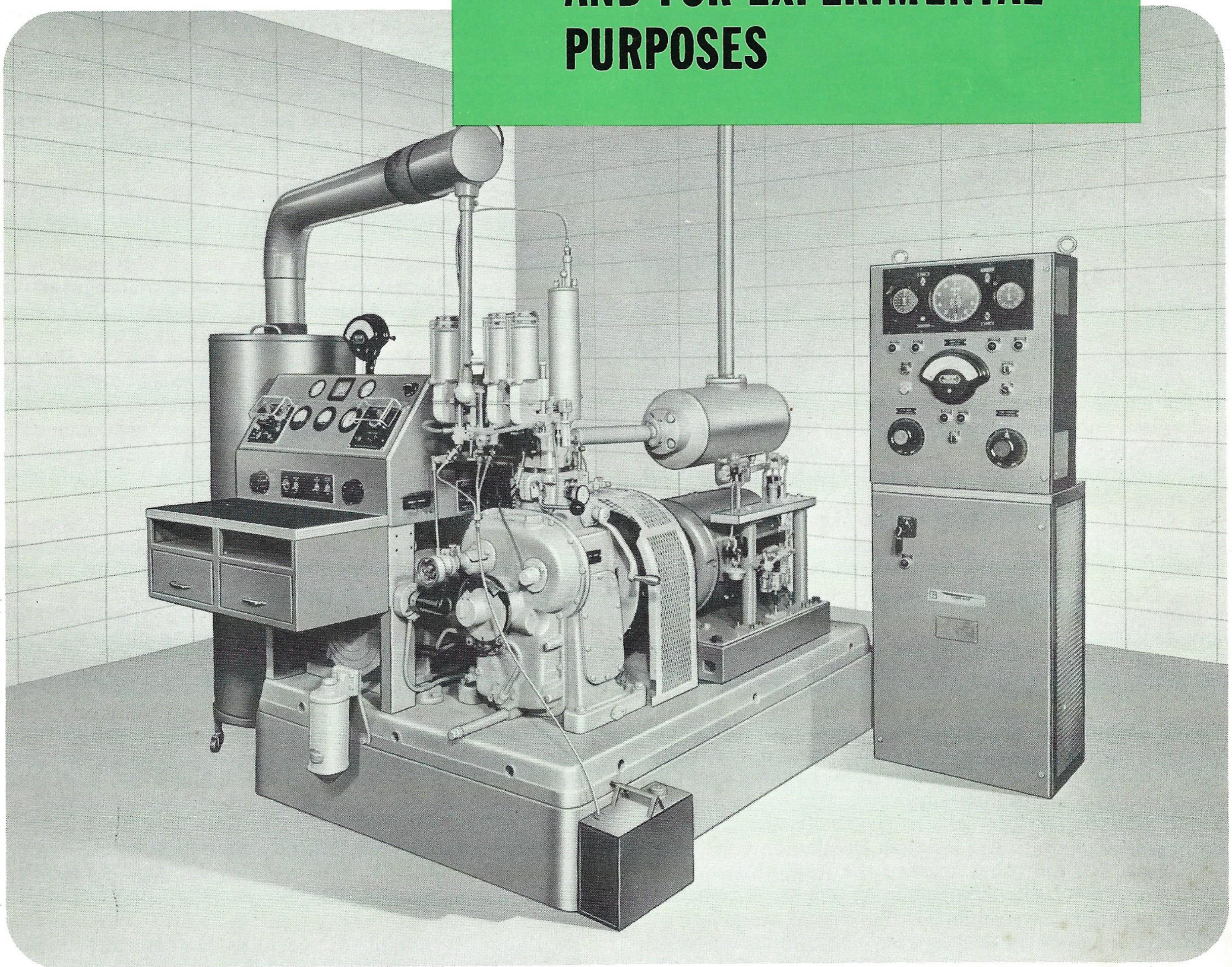
BULLETIN 850M

Waukesha laboratory engines

FOR RATING GASOLINE AND DIESEL FUELS AND FOR EXPERIMENTAL PURPOSES



General recognition of the interdependence of engine performance on compression ratio and fuel anti-knock property, as taught by Ricardo, prepared the way for a co-operative development by the major fuel and engine producers. With the advent of modern cracking processes, the wide range of anti-knock quality existing in motor fuels was generally recognized, and this emphasized the necessity for a standard test-method. In 1928, a far-sighted group of fuel producers and engine manufacturers, who had formed the Co-operative Fuel Research Committee, assigned the problem of developing a test method and equipment for knock rating to a group of petroleum and engine technologists designated as the Detonation Sub-Committee of the Co-operative Fuel Research Committee.

