

# AIR CORPS INFORMATION CIRCULAR

PUBLISHED BY THE CHIEF OF AIR CORPS, WASHINGTON, D. C.

Vol. VI

November 1, 1927

No. 589

## POWER-PLANT LABORATORY STANDARD TEST METHODS AND COMPUTATIONS

(POWER PLANT SECTION)



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March 24, 1924  
Revised March 12, 1925



UNITED STATES  
GOVERNMENT PRINTING OFFICE  
WASHINGTON  
1927

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# POWER-PLANT LABORATORY STANDARD TEST METHODS AND COMPUTATIONS

## GENERAL INSTRUCTIONS

The general foreman is directly responsible for the installation of the engine and laboratory apparatus to be used in connection with all tests. He is responsible also for checking of the dynamometer, fuel and oil scales before each test is started. Instructions for changes in apparatus or equipment must be issued to him only. No more than minor modifications may be made without his approval. The general foreman should also be notified as soon as possible after the completion of the test or any series of runs so that he may make arrangements for changes in set-up and reassignment of laboratory personnel. Stop watches and special instruments are kept in the general office under the supervision of the office manager and are issued to engineers and dynamometer operators on check or memorandum receipt. Persons to whom such material is issued will be held responsible for its care until returned. Any failures or inaccuracies of such instruments should be reported to the chief of the laboratory immediately so that repairs or replacements may be made promptly.

Before starting the test the engineer should carefully inspect the apparatus to detect any errors in installation and to be sure that all necessary instruments are provided and properly adjusted. Any changes of test procedure or serious difficulties with laboratory apparatus which are likely to affect the test program should be taken up with the chief of the laboratory so that he may make proper accommodation in the general laboratory program.

A complete description of the Power Plant Laboratory has been issued under the title "Description of the Power Plant Laboratory"—Engineering Division Report, Serial No. 1987.

## GENERAL INSTRUCTIONS FOR OPERATING ENGINES

All new or overhauled engines must be thoroughly "run in" before test runs are started. The general foreman will specify the "running in" required for each engine and will decide in all cases whether or not the condition of the engine is satisfactory for test. Engines should never be started or stopped abruptly unless the nature of the test requires it or emergency makes sudden stops necessary. The rapid heating and cooling of parts resulting from abrupt starts or stops is rather severe. Engines should not be run at full speed or full throttle until the oil has been heated sufficiently to assure circulation. It is ordinarily advisable to allow the temperature to rise above 100°

F. before the test is started. To clear the fuel system and to prevent accidental starts, etc., the engine should always be stopped (except in emergency) by shutting off the fuel.

Before starting any test, the full power and fuel consumption of the engine should be checked to detect any inaccuracies in assembly or adjustment. During this check run, the tachometer, thermometers, pressure gauges, manometers, and other instruments should also be checked.

## STANDARD METHODS OF TAKING TEST READINGS

The following methods of taking test readings have been adopted by the power plant laboratory as the most accurate readily applicable. In taking readings the operating conditions should be held constant for several minutes before any reading is attempted in order to permit the apparatus to "settle down" completely and to eliminate distortions due to momentary variations.

Log sheet forms obtainable in the general office are shown at end of text.

### REVOLUTIONS PER MINUTE

In adjusting the speed on test the tachometer indicator may be followed. Actual readings of revolutions per minute, however, should be made with the revolution counter by noting the counter difference for a given interval of time, ordinarily one minute, measured by stop watch. To avoid errors, counter readings should be recorded directly on the log sheet.

### BRAKE LOAD

Not less than two readings of brake load should be made for each setting.

### WATER AND OIL TEMPERATURES

Water and oil thermometers should be placed as near as possible to the inlet and outlet connections of the engine. Standard fittings for mercury thermometers are incorporated in the lines at each dynamometer. For particular accuracy, however, for heat rejection determinations and the like, electric resistance thermometers measuring differential or direct temperatures are available. These thermometers should be very carefully installed to avoid distortion of readings by radiation from water lines, etc. In reading water temperatures the observer should be careful to take no readings while any considerable adjustment of the water temperature is being made.

## OIL PRESSURE

The oil pressure is determined by standard pressure gauge on the instrument board.

## AIR TEMPERATURE

Wherever possible conditioned air should be used on engine tests. The temperature of the conditioned air should be automatically maintained within 2° of 60° F. at all times. If it is not, the general foreman should be notified so that adjustments can be made. Air-temperature determinations should be made with mercury thermometers in the carburetor air pipe as close as possible to the engine.

## INDUCTION-SYSTEM PRESSURES

Induction-system pressures should be determined by means of mercury or water manometers. For comparative purposes standard induction system pressure readings will be taken at the cylinder elbow of the intake manifold branch farthest from the carburetor (in symmetrical manifolds the manometer fitting will be located in the rear branch), at the intake manifold uptake directly above the throttle barrel, and in the float chamber of the carburetor. In using the single column mercury manometers the level should be adjusted before each reading to insure accurate results. Note should be made as to whether there is water or gasoline on the mercury column. For the float chamber depression reading a water manometer should be used.

## FUEL CONSUMPTION

Three methods are available for measurement of fuel consumption—the tank scales by which the weight of fuel consumed may be determined directly, volumetric gauges by which a given volume of fuel may be timed, and Brown and Barlow flowmeters which indicate directly the volumetric rate of fuel flow. In reading either the scales or the volumetric gauge the time required for the consumption of a given quantity of fuel must be determined. The flowmeter measures the rate of fuel consumption directly. The bulbs of the volumetric fuel gauge have capacities as indicated. They have been calibrated, however, for fuel with a specific gravity of 0.710. It is important when measuring fuel consumption with either the volumetric gauge or the flowmeter that the proper correction be applied for specific gravity. Care should also be taken to see that too great a variation of fuel head is not introduced by the position of the volumetric gauge. Lines have been painted on the gauge boards and ways to assist in maintaining proper fuel head. When the volumetric gauges are used the time interval should not be less than 90 seconds. A similar accuracy with the tank scales requires a reading of about five minutes.

In specifying mixture control positions for fuel readings "full rich" and "full lean" will be regarded as the richest and leanest settings possible with the given control. "Best setting" or "best" is setting which gives the leanest mixture on which the engine will just hold maximum power. The leaning should

not cause a drop in power of over  $\frac{1}{2}$  of 1 per cent. The "best setting" should be determined very carefully for there is sometimes considerable lag in the engine's response, and several settings may be necessary before the "best position" is actually reached.

