamometer. Then add the 25-lb (11-kg) weight *I*.

A5.5.1.9 Install the 15¼-in. (387-mm) steel rod *R* from the scale saddle on the tare-beam lever to the dynamometer-linkage assembly with the clevis at the bottom and the sleeve nut and lock nut at the top end as shown.

A5.5.1.10 The dashpot *B* (see Fig. A1.21) is bolted to the dynamometer base on the side opposite the scale, with the plunger attached to the cradled frame of the dynamometer. Remove the filler cap *A* and fill the dashpot with engine oil having a Saybolt Universal viscosity of 290 s at the operating temperature (room temperature). About 400 to 425 mL of oil are required, enough to keep the dashpot plunger submerged at extreme operating positions of the dynamometer cradle.

(a) The viscosity of the oil is important as it must be high enough to give stability to the dynamometer scale pointer and yet low enough to permit friction readings in 10 s. Detailed instructions for adjusting the dashpot are given in A4.5.6.

A5.5.1.11 To adjust the linkage length, rotate the dynamometer frame until the knife-edges of *TT* (see Fig. A1.20) are in the same horizontal plane as the dynamometer shaft. Adjust scale rod *R* until the dynamometer link is suspended midway between the upper and lower knife-edges of *TT* and does not bind on either side. If side interference does occur, loosen the capscrews that hold the scale head to the pedestal, and shift the position of the head until the link hangs free at *TT*. Then tighten the capscrews of the scale head and the lock nut on the scale rod.

A5.5.1.12 With the 40 and 25-lb counterweights in place, adjust scale indicator to zero by turning the screw in the housing at *D* (see Fig. A1.20).

A5.5.1.13 Check the adjustment of the linkage rod by applying pressure with the hand to the dynamometer frame. If full scale deflection cannot be obtained in either direction, readjust as described in A5.5.1.11.

A5.5.1.14 Replace the front and back covers of the scale head and those for the beam and fulcrum compartment.

A5.6 Panel and Desk Assembly

A5.6.1 The control panel, complete with instruments and mounting legs, is packed separately and includes the fuel weighing devices, instruments, switches, levers, control knobs, and supporting legs, all mounted as shown in Fig. A1.10. When mounting the panel, be careful not to drop the contents of the fuel weighing cabinet and leave the scale tied in position until later.

A5.6.2 To ensure alignment of the panel with the unit, bolt the two iron braces to the panel supports and to the bedplates. Plumb the panel with a level and drill the holes in the floor for the panel legs. One expansion bolt per leg should be sufficient to hold the panel rigid. It will be convenient to leave the desk unmounted until all other installation operations are completed.

A5.7 Intake Manifold

A5.7.1 Remove the two heaters from the boxes and install them as shown at *A* and *E* in Fig. A3.1. Screw the 1500-W intake-air heater into the pipe tee ahead of air tank No. 1 as shown at *A*.

A5.7.2 Mount the Fenwal thermostats as follows: The long thermostat controls the air temperature in the intake-manifold surge tank and is mounted at *EE* (see Fig. A1.10). One short thermostat controls the orifice-meter air temperature and is mounted in the upstream orifice-tank at *H*. The other short thermostat goes in the top of the condenser at *F* to operate the safety shutdown control. The short thermostats have different thread sizes to prevent confusion.

A5.8 Wiring

A5.8.1 At this point, start working on the electrical wiring of the unit, *but never connect the 110-V or the 440-V or 220-V main power supply lines until all other wiring has been completed.*

A5.8.2 Partially install the wiring for the unit at this time. After removing the cover of the safety control relay box, mount it either on the wall (see Fig. 1) or on a utility pipe so that it will be convenient to both the engine and the back of the instrument panel.

A5.8.3 Mount the starting compensator box on the wall or on a support near the entrance of the main power line. Open the compensator box, remove the jumper connection from the lock-in contact to the overload relay (see Fig. A1.3) and install the wiring from the unit to the safety control box and the starting compensator. A separate switch box, fused for 60-A and furnished by the purchaser, should be installed in the 110-V circuit near the starting compensator. Connect this 110-V circuit to the safety control box to feed the two air heaters, pilot lights, clock and timer, and the relays in the safety control box itself. Install a second and independent 110-V circuit, preferably from the same switch box, and fuse it for 15 A to furnish current for the crankcase oil heater.

A5.8.4 Install the wiring for both circuits, and as the final operation make the 110-V power line connections to both the switch box and starting compensator. Do not install the final wiring for the 440-V circuit to the compensator at this time (see Sections A5.23 and A5.24).

A5.9 Manometer

A5.9.1 The 30-in. water manometer and the 100-in. mercury manometer are packed separately. Facing the panel board, bolt the 30-in. manometer *H* (see Fig. A3.1) to the left panel support and the 100-in. manometer *M* (see Fig. A1.10) to the right support. Final instructions for filling and adjusting the manometers are given in Section A5.16.

A5.10 Crankcase Ventilation

A5.10.1 The breather outlet is tapped for a ¾-in. pipe to conduct crankcase fumes out of the laboratory. This pipe must be as short as possible and have an offset to provide greater accessibility to the spark plug and valve gear.