At the first meeting of this group it was determined that there were three basic items essential to the pursuit of a comprehensive motor fuel research: (1) A standardized engine and accessories; (2) A common reference fuel and rating scale; (3) A uniform testing procedure. By 1931, all three had become realities. Waukesha Motor Company had developed a fuel testing engine meeting the approval of the Co-operative Fuel Research Committee; Dr. Graham Edgar of the Ethyl Gasoline Corporation had suggested Iso-Octane and Normal Heptane, both stable hydrocarbons, as reference fuels, and these were made commercially obtainable; a rating scale based on these two reference fuels was adopted; and a uniform test procedure was tentatively approved.

MOTOR FUEL TESTING...
a review

In 1932, a correlation of laboratory knock ratings with the behavior of motor fuels in field service was undertaken. Road tests at Uniontown, Pennsylvania, and subsequent correlation at the Waukesha Motor Laboratories brought about modification and improvement of the standard testing unit and its operating technique. This improved test method was named the "CFR Motor Method" and adopted as the standard; but the older "Laboratory Method" was not discarded, since it had proved valuable from the experimental standpoint in measuring a fuel's sensitivity to operating conditions. It was retained under the name "CFR Research Method."

Additional road checks were made in 1934, also held at Uniontown, with nearly twice as many motor car builders participating as in the first program. These tests still further substantiated and confirmed the findings of the 1932 tests.

To maintain the greatest possible degree of accuracy, a group of the Co-operative Fuel Research (CFR) member laboratories originally, and now ASTM, conducts co-operative tests each month. Results are tabulated and circulated so that each of the co-operating laboratories may compare its results with the entire group's average. The Research Division 1 of the ASTM Committee D2, which has assumed the work of the original CFR group, with the co-operation of the U. S. Bureau of Standards, is working continually on research projects to improve the knock rating technique. This continuous development program insures the maintenance of accuracy in the CFR unit as well as in the testing technique, and the improvements developed in both equipment and test methods are made continuously available to CFR engine owners.

The proved reproducibility of results by the CFR method has caused its acceptance and recognition as the industry's yardstick for gasoline motor fuel rating. Approval by the American Society for Testing Materials resulted in its receiving ASTM designation D-357.

In addition to the ASTM approval, this Standard Method of Test for Knock Characteristics of Motor Fuels by the Motor Method is approved as American Standard by the American Standards Association.

In 1940 the CFR Aviation Method 1-C (now F-3) was developed to meet the needs for an aviation fuel test method for gasolines up to 100 octane. It was run at 1200 rpm engine speed, and a thermal plug connected to a potentiometer was used as a means of measuring knock intensity. This method was adopted by the ASTM in 1941 as a "Tentative Method of Test for Knock Characteristics of Aviation Gasoline (D-614-T)."

In 1941 the CFR Supercharge Aviation Gasoline Test Method 3-C, (now F-4) was developed for rating high output aviation gasoline above 100 octane for the military services. This method was run with the engine speed at 1800 rpm, a dynamometer was employed for power measurement, and an inlet air flow meter and a fuel weighing device for fuel-air ratio determination was included. The development of this unit and its method was given the highest war priority, and production of the units was scheduled to keep step with the construction of refineries for fighting grade aviation gasoline. The entire production of fighting grade gasoline for the Allies in World War II was controlled on the CFR 3-C, (now F-4) unit. This method was adopted by ASTM in 1947 as a "Tentative Method of Test for Knock Characteristics of Aviation Fuels by the Supercharge Method (D-909-T)."

In 1942 the Co-operative Research Council was organized to sponsor the CFR activity. The name was later changed to Co-ordinating Research Council (CRC). Designations of the old CFR Methods were given a new numbering system.