## OIL CONSUMPTION

The rate of oil consumption can be determined satisfactorily only during runs of one hour or more duration. Before readings are taken the engine should be run at the required speed and load for not less than 10 minutes to permit the oil circulation to become uniform. During the run all operating conditions, especially speed, water temperatures, and oil temperatures, must be held constant. Readings of the oil scales, engine speed, brake load, water and oil temperatures, and oil pressure should be recorded every 10 minutes throughout the run. For the best results the quantity of oil in the pipes between tank and engine should be kept as small as possible.

## COOLING AIR VELOCITY

Cooling air velocity in air-cooled cylinder tests is measured by a fixed air-speed indicator fitted at the mouth of the cooling air duct. Where greater accuracy is desired traverses of the mouth of the duct may be made with a portable indicator.

## CYLINDER TEMPERATURES

Cylinder temperatures are measured whenever possible by means of thermocouples embedded in the metal ordinarily at the hottest point of the head. A potentiometer is used to indicate the temperature at the thermocouple. When it is impossible to embed the couple in the metal or when an exploration of the cylinder is desired, a "contact" type of thermocouple is used. Care must be taken when using thermocouples with millivoltmeters and uncompensated potentiometers to correct for the cold junction temperature by adding the cold junction temperature to the indicated temperature. In connecting the thermocouples to the instrument by leads of the same materials as the thermocouples precautions must be taken to insure that like leads are connected together at intermediate junctions to avoid cross compensation.

## SPARK ADVANCE

Unless otherwise specified, the spark advance should be determined by means of a rotary spark advance indicator. In case the spark advance is determined by the position of the control lever on the graduated sector the positions for full advance and full retard must also be recorded. The position of best spark advance is minimum spark advance which will give full power.

## THROTTLE POSITION

The throttle position determination is a reading of the position of the throttle control lever on its graduated sector. This reading is obviously valueless unless the sector positions for full open and closed throttle are also recorded.

## MIXTURE CONTROL POSITION

The mixture-control position determination is a record of the position of the carburetor mixture-control lever on its graduated sector. This record also should be accompanied by record on the log sheet of the position for full rich and full lean mixture.

## METHOD OF CHECKING SCALES

Dynamometer, fuel, and oil scales should be checked before every test. The following methods have been adopted, and scale checking forms, Engineer Division Form 736, provided for that operation. The scale checking form should be filled out and turned in for approval to the chief of the laboratory before the test is started.

*Dynamometer scales.*—Whenever possible the dynamometer scales should be checked with the engine disconnected from the armature. The 63-inch checking arms should be firmly clamped on the field housing perpendicular to the dynamometer shaft and with the two ends equidistant from the floor. The dynamometer, linkage, and exposed scale mechanism should be carefully inspected to detect any interference with free movement of the dynamometer or linkage or any improper adjustment of the linkage. Any defects noted should be corrected before the checking is started.

Starting with the scale side checking arm, lift the arm until about 100 pounds load is recorded on the scale. Release the load gently and record in the "UP" column on the sheet the scale reading when the hand comes to rest. Repeat the operation, depressing the arm to 100 pounds load and releasing it gently and record the scale reading at rest in the "DOWN" column. These up and down loads should be released so gently that the scale hand moves continuously in one direction to the point of rest without oscillating. Attach one 50-pound weight to the scale side checking arm and reduce the load by about 100 pounds by lifting the arm. Release the arm gently and record the reading of the hand at rest in the "UP" column. Repeat the operation, increasing the load by depressing the arm, and enter the reading in the "DOWN" column on the sheet. Continue in this manner adding one 50-pound weight at a time until the scale hand has covered the range to be used in the test.

Remove all the weights from the scale side checking arm and repeat the procedure on the opposite arm.

If the scales show an average error on either side of more than 1 per cent, the general foreman should be notified so that adjustments can be made. After the adjustments have been completed the scale checking operation must be repeated. Only in emergency, and then only when the scales appear to be in good mechanical condition, may a calibration curve be drawn by which to correct the test readings. In general no test should proceed until the scales check satisfactorily.

*Fuel and oil scales.*—The fuel and oil scales are checked by adding standard test weights to the scale platform, ascending to the capacity of the scales and descending to zero. The readings as each weight is added or removed should be recorded on the log sheet. The allowable error in this check also is 1 per cent.

## INSTRUCTIONS FOR WEIGHING ENGINES

1. For the purpose of determining engine weight the basic engine will include the following accessory parts, and whenever possible (unless otherwise specifically instructed, as in contracts, etc.) the dry weight will be so quoted:

- Carburetors.
- Air intake stacks.
- Water pump.
- Oil pumps.
- Ignition system (including coils if separate).
- Generator (when an integral part of the ignition system).
- Propeller hub and bolts.
- Gun synchronizer drives.
- Any piping, fittings, controls, etc., supplied by the manufacturer and obviously part of the engine unit.

2. The following parts are *not* to be considered part of the basic engine, and when they accompany the engine they should be weighed separately and their weights quoted as accessory items:

- Fuel pumps.
- Exhaust pipes or flanges.
- Generators (part of the basic engine only when an integral part of the ignition system).
- Starters.
- Switches.
- Voltage regulators.
- External primary and starter wiring, piping, or controls.
- Primer lines and fittings.
- Starting magneto.
- Miscellaneous items obviously not a part of the operating engine.

3. Whenever, for any reason, the basic engine differs from that described in paragraph 1 the parts included in the weight should be specifically described. Those items, weighed separately, should be completely identified (by type number, manufacturers' name, etc.) in listing their weights.

4. When making engine weight determinations every precaution must be taken to assure that the engine contains as little as possible of oil and water, that the zero weight is subtracted from the total, and that the scales are accurate. (The most recent scale checking sheet should not be more than 2 months old.)

## THE FULL-POWER RUN

The full-power run is made to determine the full throttle horsepower and fuel consumption of the engine over a range of speeds likely to be encountered in service or of interest for purposes of design or comparison.

A complete full-power run consists of two full-power curve determinations, one at full rich and one "best" setting of the carburetor mixture control, taking a complete set of readings at each 100 revolutions per minute over a speed range from 400 revolutions per minute below to 200 revolutions per minute above normal speed. "Best setting" of the carburetor mixture control is the leanest setting at which the

engine will hold full power. A brake load lower than one-half of 1 per cent below maximum will not be considered full power. At each speed the spark advance should be set at the minimum advance required to give maximum power. Conditioned air to the carburetors at approximately 60° F. should be used for all full-power runs. The temperature of the cooling water leaving the engine will be maintained as closely as possible at the point specified by Air Corps or the manufacturers' instructions.