A5.10.2 Do not connect the vent line to the exhaust system, as back pressure may result and cause oil leakage at crankcase seals. To protect the engine from condensation drain-back, install a trap in the pipe from the breather. The piping from the outlet should have sufficient vertical play to permit removal of the breather assembly for cleaning.

A5.11 Water Cooling System

A5.11.1 All water and drain lines should be installed, leaving enough space around the engine for service adjustments without disturbing the piping and connections. A neat and convenient arrangement for the supply lines is obtained by making a water distributing manifold of ¾-in. pipe and fittings, and installing it behind the unit. A ¾-in. gate valve may be conveniently located between the end of the manifold and the main supply line with ¼-in. valves to control the water flow to the various units. Connect the various units to the manifold as follows:

A5.11.1.1 ⅜-in. copper tubing to the water inlet *F* (see Fig. A1.1) of the condenser coil. The tubing should be behind the cylinder and parallel to the condenser.

A5.11.1.2 ⅜-in. copper tubing to the water inlet of the oil cooler *I*.

A5.11.1.3 5⁄16-in. copper tubing to the water inlet of the flexible water-cooled exhaust manifold *G*, at the underside of the outer end.

A5.11.1.4 5⁄16-in. copper tubing to the exhaust-spray ring *K*, at the entrance to the exhaust surge tank.

A5.11.2 An auxiliary water-cooling system may be required for the fuel cooler plug on the injection pump. A suggested water cooler which can be made (see Fig. A5.4) consists of an auxiliary ice chest containing a coil of copper tubing. Install the water cooler between the control valve *D* (see Fig. A1.1)

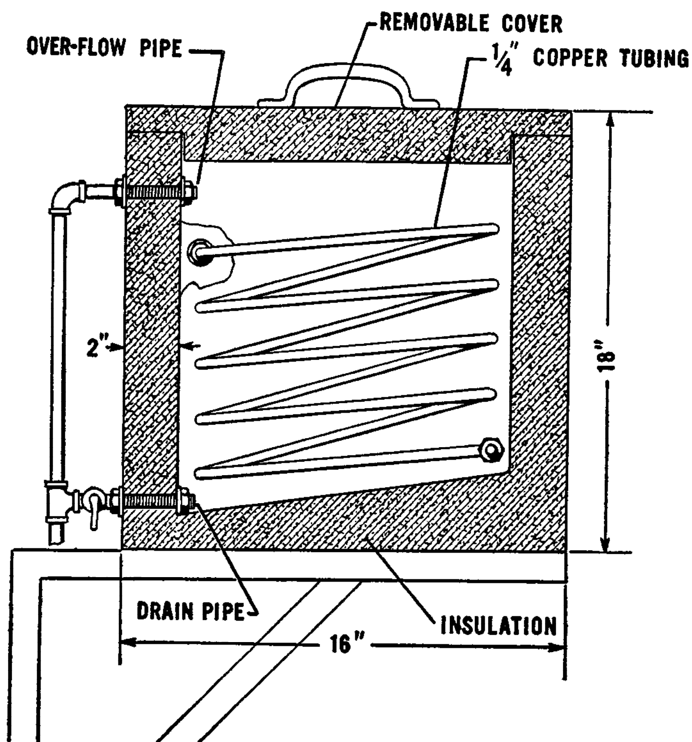


FIG. A5.4 Diagram of Auxiliary Water Cooler for Tropical Climate

and the fuel injection pump *H* so that the water flows from the control valve through the coil to the fuel cooler in the injection pump. To reduce the frequency of filling the box with cracked ice, its capacity should be at least 15 lb (6.8 kg). A drain with a stopcock and overflow pipe should be provided, as shown in Fig. A5.4.

A5.12 Induction System Control and Indicating Lines

A5.12.1 Coiled lengths of 3⁄8 , 5⁄16 , and 3⁄16-in. copper tubing with the necessary flare fittings and two safety valves are packed in one of the boxes. Install these lines and parts as follows in the order given:

A5.12.1.1 A 5⁄16-in. line *R* (see Fig. A1.11) either directly or through the conduit in the foundation (see Fig. A5.3) from the tee between the filter *M* (see Fig. A1.11) and the pressure regulating valve *L*, to the top connection *F* (see Fig. A3.2) of the pressure control valve.

A5.12.1.2 A 5⁄16-in. line *S* (see Fig. A1.11) through the conduit, from the bottom of the regulating valve *L*, to the tee fitting *G* (see Fig. A3.2).

A5.12.1.3 A 3⁄8-in. line from the opening in the air tank *V* (see Fig. A1.11) to the panel pressure gage connection *H*.

A5.12.1.4 A 3⁄8-in. line from the upper orifice flange *G* (see Fig. A1.11) to the lower connection *I* (see Fig. A3.2) of the 30-in. water manometer.

A5.12.1.5 A 3⁄8-in. line from the lower orifice flange *G* (see Fig. A1.11) to the top of the water manometer *E* (see Fig. A3.2).

A5.12.1.6 A 3⁄16-in. line *X* (see Fig. A1.11) from the side outlet of the intake-manifold surge tank to the back of the 100-in. manometer *M* (see Fig. A3.2).