In 1947 the Co-ordinating Research Council (CRC) transferred all fuel test method activities to ASTM Committee D-2 on Petroleum Products, Research Division 1, on Combustion Characteristics. All co-operative committee activities on fuel test method research and development are now conducted under ASTM sponsorship.

In 1947 the use of the old Research Method had become so widespread as a measure of fuel sensitivity, and also by refiners for manufacturing control of passenger car gasoline, that ASTM published it for information, and in 1951, after some revision, it was adopted as "Standard Method of Test for Knock Characteristics of Motor Fuels by the Research Method (ASTM-D-908)." This method has now been approved as American Standard by the American Standards Association.

In 1964, ASTM adopted two new methods for rating fuels above 100 octane. Method D-1656 was used for rating fuels above 100 octane number by the Research Method. Method D-1948 was used for rating fuels above 100 octane number by the Motor Method. The two formerly adopted methods D-908 and D-357 still remained for rating fuels below 100 octane number.

In 1968, ASTM combined the above and below versions of each method into single methods. The new method, D-2699 is a combination of Research Methods D-908 and D-1656. The new method D-2700 is a combination of Motor Methods D-357 and D-1948. Also, a new method D-2623 was adopted for the rating of Liquified Petroleum (LP) Gases by the Motor (LP) Method.

Test Unit and Method Designation

Former CFR	Former CRC	Present ASTM
Research Method 1939	F-1	D2699
Motor Method	F-2	D2700
Aviation Method (1-C)	F-3	D-614-T
Supercharge Aviation Method (3-C)	F-4	D-909-T
Diesel Cetane Method	F-5	D-613
Motor L. P. Method	None	D2623

DIESEL FUEL TESTING

The importance and need for a method and apparatus for testing the ignition quality of diesel fuels was brought about principally by two factors.

First, was the growth in importance of the Diesel engine and the resulting increase in use of diesel fuels. Second, and more important, was the change in quality of available diesel fuels — due to the changes in the refinery cracking processes. This change took straight run gas oils off the market, and replaced them with cracked fuels, many of which were unsuitable for use in diesel engines.

With the world-wide recognition of new needs, independent researches were begun in various laboratories. Among the foremost of the original methods were those proposed by: (1) R. Stansfield and L. J. LeMesurier of the Anglo-Persian Oil Company (now Anglo-Iranian Oil Company) in England, (2) G. D. Boerlage and J. J. Broeze of the Royal Dutch Shell Company in Holland, and (3) A. W. Pope Jr., and J. A. Murdock of the Waukesha Motor Company in the United States. The two European investigations were directed toward measuring the actual ignition delay in a running engine, whereas the Waukesha Motor Company method was designed to measure the ignition quality by determining the critical compression ratio necessary to ignite the fuel in an engine.

The need for a reproducible pure hydrocarbon as a standard reference fuel was apparent from the start. Cetene and Alpha-methylnaphthalene were established as the high and low reference fuels respectively, principally through the efforts of J. J. Boerlage of the Royal Dutch Shell Company who also made these fuels available for other laboratories.

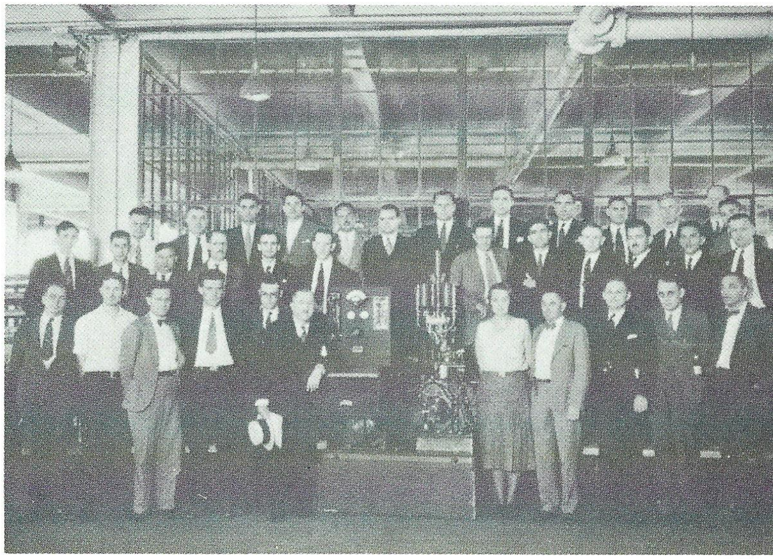
In July, 1933, a summary of world-wide progress in measuring the ignition properties of diesel fuels was made at the World Petroleum Congress. This meeting was held at the Imperial College of Science and Technology in London, and both the Critical Compression Ratio and Ignition Delay Methods were discussed and recognition of the advantages of each method fully established. The Critical Compression Ratio (CCR) Method was the most simple, and easiest to maintain, and had the exclusive advantage of providing a fuel rating which not only revealed the combustion characteristics as related to knock properties, but also indicated starting characteristics with maximum accuracy. The Ignition Delay Method was recognized as presenting more difficulties of operation and test condition maintenance, but it had the very definite advantage of testing under close to actual operating conditions.