No readings should be taken until the engine has settled down to uniform operation at each setting. The quantity of fuel used for determination of fuel consumption should be such that the reading covers a period of not less than 90 seconds. A full set of readings required at each point on the power curve consists of the following:

- Revolution counter, one minute.
- Brake load, before and after other readings.
- Fuel consumption, for a period not less than 90 seconds.
- Cooling water temperature, in and out.
- Oil temperature, in and out.
- Oil pressure.
- Carburetor air temperature.
- Intake manifold depression.
- Carburetor float chamber depression.
- Spark advance.
- Throttle position.
- Mixture control position.

In addition, all information called for on the log sheet, Engineering Division Form 737A, should be provided.

If any point or points on the full-power curves obtained from this test appear at all doubtful the run should be repeated. The curve, therefore, should be plotted at least in rough form before the engine is removed from the test stand.

### THE PROPELLER LOAD RUN

The propeller load run is made to observe the performance of the engine under conditions of speed and power approximating those encountered in service.

The propeller load run starts at full-power normal speed. Readings are taken at normal speed and at speeds reduced by 100 revolutions per minute increments from normal speed over a range of at least 500 revolutions per minute, preferably 600 revolutions per minute. At each speed the throttle should be so adjusted that the horsepower varies as with propeller load directly as the cube of the speed and the brake load, therefore, as the square of the speed. Curves in Figure 1 showing the variation of brake horsepower and brake load with engine speed in per cent may be used in computing brake loads. In tests of geared engines the engineer must be careful to avoid errors resulting from confusion of engine speeds and propeller speeds and engine and propeller torque.

The propeller load run should be started at full throttle, normal speed of the engine and readings taken there and at each 100 revolutions per minute below that speed, covering a range of at least 400 revolutions per minute. At full throttle, normal speed, the spark and throttle controls should be set

to give maximum power and the carburetor mixture control set at "best position." The instructions for obtaining "best setting" of the mixture control are given under the description of the full-power run, page 3. The throttle and brake load only are to be adjusted to reduce speed and power. The full-power spark and mixture control settings should be retained throughout the propeller load run.

The full set of readings to be taken at each speed during the propeller load run consists of the following:

- Revolution counter, one minute.
- Brake load, before and after other readings.
- Fuel consumption, for a period not less than 90 seconds.
- Cooling water temperature, in and out.
- Oil temperature, in and out.
- Oil pressure.
- Carburetor air temperature.
- Intake manifold depression.
- Carburetor float chamber depression.
- Spark advance.
- Throttle position.
- Mixture control position.

In addition, all information called for on the log sheet, Engineering Division Form 737A, should be provided.

The propeller load run should be repeated if any of the points obtained fall any distance from the curve faired through the other points. The curve should be plotted at least in rough form before the engine is removed from the test stand.

### THE FRICTION HORSEPOWER RUN

The friction horsepower of an engine is the power required to overcome its mechanical friction and to pump the mixture through the engine. It is measured at the dynamometer by determining the power required to drive the engine at a specified speed with full-open throttles, fuel and ignition shut off, and normal water and oil temperatures.

In order to reproduce as closely as possible actual operating temperatures, the engine must be thoroughly warmed up under its own power before starting the friction horsepower run and the friction run started with least possible delay after the "warming up" has been completed. Readings at each speed should be taken rapidly as soon as engine operation has become steady and the first readings repeated immediately after the last to check any variations in running conditions. It is essential that oil and water temperatures be maintained as nearly constant as possible during the friction horsepower run.

The friction horsepower run should cover a range of speeds from at least 400 revolutions per minute below to 200 revolutions per minute above normal speed. Readings should be taken at every 100 revolutions per minute throughout the range. A complete set of readings for the friction horsepower run consists of the following:

- Speed by tachometer (to save time, counter readings will not be taken; the tachometer should have been carefully checked, however).
- Friction load, before and after other readings.

Water temperature, in and out.  
 Oil temperature, in and out.  
 Oil pressure.  
 Carburetor air temperature, average for the run.

### THE COMPRESSION PRESSURE RUN

For comparative purposes, the standard compression pressure run has been established as the determination of cylinder compression pressures with the engine "motored" at 120 revolutions per minute with full-open throttle, fuel and ignition off, and normal operating water and oil temperatures. The compression pressure is measured with a Crosby indicator with hand-operated drum. For determination of the condition of the engine the compression pressure of all the cylinders should be determined. For comparison of two engines (in good condition) of different types the compression pressure of not less than three cylinders of each bank should be measured.

### THE ONE-HOUR FUEL AND OIL CONSUMPTION RUN

The purpose of the one-hour fuel and oil consumption run is to determine accurately the normal-speed full-throttle fuel and oil consumption of the engine.

The run should be made at full throttle, normal speed of the engine (mixture control at "best setting") with water and oil temperatures carefully maintained within manufacturer's or Air Corps limits. No readings should be taken until all operating conditions have become uniform. The engine operation will probably not become uniform in much less than 10 minutes running at full throttle, normal speed. A complete set of readings should be taken at the start of the run and every five minutes thereafter. If it becomes necessary during the run to replenish fuel or oil, note of that fact should be made on the log sheet and the exact amount of added fuel or oil recorded. The engine operation should be carefully observed throughout the run and any indication of unsatisfactory condition recorded. Success in obtaining consistent oil-consumption measurements depends on maintaining uniform operating conditions—constant water and oil temperatures, oil pressures, and engine speed.

The complete set of readings required every five minutes include the following:

- Speed counter, progressive reading.
- Brake load.
- Fuel consumption, progressive scale reading.
- Oil consumption, progressive scale reading.
- Cooling water temperature, in and out.
- Oil temperature, in and out.
- Oil pressure.
- Carburetor air temperature.
- Intake manifold depression.
- Spark advance.
- Mixture-control position.

In addition, all information called for on the log sheet, Engineering Division Form 737A, should be supplied.

### THE ROUTINE ENGINE TEST

The routine engine test is conducted to prove the acceptability of the engine for flight service. All engines overhauled at the Engineering Division must pass this or an equivalent test before they are approved for service.

The routine engine test is conducted under the supervision of the Chief of the Engine Liaison Branch and approval of the engine for release is given by him. He is, therefore, the final authority in all decisions relative to routine engine test or final inspection. No deviations from the routine test procedure here described should occur without his direct approval.

The routine engine test may be performed at either a torque stand or a dynamometer. If the test is conducted at a dynamometer, conditioned air should be supplied to the carburetors. The following is the standard test procedure (a log sheet form is included):

1. *Preliminary inspection.*—Record expenditure order number, engine model, and number on log sheet.