A5.12.1.7 A 3⁄16-in. line *FF* (see Fig. A1.11) from the vertical leg of the pressure regulating valve *L*, to the 1⁄8-in. pipe tapped boss in the side of the upper air tank *V*.

A5.12.1.8 The two safety valves in the air tanks, as shown at *D* (see Fig. A1.11).

A5.13 Installing Induction System

A5.13.1 Remove the bellows *B* (see Fig. A1.14) and its two gaskets from the loose parts box for the induction system, clean the mounting surfaces thoroughly, and attach the bellows to the surge tank with the four capscrews, using the proper gasket. Tighten the capscrews evenly to prevent the bellows flange from cocking. Remove the injector from the intake manifold and slip the bellows guard *D* over the intake manifold with the screw holes in the side of the guard uppermost.

A5.13.2 When sufficient time has elapsed for the grouting between the foundation and the base plate to set, move the induction system, previously assembled, as described in Section A5.3, into position and adjust it so that the flange on the bellows connection to the intake is in exact alignment with the flange *Z* (see Fig. A1.11) on the intake manifold of the engine. The union must be loose so that the surge tank may be swung around to facilitate its alignment to leave the bellows absolutely free of any strain.

A5.13.3 After exact alignment is obtained, insert the gasket and tighten the capscrews evenly. Then tighten the union nut, drill holes to anchor the air tanks to the floor, and bolt the tanks in position. Slip the bellows guard *D* (see Fig. A1.14) over the bellows and attach it to the surge tank with screws. Reinstall the injector in the intake manifold using the rubber ring gasket and tightening the nuts evenly to avoid cocking the injector on its seat. Connect the main air supply line to the filter *M* (see Fig. A1.11).

A5.14 Induction Line Remote Control

A5.14.1 Fig. A1.10 shows two valves *B* and *C* in the air line ahead of the intake-manifold surge tank, having operating knobs and rods mounted on top of the panel board. These remote control rods and connecting joints are packed as loose parts for the induction system. The eye bolts are mounted on the top flange of the panel board frame and are held by two nuts on each eyebolt shank. Assemble the remote control to the valves through the eye bolts.

A5.15 Remote Fuel Control

A5.15.1 After the exhaust system has been completed, untie the flexible control cables attached to the back of thepanel board. Uncoil these cables carefully and thread them in easy sweeps to the rear of the engine. Be careful that the cables do not interfere with any moving parts, such as the dynamometer frame, the flywheel, or the coupling. Also, keep them at a safe distance from the exhaust pipe. The clevises, links, and pins to attach the cables are packed as loose parts.

A5.15.2 Thread the cable housings through the anchor block (see Fig. A3.1) and screw a clevis to the end of each cable. Connect the top cable from the control panel (see Fig. A3.2) to the fuel pump lever that has a pointer which registers on the quadrant attached to the mounting bracket of the lever. This connection is made by clevis and link at the fuel pump quadrant *AA* (see Fig. A1.10). The lower cable should also be connected by clevis and link. Use the short pin for the top lever so that the levers can be moved independently of their respective controls.

A5.15.3 Set the cables as far forward as possible by pushing the control knob on the panel. Adjust each cable in the anchor block on the crankcase so that the head of the fuel pump lever is 1⁄16-in. from the contacting end of the control cable at the anchor block. For quick action release the vernier control and pull or push the knob. To use the vernier adjustment, simply screw the knob in or out.

A5.16 Filling Manometers

A5.16.1 *Water Manometer*—A 2-oz bottle of wetting agent is packed with the 30-in. water manometer. As directed on the bottle, mix the fluid with distilled water in a clean glass container. Remove the thumb screw *R* (see Fig. A1.9) projecting from the bottom of the manometer case, and adjust the movable scale back of the tube to its lowest position. Loosen the top connection at *A* to vent the tube, and remove the hex-headed filler plug *T* from the well. Pour in just enough of the greenish water mixture to bring the level in the tube to a point slightly above zero. The scale may be readjusted to read zero. Replace the filler plug and the top connection and then tighten so that all connections and plugs are leakproof. Daily, before admitting air into the induction system upon starting the engine, the water level should be readjusted to zero by turning the thumb screw, *R*.

A5.16.2 *Mercury Manometer*:

A5.16.2.1 A 3¾-in bottle of mercury is packed with the 100-in. mercury manometer. To fill the manometer well, remove the filler plug *L* (see Fig. A3.2) and add the 3¾ lb mercury. Read the laboratory barometer in inches and adjust the knob *S* (see Fig. A1.10) on the manometer until it gives the same reading as the barometer. Remove the glass cover plate of the manometer and set the connection scale to read the same as the manometer.

A5.16.2.2 To maintain clean mercury surfaces in the well and tube, it is recommended that a small quantity of dibutylphthalate be poured on the mercury in the well and tube. This will not change the readings, which are taken at the top of the meniscus of the mercury column. Now replace the filler plug and glass cover, and tighten the cover firmly.