Formation of a "Volunteer Group for Compression Ignition Research" was the first organized effort in the United States with the fixed intention of avoiding the futility of many separate investigations. This group undertook co-operative tests to develop a standard method and to investigate reference fuels.

With the co-operation of the E. I. du Pont de Nemours Co., Cetane was found to be a more desirable reference fuel than Cetene because it is more stable, more easily identified, and has a lower ignition temperature. As a result, Cetane has been adopted as the standard primary high reference diesel fuel.

The co-operative tests of the Volunteer Group included comparisons of the Critical Compression Ratio and Ignition Delay Methods in order to judge their relative merits, and with the hope that one standard method could be agreed upon.

A general recognition by the original CFR Committee that there was a definite need for a standard method of rating diesel fuels prompted the admittance of the Volunteer Group and the formation of the CFR Automotive Diesel Fuel Division. It was through the work of this division that a simplified instrumentation for the Ignition Delay Method, known as the Co-incident Flash Method, was devised.



CFR Fuel Testing Committee — September, 1932

As a final comparative check preceding the introduction of the Co-incident Flash Method, six systems of instrumentation were tried out in simultaneous tests made at the Shell Petroleum Corporation Laboratories at Wood River, Illinois, in June, 1938. These tests were witnessed by a complete representation of the CFR Automotive Diesel Fuel Division, and conclusively demonstrated the superior qualities and reliability of the Co-incident Flash Method with the simplified instrumentation developed at Waukesha. At a later meeting, the CFR Committee gave formal approval to this instrumentation, and to the "Delay Period Method of Rating Diesel Fuels Using Tentative Co-incident Flash Principle with Direct Contact Indicators."

The American Society for Testing Materials has adopted this method as a "Standard Method of Test for Ignition Quality of Diesel Fuels by the Cetane Method (D-613)."

The basic CFR engine is used with variations in equipment on all of the ASTM gasoline motor and aviation knock test methods and the diesel fuel ignition quality test method. The current production CFR-48 design crankcase replaces the original low speed and high speed designs. This new engine has a larger crankshaft, closer spaced bearings, and is equipped with rotating counterweights to provide smooth operation over a wide speed range. Accessibility has been improved and the design arranged to be adaptable for general research work. The engine is rugged enough to carry easily loads resulting from the latest high output fuels. The new crankcase will fit all of the old CFR engine cylinders and therefore has not caused obsolescence of any of the standardized cylinder equipment.

The engine design includes the following features:

Crankcase: Heavy box type structure provides maximum strength and rigidity. Removable side doors for quick access to connecting rod bearing. Timing gear housing separate from crankcase casting permitting modification for special drives.

Accessory Drives Include: One half-speed accessory drive and one engine-speed drive. Provision for extra half-speed drive. Standard tachometer drive.