(a) Test compression of each cylinder roughly by turning engine slowly.

(b) Check carburetor flooding.

(c) Inspect for water and oil leaks.

(d) Record carburetor setting on log sheet.

2. *Running in.*—The engine should be run in under its own power at light load for a period specified by the general foreman, varying according to the number and character of new parts in the engine. The speed and load for the running in will also be specified by the general foreman, but ordinarily the period will start at idling speed and gradually increase to normal speed at the end of the run. During the running-in period the oil pressure should be adjusted with thoroughly warm oil to specified idling and normal speed pressures; 120° F. will be considered the standard temperature for pressure adjustment. The following readings should be taken and recorded on the log sheet every 15 minutes during the running-in period:

Time.

Tachometer indicated speed.

Torque load.

Water temperatures, in and out.

Oil temperatures, in and out.

Oil pressure.

Carburetor air temperature.

3. *Idling run.*—For the idling run the throttles should be set so that the engine fires uniformly with fully advanced spark at not more than 350 revolutions per minute. (If the engine is tested at a dynamometer the brake load should not exceed 20 pounds.) The idling run is of 15 minutes duration. Every 5 minutes readings should be made of counter, indicated revolutions per minute, water and oil temperatures, oil pressure, fuel scales, and carburetor air temperature. Record should be made of the cylinders "missing" during the run and of the number and location of plugs cleaned or replaced after the run. The engine should be run at full throttle at the end of the idling run and its behavior noted. The whole purpose of the idling run is to detect overoiling and plug-fouling

## FREE OIL PUMP TEST

The capacities of the oil pumps with free inlet and outlet are determined in the accessories laboratory. For this test also the inlet oil temperature is maintained at 120° F. The pump is connected to a small dynamometer and the capacity determined at speeds corresponding to engine speeds covered in the full-power run—400 revolutions per minute below to 200 revolutions per minute above normal speed. Readings are taken at 200 revolutions per minute increments throughout that range. Separate tests are made of the pressure and scavenging pumps.

The following readings are taken at each speed:

- Pump speed.
- Brake load.
- Oil temperature at discharge.
- Pump suction head.
- Pump discharge head.
- Pump capacity, determined by weighing the oil discharged.
- Oil specific gravity at test temperature.

Record should be made of complete physical properties of the oil used in this test.

A determination is also made of the maximum suction head against which a dry pump will operate at normal speed.

## SPARK PLUG TESTS

Standard spark plug tests are described in Air Service Specification No. 28017-B, dated April 12, 1922.

## THE 50-HOUR ENDURANCE TEST

The 50-hour endurance test here described is conducted to obtain comparative endurance information on aviation engines. While it does not at all compare in severity with the endurance runs frequently applied to measure the durability of aircraft engines, it is believed to be sufficiently rigid to represent several times its duration in actual service and therefore a fair measure of the serviceability of the engine.

*Engine calibration.*—Before undergoing 50-hour endurance test every engine must be calibrated by the electric dynamometer. The calibration should consist of one full-power run (full rich and best mixture control setting) and one friction horsepower run. Conditioned carburetor intake air must be provided. The results thus obtained should not fall any considerable amount below the average performance for the engine under test unless such a divergence can be accounted for in special equipment or adjustment. During calibration runs the engine should be carefully inspected for leaks or other indications of improper assembly or adjustment. If the calibration results are satisfactory and no unsatisfactory behavior develops, the engine may be approved for the endurance test. If, however, the performance or general behavior of the engine is unsatisfactory or defects develop, repairs must be made and the dynamometer calibration rerun. Before removing the engine from the dynamometer the compression in

each cylinder should be tested by motoring the engine slowly and listening for leaks.

*Preliminary adjustments.*—With the engine mounted on the test stand the following preliminary adjustments should be made:

- (a) The engine should be thoroughly cleaned externally and spark plugs cleaned and reset if necessary.
- (b) The propeller should be fitted to its hub and balanced and tracked. The hub should then be installed on the shaft following the procedure described by Air Corps or manufacturer's instructions.
- (c) The torque stand if used should be carefully balanced so that it will remain in any position and so adjusted that a weight of 10 pounds on either bearer will tip it against the stops.
- (d) The torque scales, fuel and oil scales should be carefully checked.
- (e) The control installation should be thoroughly inspected to be sure that the linkage allows them to cover their full range.

*Starting.*—Before starting the engine the lubrication system should be filled with warm oil. The start should be made following as closely as possible the manner of starting engines in service. Any starting difficulties should be noted on the log sheet.

*Warming up.*—Previous to each run the engine should be warmed up at less than 1,000 revolutions per minute until the oil temperature has reached 100° F. The warming-up period in no case should be less than 10 minutes.

*Preliminary observation.*—Before starting the first test period the following observations and adjustments should be made and recorded on the log sheet:

- (a) *Oil pressure.*—The full-throttle and idling oil pressures should conform with Air Corps or manufacturers' specification.
- (b) *Idling.*—Carburetors should be adjusted so that the engine idles uniformly at not over 400 revolutions per minute. The lowest uniform idling speed should be recorded on the log sheet.
- (c) *Ignition.*—The synchronization of breakers and condition of spark plugs should be checked by firing the engine at full throttle on single switches and noting the comparative speeds and the regularity of firing. The full-throttle engine speed on single switches should be not less than 98 per cent of the speed on all switches.
- (d) *Acceleration.*—Note the smoothness of acceleration with gradual and rapid throttle opening, and note on the log sheet the nature of any irregularities and the speed at which they occur.
- (e) *Full-throttle speed.*—The full-throttle speed of the engine should not differ by more than 2 per cent from the specified endurance test speed. If full-throttle tests show a greater divergence, propeller modifications should be made to compensate. Such tests should be made on a fairly quiet day so that wind may not affect the engine speed. The propeller must be rebalanced after the adjustments have been made.
- (f) *Propeller hub.*—After the preliminary running has been completed the propeller-hub bolts should be inspected and tightened if necessary.

## FIFTY-HOUR TEST

The 50-hour test is composed of ten 5-hour periods, each period consisting of one-half hour at full throttle and  $4\frac{1}{2}$  hours at 90 per cent power (97 per cent of normal speed). The last hour of the last 5-hour period, however, should be run at full throttle. At full throttle the spark and mixture control should be set at "best" position and left in that position for the remainder of the period. Only the throttle should be adjusted to reduce the load for the  $4\frac{1}{2}$  hours at 90 per cent power.