A5.17 Fuel Systems

A5.17.1 Install the fuel can shelf above the end of the dynamometer, bracing it to the scale pedestal. Connect the flexible fuel hose with the fuel filter to the fitting *N* (see Fig. A3.2). Connect the other fuel hose to the fitting *O*. Run the required length of ¼-in. copper tubing, fitted with flare nuts, from the unconnected valve fitting *J* (see Fig. A3.2) through the foundation conduit, to the inlet of the fuel supply pump *L* (see Fig. A1.7).

A5.17.2 To provide a fuel return line run a similar length of ¼-in. tubing from the unconnected valve fitting *K* (see Fig. A3.2) to the fitting *P* (see Fig. A1.7). Unwrap the beaker and place it on the scale pan, and place the scale weights on the other pan.

A5.17.3 The fuel system now is complete except for removal of the restraining bumpers between the beam and the pedestal beneath each pan of the fuel weighing scales, and cutting the cords holding the beam during shipment.

A5.18 Oil Lines

A5.18.1 A diagram of the lubrication system is shown in Fig. A1.15. As shipped, the thermal element and tube of the temperature indicator *C* (see Fig. A3.2) is coiled and tied to the back of the control panel. Uncoil the tube carefully to avoid kinks. Pass it through the foundation conduit, insert the bulb into the crankcase at *H* (see Fig. A1.2) and tighten the retaining nut securely. Screw the ⅛-in. pipe elbow into the crankcase at *E*. Run 3⁄16-in. copper tubing with flared ends and nuts from this elbow to the oil pressure gage *D* (see Fig. A3.2). From the connection *M* (see Fig. A3.1) run ¼-in. copper tubing to the SAE type fitting extending from the bottom of the safety control box housing on the wall (see Fig. 1).

A5.18.2 The oil lines for use to and from the oil filter and cooler have been made to fit and are shipped in a loose parts box. After cleaning the moisture proofing from the lines and connections, connect the lines to these fittings, as shown in Fig. A1.2. Using ¼-in. tubing, connect the filtered oil return line to the crankcase door *D* (see Fig. A1.2). After the cooler connections have been made, the ⅛-in. pipe plug (shipped loose with the engine) must be installed in the housing of the oil-pressure relief valve of the CFR-48 crankcase (see Fig. A1.16, Item 36). This plug diverts the full flow of oil from connection *B* through the cooler, from which it returns to connection *A*.

A5.19 Exhaust System

A5.19.1 Requirements for the exhaust system are given in Section A1.11. Begin installation by cleaning the oil-preservative compound from the gasket, the mating surfaces of the cylinder, and the flexible exhaust manifold. The manifold must be flexible and water-jacketed. With the gasket in place, bolt the manifold to the engine by tightening the nuts evenly. An adapter may be welded to the flexible exhaust pipe as shown in Fig. A1.5 to mount a ¾-in. quick-opening valve for checking exhaust pressure pulsation.

A5.19.2 If the indicated knock is altered appreciably when the valve is opened, discharging the exhaust to the atmosphere, excessive exhaust pulsations are indicated, and the system must be altered to correct the resonance. The surge tank is usually mounted horizontally, and must be supported rigidly. The exhaust gas should enter and leave the tank through the two flanges that are fitted with internal pipe extensions for noise control. Mount it so that the flexible exhaust manifold will slope down from the engine at about ¼-in. per foot of length. Align it so that the ¾-in. pipe connection is at the bottom of the tank. In bolting the manifold to the surge tank, be sure to use gaskets between the manifold and spacer, and between the spacer and the surge tank.

A5.19.3 To remove the water from the exhaust, connect a drain line to the standard ¾-in. pipe boss shown in Fig. A1.6. A trap should be provided in all water drain lines. The exhaust discharger pipe from the surge tank should have a diameter of at least 2 in. (50.8 mm) and should be no longer than 30 ft (9.14 m). Elbows or other restrictions should be avoided, but a straight-through muffler may be used at the end of the pipe if compliance with the exhaust back-pressure requirements in Section A1.11 is obtained.

A5.19.4 The exhaust should be led outside the building by the most direct route. If part of the pipe is exposed to the weather, provision should be made to prevent snow and rain from entering the open end.

A5.20 Thermometers

A5.20.1 Specifications for ASTM thermometers are given in Table A1.3. Before installation, each thermometer should be checked to insure that the mercury column has not separated during shipment. They should be installed as shown in Table A5.1.

A5.20.2 The five thermometers are packed in the box of loose parts. Use great care in unpacking these instruments, especially the thermometer with the long exposed glass shank. Mount this thermometer (100 to 300°F) in the side of the surge tank at *DD* (see Fig. A1.10) with its scale turned toward the operating station. Mount the thermometer having a range from

TABLE A5.1 Thermometer Installation

ASTM Thermometer No.	Thermometer Range, °F (°C)	Location	Illustration
85F (85C)	100 to 300 (40 to 150)	Intake surge tank	*DD*, Fig. A1.7
84F (84C)	75 to 175 (25 to 80)	Orifice air tank	*E*, Fig. A4.10
87F (87C)	300 to 400 (150 to 205)	Coolant return line	
82F (82C)	0 to 220 (−15 to 105)	Injection pump	
82F (82C)	0 to 220 (−15 to 105)	Relief valve (oil)	*J*, Fig. A1.2

75 to 175°F in the orifice air tank at *E* (see Fig. A1.11) with its scale adjusted for observation from the operating station. Place the thermometer having a range from 300 to 400°F in the coolant return line directly below the condenser. The two remaining thermometers have a range from 0 to 220°F. Mount one to indicate the temperature of the fuel delivered to the injection pump, and insert the other in the housing of the lubricating oil relief valve at *J* (see Fig. A1.2) to show the temperature of the oil as it is supplied to the main bearings.