BASIC CFR ENGINE...

the accepted standard for motor gasoline aviation gasoline and diesel fuel testing

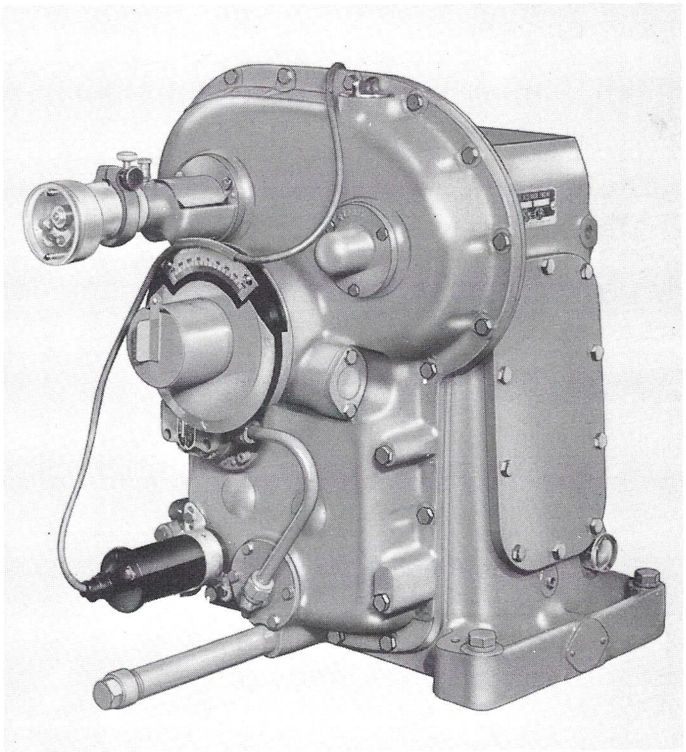
Crankshaft: Heavy single-throw counterweighted construction with large closely spaced main journals providing overlap with crank pin for maximum rigidity. Nitrided bearing surfaces.

Bearings: Sleeve type, precision, steel-backed, copper-lead main bearings. Split, precision, steel-backed, copper lead connecting rod bearings.

Balancing System: Rotating counterweights operating at engine speed in opposite directions balance the primary reciprocating forces from the piston and connecting rod upper end. Counterweights on the crankshaft balance the connecting rod and crank pin rotating mass.

Lubrication: Full pressure lubrication to all bearings. Crank pin and main journal cross-drilled to put the oil holes in the low pressure area of the bearing. External oil pump permits access to the main oil supply line for filtering, cooling, or flow measurement.

Cylinder: Variable compression cylinder of one piece cast construction which assures freedom from cylinder head gasket leakage problems, and cylinder head and barrel distortion from stud clamping pressure. Valve rocker arm carrier linkage automatically maintains constant valve clearance when raising or lowering cylinder to change compression ratio. Stellite valve seat inserts. 18mm spark plug opening on the side and 7/8-inch spark plug opening in the top for bouncing pin or knockmeter pick-up element. Uniform metal thickness of cylinder barrel, and port wall thickness are maintained at eight points to assure uniformity of cooling and cylinder rating characteristics.



CFR-48 Crankcase

Dimensions

Compression Ratio Range	4:1 to 18:1
Bore, inches	3.25
Stroke, inches	4.50
Displacement, cubic inches	37.33
Valve port, diameter, inches	1.187
Connecting rod bearing:	
diameter, inches	2.250
length, inches	1.420
Front main bearing:	
diameter, inches	3.00
length, inches	1.943
Rear main bearing:	
diameter, inches	3.00
length, inches	3.219
Piston pin, floating, diameter, inches	1.25
Connecting rod:	
length, center to center, inches	10.00
width, inches	1.620
Timing gear race, inches	1.00
Piston rings, number	5
Exhaust pipe, diameter, inches	1.25
Weight of engine, pounds (approximate)	800