The engine should be stopped during the 5-hour period only in emergency, or if it becomes impossible to maintain 97 per cent of normal speed. All stops except emergency stops should be made by throttling the engine and shutting off the fuel supply. The causes of all stops except those at the completion of the 5-hour periods should be noted on the log sheet. A 5-hour period must be rerun if a stop occurs before two hours of the period have been completed. Any period requiring more than two forced stops must also be rerun. The test should be discontinued if repetition of more than three 5-hour periods is required.

At the end of each 5-hour period the following items should be carefully checked:

- Compression in each cylinder.
- Propeller-hub nuts.
- Propeller-flange bolts.
- Manifold connections to cylinders and carburetor.
- Cylinder hold-down nuts.
- Fuel, oil, and water fittings and lines.
- Ignition connections.
- Breaker points.
- Distributors.

At the end of each 10 hours of running the oil should be completely drained from the system and fresh oil put in. At such times the oil screens should be examined for foreign matter by which engine failure might be anticipated.

*Test readings.*—Every 15 minutes during the 50-hour test the following readings should be taken:

- Time, by stop watch.
- Revolution counter reading. This reading should be taken at exactly 15-minute intervals by stop watch.
- Torque load.
- Cooling water temperature, in and out.
- Cylinder head temperature, for tests of air-cooled engines.
- Oil temperatures, in and out.
- Oil pressure.
- Air temperature.
- Fuel scales. These readings must be taken at exactly 15-minute intervals.
- Oil scales. These readings must be taken at exactly 15-minute intervals. (NOTE.—When it becomes necessary to add fuel or oil, the exact weight added and the time of addition should be recorded on the log sheet.)
- The barometric pressure should be recorded every hour.

Once during each period a record must be made of the fuel specific gravity.

During the 50-hour test notes should be made on the log sheet of all indications of unsatisfactory behavior of the engine, including comments relative to vibration, leakage, mixture distribution, valve temperatures speed variation, ignition, carburetion, etc.

## PROCEDURE AFTER TEST

At the completion of the last 5-hour period the usual inspection should be made and the engine returned to the dynamometer for another calibration. The method of calibration after test should be identical with that before test.

## THE CARBURETION RUN

The carburetion run is made to obtain complete performance information on the carburetor engine combination. This test is applicable only to carburetors which have been fully developed to a point where they are thought suitable for use in service. The setting for the carburetor must be obtained before the beginning of this run and a record made of the flow of the carburetor jets. For preliminary determinations of setting, mixture-control orifices, etc., less formal tests will be made.

All runs should be made with conditioned intake air, except where specific instructions to the contrary are issued. The following readings should be taken in addition to the standard power and fuel consumption readings:

- Vacuum at *throat* of carburetor Venturi in inches of water when possible.
- Intake manifold vacuum, inches of mercury.
- Carburetor float chamber vacuum, inches of water.
- Position of throttle lever on carburetor.
- Position of mixture-control lever on carburetor.

The position of the throttle lever will be read on a graduated sector. It is preferable that this sector be attached to the carburetor itself so that direct readings of the throttle movement are obtained. However, this is not essential, and where time and labor can be saved the readings may be made on a sector attached to the control board. Sector readings for full, open, and closed throttle should be recorded.

The position of the mixture control-valve will be read on a sector, preferably of metal, attached directly to the carburetor itself. The sector should be graduated in degrees or have 10 equal angular graduations covering the range of the control, and the readings should be made from a pointer attached directly to the mixture-control valve in the carburetor.

The following group of runs will then be made (care being taken that there are no duplications of runs previously made during the test on hand). In many cases where the carburetion run is a part of a general test, some of the propeller load and full throttle runs will be made prior to the carburetion run, and these should not be duplicated.

(a) *Idling adjustment.*—Adjust the idling so the engine will fire uniformly on all cylinders at 300 revolutions per minute propeller load.

(b) *Run to locate "flat spots."*—Run the engine at every 100 revolutions per minute from idling to full throttle on propeller load. Note all speeds at which the engine operation is not satisfactory and describe its behavior at each of these speeds. Make minor changes, if possible, to correct these conditions.

(c) *Acceleration run.*—Compare the acceleration from idling with that of similar engine-carburetor combinations on the type of test stand used, keeping the operating conditions as nearly identical as possible. The accelerating qualities of the carburetor should be noted with the cooling water both warm and cold and record made on the log sheet.

(d) *Full-power run.*—Make two full-power runs, taking readings at 100 revolutions per minute increments from 400 revolutions per minute below normal speed to 200 revolutions per minute above normal speed. These runs will be made with the mixture control in the "full rich" and "best setting" positions. They are better made together—that is, at each speed take readings with the control in the full rich position, then shift control to the best setting position and take readings. The control should always be brought back to the full rich position when changing from one speed to another. Great care should be taken in adjusting the mixture control, for if this is not done the maximum efficiency becomes a function of chance rather than being a true indication of the carburetor-engine efficiency. Different types of controls show different characteristics, and the type on the carburetor tested should be studied in advance. Some controls show a definite lag in their response to the mixture control adjustment, so that to obtain the best setting it may be necessary to make a second adjustment, after conditions have balanced, before readings are taken. (For general instructions as to making full-power runs, see p. 3.)

(e) *Propeller load (standard).*—(For general instructions as to making propeller-load runs, see p. 4. These instructions are to be modified as indicated below.)

Take a standard propeller load run with readings at 200 revolutions per minute increments from normal speed to 800 revolutions per minute below normal speed. The mixture control should be set at best setting at normal speed and clamped there for the remainder of the run.

(f) *Propeller load (full rich and best setting).*—Take a propeller-load run at 200 revolutions per minute increments from normal speed to 800 revolutions per minute below normal speed, making all major speed and load settings at full rich and best setting mixture control positions.

Following is the test procedure:

At full rich mixture control setting, normal speed, a full set of standard readings should be taken. The brake load recorded at this condition will be the basis for computing the brake loads for other speeds.

The mixture control will be adjusted to the best setting, the speed adjusted to normal speed by manipulation of the field resistance of the dynamometer, and another full set of standard readings taken.

The mixture control must next be restored to full rich position before the speed is reduced for the following set of readings.

The engine output should be reduced by the throttle to propeller-load operation (from full rich normal speed) and the throttle clamped in position for all readings at this reduced speed.

With the throttle still clamped, the mixture control will be adjusted to the best setting, and any variations in speed which occur due to power change will be rectified by use of the dynamometer field resistance. A full set of standard readings, including those listed on page 9, will be taken with this setting of the mixture control.