A5.21 Control Panel Desk

A5.21.1 The two-drawer desk is fastened to the control panel frame by cap screws packed with the desk. Remove the drawers after pressing up on the spring stops beneath them. These stops prevent over-travel and dropping. Insert the cap screws, mount the desk, and replace the drawers.

A5.22 Final Check of Assembly

A5.22.1 Except for electrical power supply connections, the unit is complete. A final check should now be made to make sure there are no dangling wires, insecure pipes, or unsupported copper tubes to vibrate loose or out of position and interfere with moving parts. Apply clips and support straps wherever necessary.

A5.22.2 If the installation has been made with crossover conduits in the base as previously suggested, safety rubber wedges inserted at both ends of the conduits to hold the tubing and wires securely will prevent vibration and wear that might damage the insulation or cut the tubing.

A5.22.3 Use a compressed air jet to clean off all chips, dirt, and dust from the unit, the control box, and especially the dynamometer. Blow through the dynamometer frame with a low-pressure air jet of wide orifice to make sure no pipe cuttings, plaster, or concrete chips have lodged inside. Rotate the unit by hand while passing the air through the dynamometer. This should dislodge any foreign particles that might otherwise remain. *At no time should high-pressure air be used inside the dynamometer or any electric motor or generator, as this may cause foreign particles to become imbedded in the windings.*

A5.23 Connecting Electric Power Lines

A5.23.1 All parts having been assembled, refer to the wiring diagram (see Fig. A1.3) and make the connections in the starting compensator from the 440-V (or 220-V) power lines at the L-1, L-2, and L-3 terminals in the compensator box. From the 110-V power supply, make the connections in the switch boxes that feed the safety control relay box and the crankcase oil heater. This is the final operation in the installation of the unit.

A5.24 Starting Unit

A5.24.1 After completing installation of the unit, do not attempt to start it, even to test the electrical circuit, until the preparations for starting have been completed, as described in Sections A3.4 and A3.5. *This is very important.*

A6. BUILDING AND UTILITY REQUIREMENTS

A6.1 Utility Services

A6.1.1 The main factor to be considered in the selection of a site for a knock testing laboratory is the availability of the services required for the operation of the engines and the handling of the samples that are to be rated. The services necessary are as follows:

A6.1.1.1 Easy access by truck to permit delivery of samples and supplies such as ice and barrel quantities of reference fuels.

A6.1.1.2 Fresh water, both hot and cold.

A6.1.1.3 Electrical services, 440 V, 60 Hz, three phase ac for the dynamometer (dynamometers for other voltages and frequencies are available) and 110 V, 60 Hz, single phase for heats, panel clock, and so forth. (50-Hz panel clocks are available also). The dynamometer requirement is 38 kVA, and the heater load about 5 kW per unit. Line capacity should be provided for a maximum inrush current of 170 A for 440-V dynamometers, or 340 A for 220-V dynamometers. Inrush current for 50 Hz motors is about 20 % higher.

A6.1.1.4 Compressed air for the engine and for general laboratory use. The probable maximum air requirement per engine is 225 lb/h at 90 in. Hg (304.8 kPa) absolute. However for control purposes, the air should be supplied to the engine at a pressure of at least 60 psi (0.41 MPa) gage. If high-pressure air is not available at the knock test laboratory, it will be necessary to provide an air compressor capable of supplying these requirements. The compressed air should be free of contaminating chemicals or vapors.

A6.1.1.5 Stream, if required for heating or cleaning purposes.

A6.1.1.6 Washroom facilities, keeping in mind local regulations.

A6.1.1.7 Telephone.

A6.2 Laboratory Site

A6.2.1 The laboratory is generally located as near as possible to the plants where the samples to be tested will originate. If located in a refinery, it should not be near any plants that are noisy since it is frequently desirable to listen to the audible knock produced by the test engine. Likewise, the exhaust from the knock testing engines occasionally becomes audible even though mufflers are used. It is therefore desirable to locate the knock testing laboratory where the exhaust fumes and noise will not be objectionable to other personnel.

A6.2.2 In most instances, knock testing laboratories are started with one or two engines and additional ones added as the number of samples to be tested increases or as it becomes necessary to provide for different test methods. Thus, the laboratory should be located so that the building can be expanded as required.