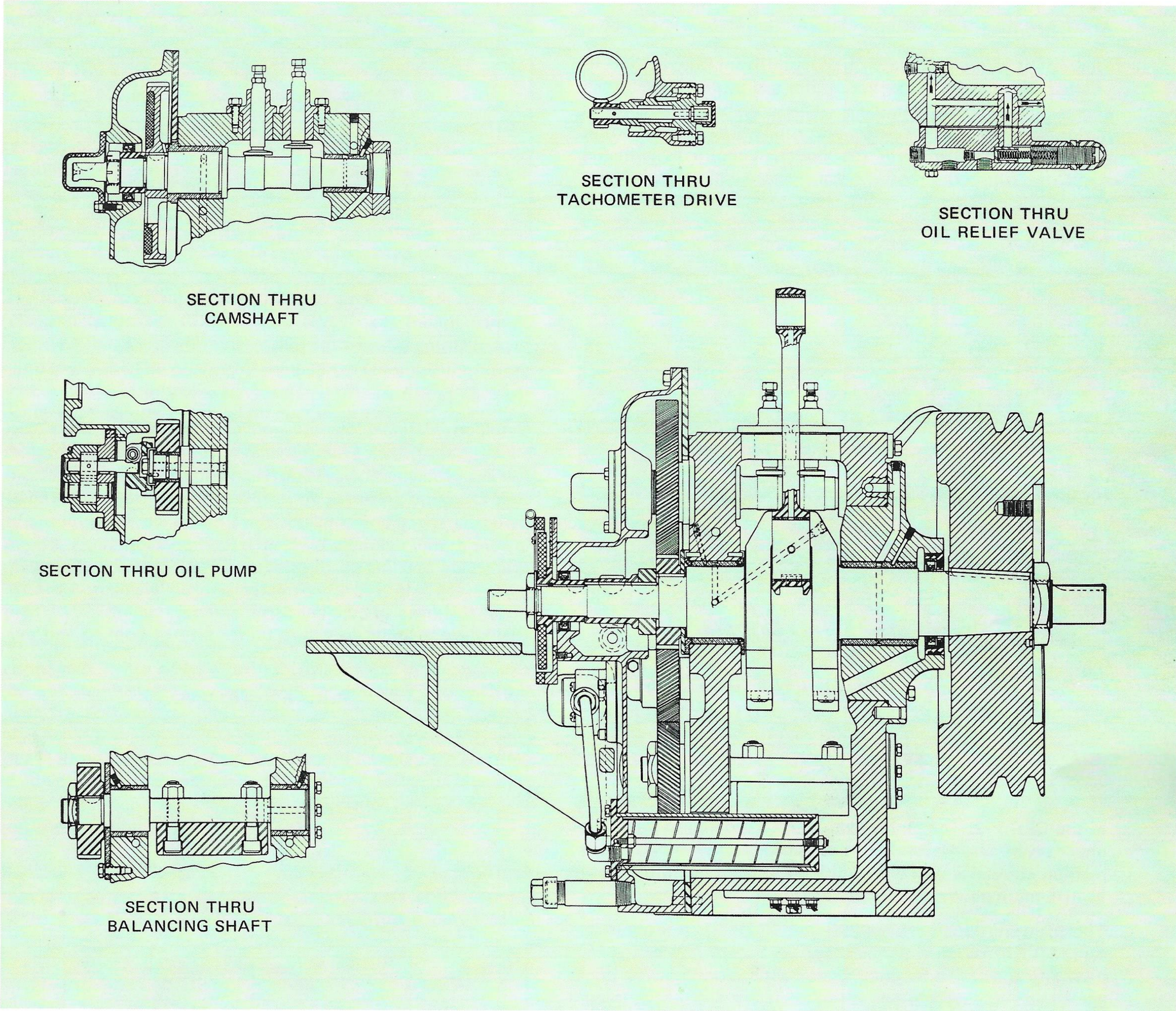
Piston: Five-ring, cast iron heavy construction for motor fuel and diesel fuel rating. Aluminum with wedge-type rings for the aviation test engine.

Cooling: Gravity return evaporative cooling with surge chamber and condenser attached to the cylinder. Due to open free-flowing water jacket space unobstructed by stud bosses, evaporative cooling automatically maintains uniform jacket temperature within close limits and with no tendency toward unstable cooling conditions at high compression ratio. The use of water or water-glycol blends permits obtaining controlled jacket temperature between 212^{o} and 375^{o}F.

Ignition: Special 110 volt condenser discharge type ignition. This system completely eliminates irregularity due to breaker point arcing, as the spark occurs at the make of contact instead of the break. Neon indicator on the front end of the crankshaft indicates the exact spark angle. Linkage to variable compression cylinder automatically adjusts spark advance with compression ratio.

Intake Manifold: Equipped with blade type electrical mixture heater, 110 volt AC. For higher voltages a step-down transformer is required.