This same procedure will be followed at the next lower speed, etc. This will give two sets of readings constituting data for two curves—

(1) A curve of horsepower and fuel consumption on propeller load with the mixture control set full rich.

(2) A curve of horsepower and fuel consumption with the same throttle openings at each speed as on the first curve, but with the mixture control adjusted for the best fuel consumption consistent with maintenance of the desired power.

(g) *Mixture control run.*—Bring engine to full throttle normal speed with the mixture control in the full rich position. Take a set of readings. Move mixture control to second position on quadrant, adjust speed to normal with dynamometer resistance, and take set of readings. Move mixture control to third position and repeat. Repeat this procedure, moving mixture control one increment each time until either the readings have been obtained for the total 10 increments of mixture-control movement or the engine functions so poorly as to make readings impossible.

(h) *Maximum and minimum fuel heads.*—(For instructions for making this run, see below.)

## THE CARBURETOR HEAD TEST

The object of the carburetor head test is to determine the effect on brake horsepower and specific fuel consumption of variations of fuel head at the carburetor and to discover the minimum fuel head at which a carburetor may safely be operated in an airplane.

Fuel should be supplied from a closed tank with airline connections for pressure variation. A vent valve on the tank will make possible fine adjustments of pressure. The rate of fuel consumption may be determined by means of a special volume gauge constructed for this purpose. For this run conditioned air should be supplied to the carburetors.

Unless it already has been definitely determined, the static flooding head will be determined on the bench with several carburetors of the type under test.

With the carburetor on the engine, the engine running at full throttle, normal speed, *mixture control full rich*, the fuel head will be lowered very slowly from about 3 pounds per square inch until the power drops. At the lowest fuel head at which the engine operates smoothly enough to permit readings, standard power and fuel consumption readings should be taken. The fuel pressure should then be raised to the point

at which definite power drop began and standard readings taken. It is important that these points be so placed that the nature of the power-fuel head curve at this end is clearly defined. If necessary, several closely grouped points should be selected for additional readings to locate the curve of power drop. Power and fuel consumption readings should be taken at three equally spaced points between the point of power drop and the static flooding point and also at the static flooding point. The exact fuel head at the carburetor inlet should be recorded for each condition. The engine should be allowed to run long enough at each point to insure uniform operation.

The minimum operating head will be considered that point at which the fuel consumption begins to drop rapidly indicating a metering in the fuel line rather than in the carburetor.

### STANDARD CARBURETOR FLIGHT TEST

The object of the standard carburetor flight test is to observe the operation of a carburetor under service conditions, particularly with regard to the following features:

- (a) Altitude control.
- (b) Acceleration.
- (c) Action during maneuvers.

The test should be conducted as follows:

(a) The carburetor should be tested in an airplane with a fairly high ceiling. The mixture control lever quadrant will be graduated in 10 divisions, numbered from 1 to 10, starting from the full rich position of the control. The only special instrument required for this test will be a barograph.

(b) Warm up engine on ground and try acceleration from lowest idling speed to full throttle, both with a quick and slow throttle opening. Run engine for a moment at every 100 revolutions per minute from idling to full throttle, noting carefully the smoothness of operation. The pilot's remarks on acceleration and general operation on the ground should be noted on the log sheet.

(c) Climb to service ceiling, keeping mixture control in the leanest possible position for maximum revolutions per minute. Take readings of the position of the mixture control lever on the quadrant every 2,000 feet. Note on log sheet pilot's observations on operation of carburetor during climb.

(d) At service ceiling fly level <sup>1</sup> at full throttle and take the following reading:

At best setting of mixture control—air speed, engine revolutions per minute, and position of control lever.

At full-rich setting—air speed, engine revolutions per minute, and position of control lever.

At full-lean setting—air speed, engine revolutions per minute, and position of control lever.

(e) Repeat the level flights required under (d) 15,000, 10,000, and 5,000 feet altitude.

(f) At several altitudes, including about 15,000 feet, 10,000 feet, and 5,000 feet, make the following tests and note pilot's observations on log sheet:

- (1) Acceleration after a long glide with engine cold.
- (2) Action of carburetor during service maneuvers, especially steep angles of climbing, diving, and side-slipping.

### INSTRUCTIONS FOR PREPARING LOG SHEETS

The following instructions have been prepared with the purpose of making more valuable the original log sheet test data both by making the records complete and by establishing a uniformity of procedure which will make such data intelligible to others. In the past such test records have frequently been made with no thought beyond immediate convenience, and there are consequently in the files numerous log sheets which are meaningless to anyone except the engineer who conducted the test—often unintelligible even to him—simply because the entries are badly confused or the conditions of test are not completely described.

Supply all the information required on the sheet. It is all necessary to properly identify the test. Only such information as obviously does not apply may be omitted. For instance, the throttle and mixture control limits (lower left corner) are needed only when the throttle and mixture control positions are recorded in the data by their positions on graduated sectors.

All miscellaneous information called for on the log sheet must be filled in *before* the test is started. If several runs are to be made in rapid succession without interval for preparation of additional sheets a sufficient number of sheets should be prepared before the runs are started so that each run may be recorded on a separate sheet.

Each test run shall be recorded on a separate log sheet so that there may be no confusion as to the particular conditions of each run. A "run" consists of a set of readings taken with a given test set-up and under specific test conditions. If the set-up is changed (new carburetors, spark plugs, fuel, etc.) or adjustments made (such as carburetor setting changes) a new run shall be considered started and a new log sheet used.

To identify the run the title, as it is to appear in the final report, shall be written clearly in the space marked "number and title of run." The title should be as complete as possible. For example, "propeller load run" is meaningless. "Propeller load run, standard equipment" or "propeller load run, ED-52 carburetors" is more specific and clearly identifies the run.

In the space for "Remarks" (lower right corner) notation shall be made of special conditions making the run necessary, such as "Carburetor main jets increased in attempt to get more power" or "Spark plugs changed from Mosler M-1 to B. G. 1-XB to eliminate detonation." All special equipment also should be listed in that space so as to positively identify it. For example, "7,500-foot supercharger" is insufficient to definitely identify the supercharger

<sup>1</sup> It is important that a constant angle of attack be maintained during "level" flights, even if the altitude changes slightly. Fly by horizon rather than by altimeter.

equipment but "G. E. Form G 7,500-foot geared supercharger" applies to only one particular design and will not be confused with other superchargers that may appear later.

All runs must be numbered and the log sheet must bear the number of the run it records. Every test log must be filed with the original data for the test even though its data be worthless. If for any reason the data on any sheet is erroneous the sheet should be marked "Reject" and the reason for rejection given, but it should in no case be destroyed.