A6.3 Type of Structure

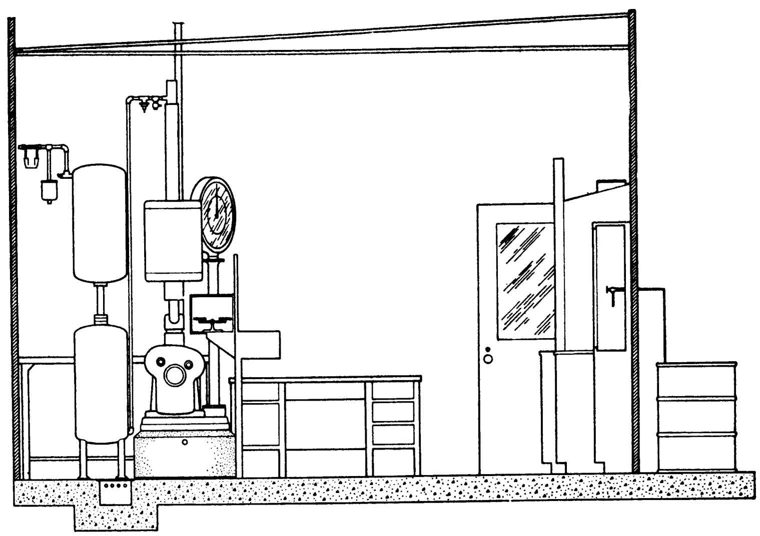
A6.3.1 The exact type of structure used for the laboratory is not critical, provided it is fireproof. Since large numbers of gasoline samples will be handled within this building, only fireproof construction should be used. Recommended types are brick, reinforced concrete, or building tile.

A6.3.2 In areas where relatively mild climatic conditions exist, a steel frame building covered by a fireproof or fire-resistant material may be considered. No specific recommendations for the building type are made since in most cases the exact type selected will be determined by the climatic conditions and the type of buildings already in existence in the area surrounding the laboratory site.

A6.4 Laboratory Foundations

A6.4.1 The foundation to be used for the laboratory will vary, to some degree, with the condition of the soil upon which it is to be constructed. In extremely sandy soil, or where the area has recently been filled, it may be necessary to use piling, but in most instances piling is not required.

A6.4.2 Use of a reinforced-concrete floor, approximately 8 in. (200 mm) deep with increased depth in the area of the service trenches, has been found adequate. The trenches, shown by dotted lines in Fig. A6.1, should be approximately 12-in. (300-mm) wide by 8 and 12-in. (200 and 300-mm) deep with the floor recessed at the edges so that they can be covered with steel plates.



SECTION THROUGH FLOOR PLAN AT INDICATED ARROWS

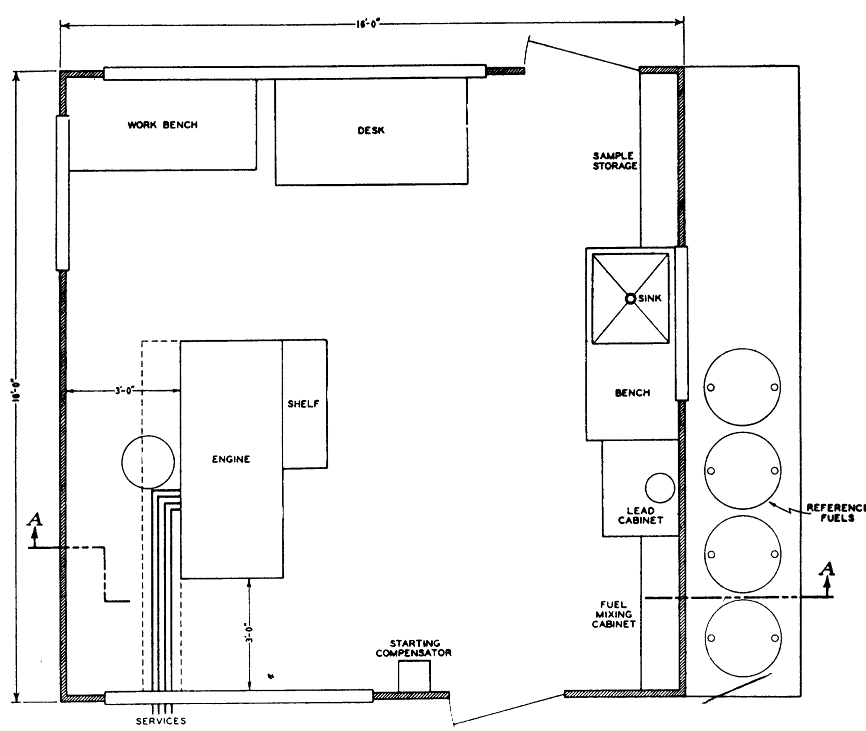


FIG. A6.1 Minimum Floor Dimensions of Room for Supercharge Unit

A6.5 Test Unit Foundation

A6.5.1 In some locations, a concrete block, 15-in. (381-mm) thick and poured on top of the floor, has proved satisfactory as an engine foundation. However, more recent developments indicate that noise and vibration may be reduced appreciably by isolation of such a reinforced concrete block from the building structure.

A6.5.2 Suitable pads for absorbing vibration are available from several suppliers. The foundation dimensions are shown in Fig. A5.3. Bedplates of late design are drilled to accommodate anchor bolts if needed.

A6.6 Service Installations

A6.6.1 The following services should be brought to the engines through trenches:

A6.6.1.1 Electrical conduits.

A6.6.1.2 Cooling water supply lines, either ¾ or 1-in. pipe.

A6.6.1.3 Water drain line.

A6.6.1.4 Compressed air line.

A6.6.2 In some areas it may be desirable, because of building restrictions or preference, to introduce the electrical services by means of conduit from the ceiling. The main switches should be so located inside the building so that they can readily be cut off in case of fire.

A6.6.3 A separate trench about 12-in. (300-mm) wide by 8-in. (200-mm) deep is provided (see Fig. A6.1) for the introduction of the lines carrying the reference fuels from the barrels to the cabinet where the reference fuel blending is to be done. These fuel lines should be kept off the bottom of the trench with metal supports, and adequate drainage should be provided in the trench to remove any leakage and to permit flushing it with water or steam.

A6.6.4 The engine exhaust line from the surge tank should extend through the roof or the wall and then vertically upward, ending above the eaves of the building. This line should have an inside diameter of at least 2 in. (50 mm). If there is a horizontal section, it should be sloped so that condensed moisture will drain away from the surge tank. To prevent freezing, insulation of the outside vertical section may be necessary in cold climates.

A6.6.5 The vent line from the breather connection on the engine crankcase should be a ¾-in. pipe, and as short as possible, passing through the wall adjacent to the exhaust line (see Section A5.10). This pipe should also drain away from the engine and discharge directly into the atmosphere through an elbow turned downward.

A6.7 Floor Drainage

A6.7.1 Adequate facilities for floor drainage should be installed so that they are readily accessible. The highest point of the concrete floor should run lengthwise through the room, parallel to and between the service trenches about 2 to 3 ft (0.6 to 0.9 m) from the engine base. The floor should slope so that any spillage on the engine side of this elevation will flow into the service trench behind the engine and then to a suitable drain. The floor of the other half of the room should slope so that any spillage will drain to the service trench in front of the fuel-mixing cabinet. These drains should be large enough to handle large quantities of water so that both floor and service trenches can be flushed with water or steam periodically or after a flammable liquid has been spilled. All services should be supported so that the pipes will not interfere with drainage of the trench.

A6.8 Ventilating, Heating, and Air Conditioning

A6.8.1 Laboratory windows should be large and designed to open because adequate ventilation is the best safeguard for the prevention of fire when spillage of flammable liquid occurs. Spacious windows also provide more pleasant working conditions. If possible, the direction of the prevailing wind should be considered so that a number of windows can be provided on the windward side of the laboratory. However, drafts around the test unit should be avoided as they will cause erratic ratings. For this reason many laboratories prefer forced ventilation.

A6.8.2 Since the knock testing laboratory will usually be built in the refinery area, steam is generally available and is an excellent source of heat. Any efficient type of steam radiator will be satisfactory. The overhead type of unit heater has proved satisfactory in mild climates.

A6.8.3 Air conditioning is highly desirable if the laboratory is located where high temperatures exist for any appreciable portion of the year. With medium to moderate atmospheric temperature, the heat generated by the engines will not be particularly objectionable. If temperatures of 85 to 90°F (29 to 32°C) occur with high humidity more than a few weeks per year, it is recommended that provision be made for air conditioning. Otherwise the heat from the engines will make the laboratory extremely uncomfortable.

A6.9 Lighting

A6.9.1 Good lighting is a prerequisite for efficiency and favorable working conditions. It is particularly essential in the knock-testing laboratory because some of the engines will undoubtedly need to be operated at night. A minimum intensity of 100 fc (1076 lm/m^2) is desirable on any working surface, that is, around the engine control panel, the fuel-blending cabinet, the work bench, and the desk.

A6.10 Soundproofing

A6.10.1 Some soundproofing for each engine is desirable but complete enclosure in a soundproof cell is normally not required. Soundproofing material should be fireproof or fire-resistant and preferably of the metallic type. If, for economy reasons, soundproofing on three sides of the engine is not possible, it should be provided at least on the ceiling and on as much of the wall area as possible. Otherwise it will be difficult to determine aurally the standard knock intensity.

A7. PRECAUTIONARY INFORMATION

A7.1 Introduction

A7.1.1 In the performance of the standard test method to determine the knocking or detonation characteristics of aviation fuels there are hazards to personnel in performing the test. These include explosion, fire, toxicity, and personal injury. At points in the text where a precaution is important, a system of coded flag symbols has been applied to alert the user. This system consists of printing flag symbols (superscripts) immediately after each point of Caution, Warning, or Danger, wherever a hazard may exist. The symbols and their meanings are:

|□ means **Caution!**

|| means **Warning!**

| means **Danger!**

A7.2 Caution Alert|□

A7.2.1 **CAUTION! COMBUSTIBLE. VAPOR HARMFUL.**

A7.2.1.1 Keep away from heat, sparks, and open flame.

A7.2.1.2 Keep container closed.

A7.2.1.3 Use adequate ventilation.

A7.2.1.4 Avoid breathing vapor or spray mist.

A7.2.1.5 Avoid prolonged or repeated contact with skin.