Remember that the log sheet is not a personal record but is to be filed as original data for the test and so must be in such form that it will be intelligible to anyone. Therefore, avoid uncommon abbreviations, supply all the information needed to completely identify the test and apparatus, write legibly, see that the engineer's and crew chiefs' names are recorded, and mention all unusual circumstances likely to influence the accuracy of the results.

### FORMULÆ AND CALCULATIONS

In the formulæ and calculations on pages 12 and 13 the following symbols are used:

$A$  = piston area in square inches.

$a$  = area of valve opening in square inches.

$B$  = cylinder bore in inches.

$b$  = barometric pressure in inches of mercury.

$BHP$  = actual brake horsepower.

$BMEP$  = brake mean effective pressure in pounds per square inch (corrected to sea level).

$C$  =  $BMEP$  constant ( $BMEP = C \times$  corrected brake load).

$D$  = total piston displacement in cubic inches.

$d$  = clear diameter of valve port in inches.

$E$  = mechanical efficiency in per cent.

$FC$  = hourly fuel consumption, pounds per hour.

$FHP$  = friction horsepower.

$FMEP$  = friction mean effective pressure, pounds per square inch.

$h$  = maximum valve lift in inches.

$HP$  = brake horsepower corrected to sea level.

$IHP$  = indicated horsepower ( $FHP + HP$ ).

$IMEP$  = indicated mean effective pressure -  $BMEP + FMEP$  in pounds per square inch.

$K$  = brake constant for dynamometer.

5252 for 12-inch arm.

4000 for 15 $\frac{3}{4}$ -inch arm.

3000 for 21-inch arm.

1300 for 48 $\frac{1}{2}$ -inch arm.

1000 for 63.025-inch arm.

$L$  = length of stroke in inches.

$l$  = length of brake arm in inches.

$N$  = engine speed - crank-shaft revolutions per minute.

$R$  = gear ratio  $\frac{\text{Propeller speed}}{\text{Engine speed}}$

$S$  = fuel specific gravity.

$SFC$  = specific fuel consumption - pounds per horsepower hour.

$t$  = time in seconds for fuel reading.

$W$  = brake load in pounds.

$w$  = weight of fuel in pounds.

$\pi$  = 3.1416.

$\theta$  = angle of valve seat in degrees.

### HORSEPOWER

Dynamometer horsepower is computed from the load, the brake circle circumference, and the engine speed.

$$BHP = W \times \frac{2\pi l}{12} \times \frac{N}{33000} = \frac{W \times N}{K} \quad (\text{for direct drive})$$

where

$$K = \frac{12 \times 33000}{2\pi l} = \frac{198000}{\pi l}$$

With a geared engine the dynamometer speed is  $R$  times the engine speed, therefore

$$BHP = \frac{W \times N \times R}{K} \quad (\text{for geared engine})$$

Since the horsepower varies approximately as the barometric pressure, the sea level horsepower can be computed by the formula:

$$\text{Corrected } BHP = \frac{BHP \times 29.92}{b}$$

When correcting for variations in carburetor air temperature it is assumed that the power varies inversely as the square root of absolute temperature. The following formula, therefore, gives the brake horsepower corrected to a standard temperature of 60° F. (520° F. absolute):

$$BHP (60^\circ \text{ F.}) = \text{Observed } BHP \sqrt{\frac{460 + T}{520}}$$

where  $T$  is the observed carburetor air temperature in °F.

Friction horsepower computed from dynamometer load is

$$FHP = \frac{W \times N}{K} \quad (\text{for direct drive engines})$$

$$FHP = \frac{W \times N \times R}{K} \quad (\text{for geared engines})$$

$$IHP = FHP + HP$$

Mechanical efficiency is the ratio in per cent of power delivered to power developed, or

$$E = \frac{HP \times 100}{IHP} = \frac{HP \times 100}{HP + FHP}$$

The brake mean effective pressure may be determined from the horsepower by the plan formula or from the dynamometer brake load by means of the  $BMEP$  constant.

$$HP = \frac{BMEP \times L \times A \times N}{12 \times 33000 \times 2}$$

or

$$HP = \frac{BMEP \times D \times N}{792000}$$

therefore

$$BMEP = \frac{HP \times 792000}{D \times N}$$

But since  $H P = \frac{W \times N \times 29.92}{K \times b}$  and since  $D$  is constant for a given engine, then,

$$BMEP = \frac{W \times 29.92 \times 792000}{K \times b \times D}$$

or

$$BMEP = \frac{WC}{b} \frac{29.92}{D}$$

where

$$C = \frac{792000}{K \times D}$$

The friction mean effective pressure,  $FMEP$ , can be determined similarly from the  $FHP$  or friction load. No correction for barometric pressure, however, is applied.

The hourly fuel consumption by weight can be simply determined by calculating the hourly flow from the time of reading in seconds; thus—

$$FC = \frac{w \times 3600}{t}$$

When the fuel is measured by the volumetric apparatus calibrated with fuel of 0.710 specific gravity the true  $w$  is obtained by multiplying the observed weight  $w'$  by the correction factor  $\frac{S}{0.710}$  thus

$$FC = \frac{3600 w'}{t} \times \frac{S}{0.710}$$

Specific fuel consumption is the fuel consumption per BHP per hour; therefore:

$$SFC = \frac{FC}{BHP} = \frac{w \times 3600}{t \times BHP} = \frac{w \times 3600}{t \times BHP} \times \frac{S}{0.710}$$

The area of valve opening is most accurately determined graphically and should be done so whenever possible. If that method can not be used, however, the area may be determined approximately by the following formulæ:

$$a = \pi (dh \cos \theta + h^2 \cos^2 \theta \sin \theta)$$

For 45° valve seats

$$a = \pi (0.707 dh + 0.353 h^2)$$

For 30° valve seats

$$a = \pi (0.866 dh + 0.375 h^2)$$

## INSTRUCTIONS FOR THE PREPARATION OF REPORTS

Four general types of reports are written in the laboratory:

- Memorandum report.
- Project record.
- Standard serial report.
- Standard engine report.

(a) The memorandum report is a brief report written in the form of a memorandum to the Chief of the Power Plant Section. It ordinarily covers the results of a minor investigation, the outcome of which is not of sufficient interest to warrant general publication, or of a major investigation terminated prematurely by

failure of test apparatus or other cause and without sufficient data to form a basis for a more complete report. It is used also as a preliminary report on some prolonged investigation, the progress of which should be reported to the chief of the section periodically.