A7.2.2 *Caution Substances*—This caution alert applies to the following substances:

A7.2.2.1 Kerosine

A7.2.2.2 Penetrating oil

A7.2.2.3 Oil

A7.2.2.4 Dry ice (noncombustible)

A7.2.2.5 Liquid air (noncombustible)

A7.2.2.6 Liquid nitrogen (noncombustible)

A7.2.2.7 SAE 30 oil

A7.3 Warning Alert||

A7.3.1 **WARNING! FLAMMABLE. LIQUID CAUSES EYE BURNS.**

A7.3.1.1 Keep away from heat, sparks, and open flames.

A7.3.1.2 Keep container closed.

A7.3.1.3 Use adequate ventilation.

A7.3.1.4 Avoid build-up of vapors.

A7.3.1.5 Avoid prolonged breathing of vapor or spray mist.

A7.3.1.6 Avoid prolonged or repeated skin contact.

A7.3.2 *Warning Substances*—This warning alert applies to the following substances:

A7.3.2.1 Ethylene glycol

A7.3.2.2 Electrician's shellac

A7.3.2.3 Alcohol

A7.3.2.4 Formula 30

A7.4 Danger Alert|

A7.4.1 **DANGER! EXTREMELY FLAMMABLE. VAPORS HARMFUL IF INHALED. VAPORS MAY CAUSE FLASH FIRE.**

A7.4.1.1 Keep away from heat, sparks, and open flame.

A7.4.1.2 Keep container closed.

A7.4.1.3 Use adequate ventilation.

A7.4.1.4 Avoid build-up of vapors.

A7.4.1.5 Avoid prolonged breathing of vapor or spray mist.

A7.4.1.6 Avoid prolonged or repeated skin contact.

A7.4.1.7 Vapors heavier than air, may gather in low areas and cause explosion.

A7.4.2 *Danger Substances*—This danger alert applies to the following substances:

A7.4.2.1 Aviation gasoline

A7.4.2.2 Blends

A7.4.2.3 *Iso*octane

A7.4.2.4 *n*-heptane

A7.4.2.5 Check fuel

A7.4.2.6 BP solvent 666

A7.4.2.7 Solvent

A7.4.2.8 Acetone

A7.4.2.9 Naphtha

A7.4.2.10 Solvent naphtha

A7.4.2.11 Fuel blends

A7.4.2.12 Lead

A7.4.2.13 80 octane number blend

A7.4.2.14 Unleaded fuel

A7.4.2.15 Tetraethyllead (TEL)

A7.4.2.16 Reference fuel blends

A7.4.2.17 Reference fuels

A7.4.2.18 Aviation fuels

A7.4.2.19 2,2,4-trimethylpentane

A7.4.2.20 Aviation standardization fuels

A7.4.2.21 Leaded standardization fuels

A7.4.2.22 Standardization fuels

A7.4.2.23 Gasoline

A7.4.2.24 Dilute fluid

A7.4.3 **DANGER! POISON. MAY BE HARMFUL OR FATAL IF INHALED OR SWALLOWED.**

A7.4.3.1 Vapors harmful, emits toxic fumes when heated.

A7.4.3.2 Vapor pressure at normal temperature exceeds threshold limit for occupational exposure.

A7.4.3.3 Do not breathe vapor.

A7.4.3.4 Keep container closed.

A7.4.3.5 Use with adequate ventilation.

A7.4.3.6 Do not take internally.

A7.4.3.7 Cover exposed surfaces with water, if possible, to minimize evaporation.

A7.4.3.8 Keep recovered mercury in tightly sealed container prior to sale or purification.

A7.4.3.9 Do not throw in sink or rubbish.

(a) This danger alert applies to mercury.

A7.4.4 **DANGER! POISON. MAY BE FATAL IF SWALLOWED, INHALED, OR ABSORBED THROUGH SKIN.**

A7.4.4.1 Unstable at high temperatures.

A7.4.4.2 Do not handle unless familiar with manufacturer's precautions, and trained in laboratory methods for toxic materials and antiknock compounds in particular.

A7.4.4.3 Do not breathe vapors.

A7.4.4.4 Do not permit contact with skin.

A7.4.4.5 Do not swallow or take internally.

A7.4.4.6 Handle only in a properly designed and well ventilated laboratory hood.

A7.4.4.7 Wear face shield as well as gloves and apron, resistant to gasoline if contact is likely to occur.

A7.4.4.8 Dispense directly from container, but only with an approved dispensing burette fitted with a vapor trap.

A7.4.4.9 Keep litre containers tightly capped and in a locked fume hood when not in use or connected to a burette.

A7.4.4.10 Store unopened containers in a locked, clean, and ventilated enclosure.

A7.4.4.11 In case of spill within hood, all apparatus and glassware must be rinsed with kerosine immediately.

A7.4.4.12 If spill contacts clothing, remove and discard immediately. To dispose of empty antiknock compound containers, rinse thoroughly and repeatedly with suitable hydrocarbon solvent, crush or deform both container and cap to prevent re-use, and burn or bury in an area approved, by local environmental protection authorities.

A7.4.5 *Danger Substances*—This danger alert (see A7.4.4) applies to the following substances:

A7.4.5.1 tetraethyllead (TEL)

A7.4.5.2 dilute TEL

A7.4.5.3 antiknock compound

A7.4.5.4 other lead alkyls