The memorandum report is divided into numbered paragraphs and treats the material of the report in the following order:

- Object of test.
- Summary of results (briefly).
- General conclusions (briefly).
- Introductory paragraph—a description of conditions making the investigation desirable.
- Test material and apparatus—a description of the devices tested or studied, together with any uncommon apparatus employed.
- Method of test—general methods employed in conducting the investigation.
- Description of test—history of investigation with difficulties encountered, reasons for delays, changes of equipment or methods, etc.
- General results and conclusions—general analysis of results and conclusions drawn therefrom.
- Recommendations—future procedure recommended as result of this investigation.
- Data and illustrations.

In general, the above outline should be followed in the preparation of memorandum reports. If the report is very brief, however, it may be limited to several paragraphs, stating the object of the test, general results, and conclusions. The form must be flexible, to be set largely by the judgment of the engineer and decided, in case of doubt, by the chief of the laboratory. Only such data should be included as are necessary to clarify the text. Data in the form of curves should be used as frequently as possible.

(b) The project record is the standard form of development record in use at the Engineering Division. It is written to cover extended developments and should be used in connection with short investigations only when such investigations are closely involved with some general development to which a project number has been assigned. The form of the project record is that of a daily log. General instructions for the maintenance of project records are given in Administrative Circular No. 8. The following specific instructions are added for the preparation of project records in the power-plant laboratory:

(1) During the active period of a development the project record must be kept up to date by adding entries not less frequently than every three days. When the development becomes sufficiently inactive to make such frequent entries inadvisable, such a note should be made at the entry terminating the active period.

(2) If for any reason the development is temporarily interrupted or permitted to lapse, the project record should contain a note to that effect explaining the reason for the interruption.

(3) At the end of each phase of the development the project record should be summarized by a general discussion of the results of that phase. This summary should be written as an explanation of the work to

date. The reason for the various runs should be stated and the curves or tabulated data used to confirm the conclusions as stated. The engineer should have the point of view of taking stock of what has been accomplished so far in the test in order to determine what is the next logical step.

(4) The project record is divided into four sections indicated by the method of page numbering employed. The text pages are numbered with plain numbers, the data pages with D numbers (D1, D2, D3, etc.), the

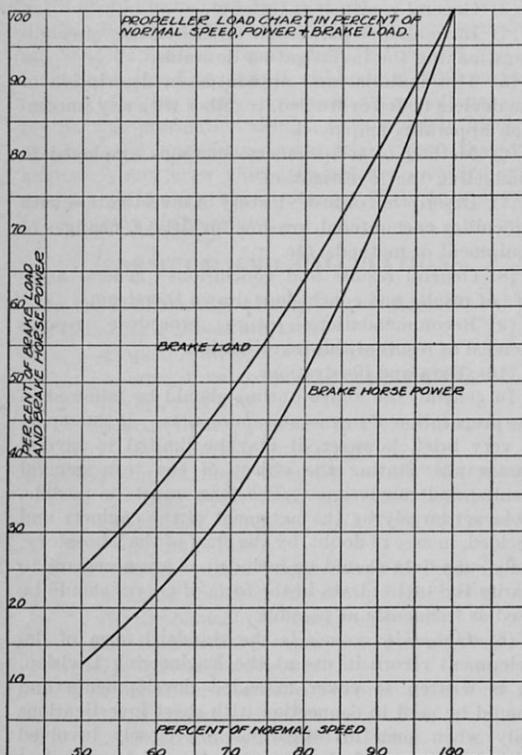


FIG. 1.

curve pages with C numbers (C1, C2, C3, etc.), and the illustration pages with I numbers (I1, I2, I3, etc.).

(5) The project record is typed on "Notear" paper with three carbon copies on plain white paper. The original and one copy are sent to the section chief, one copy goes to the laboratory files and one is retained by the engineer conducting the investigation. The original copy shall be initialed by the engineer over his typed signature.

(6) The data included in the project record should be limited to curves and simple tables. The project record is primarily a prompt report of events rather than a complete record of details, which should be recorded on the original test log sheets. The writer should bear in mind that the project record is written for the information of others and hence should give the reason for the work being done as well as the results.

(7) Whenever possible, typographical corrections should be made by pen to reduce retyping and to get the record out promptly.

(8) The project record is not the last word in reporting projects, and the engineer's duties are not fulfilled until serial reports are prepared summarizing the development, either as a whole or in its separate phases. The project record rarely gets beyond the section chief, and all projects worthy of greater publicity, therefore, must be written up in a serial report.

(c) *The standard serial report* is the form used to report the results of completed projects or investigations. It is prepared in form for blue printing, typed on black-bordered vellum (Form 288) with curves plotted on cross-section tracing cloth (Form 291).

In general form the standard serial report resembles the memorandum report, but its contents are more complete. The following outline should be followed in the preparation of the standard serial report:

(1) *Title page.*—Title of test, number of pages, date, and signature of section chief and engineer conducting test.

(2) *Index.*—When contents exceeds 15 pages.

(3) *Object of test.*—One sentence stating briefly the purpose of the investigation.

(4) *Summary of results.*—Table or brief statement of results.

(5) *Conclusions.*—Brief statement of general conclusions and recommendations.

(6) *Introduction.*—A discussion of the conditions which have made the investigation desirable, with a description of previous work in the same connection and a more complete statement of the purposes of the investigation.

(7) *Description.*—Complete description with reference to illustrations of material tested and of any uncommon apparatus used for the test.

(8) *Method of test.*—Outline of general method of test procedure, including runs made, fuel used, oil used, and detailed description of any test procedure not described in laboratory instructions.

(9) *Record of test.*—A story of the test with difficulties encountered, remedies employed, sources of possible error, and general discussion of results with reference to curves and data pages.

(10) *Conclusions.*—Complete statement of conclusions based on results described in the previous paragraph.

(11) *Recommendations.*—When the paragraphs on conclusions do not make the recommendations obvious, suggest here further investigations desirable or immediate action warranted by the results of this investigation.

(12) *Bibliography.*—List of Engineering Division reports and other references bearing on the subject.

(13) *Illustrations.*—For convenience in assembling and handling, the illustrations are placed near the end of the report.

(14) *Curves and data pages.*—These pages should include all data useful in clarifying the text. Make data graphic whenever possible to simplify reference.

*d. The standard engine report* covers the results of the standard engine test. It is completely described in "Instructions for Conducting Standard Engine Tests and Preparing Standard Engine Reports," Engineering Division Report, Serial No. 1506.