Carburetor: Three-bowl variable level carburetor, with single venturi and fixed jets. Selector valve permits operation from any one of the three supply bowls. Mixture ratio is regulated by varying the fuel level. A special horizontal air bleed tube in the venturi reduces the suction, thus permitting large jet sizes free from clogging tendency. This feature also makes mixture adjustment by fuel level extremely sensitive. Since fuel level is always visible against the level gauge, the carburetor adjustment cannot shift without the operator's knowledge.



CFR-48 Crankcase Assembly

The two ASTM motor gasoline knock test methods commonly known as the Research Method and Motor Method are run on similar basic units with slight variations in equipment. Laboratories operating continuously and requiring maximum output of ratings usually require complete individual units for Research and Motor Methods. Laboratories not operating continuously may find it practical to obtain both Research and Motor ratings from a single unit by making necessary equipment changes when switching from one method to the other. Principal steps involve changing the pulleys to reduce engine speed from 900 to 600 rpm and removing the manifold and mixture heater when operating the Research Method.

Where it is desired to switch frequently from one method to another, a two-speed induction motor can be provided instead of the standard constant speed, reluctance-type synchronous motor normally used for power absorption. The speed is not as accurately controlled with the induction motor as with the standard synchronous motor, because speed will vary with load and voltage changes, but many laboratories use the induction motor and obtain satisfactory speed control. Since two-speed induction motors are not standard equipment and furnished only on special order, the laboratory, therefore, assumes full responsibility for obtaining and maintaining the required speed.

MOTOR and RESEARCH METHODS

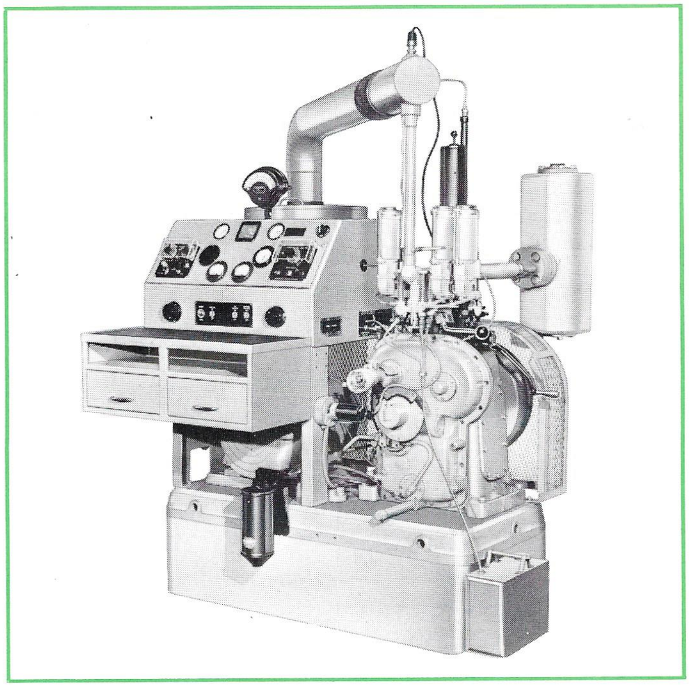
Specifications

ASTM UNIT FOR KNOCK CHARACTERISTICS OF MOTOR FUELS BY THE MOTOR METHOD ASTM D-2700

Method: The ASTM Motor Method was previously known as the CFR F-2. The Motor Method is considered to rate fuels under severe engine conditions, and the octane rating by this method correlates well with full scale engines operating close to maximum power conditions.

The operating conditions are 900 rpm, 212^{O}F. jacket temperature, 300^{O}F. mixture temperature, and spark advance automatically controlled by compression ratio.

Engine: Standard CFR-48 design rotating counterweight crankcase with nitrided crankshaft and sleeve type, precision, steel-backed, copper-lead bearings. Heavy box type crankcase provides maximum strength and rigidity. Removable side doors for quick access to connecting rod bearing. Timing gear housing is separate from crankcase casting, permitting modification for special drives. One half-speed accessory drive and one engine-speed drive. Provision for extra half-speed drive. Standard tachometer drive. Flywheel graduated around full circumference for convenient timing reference. Electric crankcase oil heater.

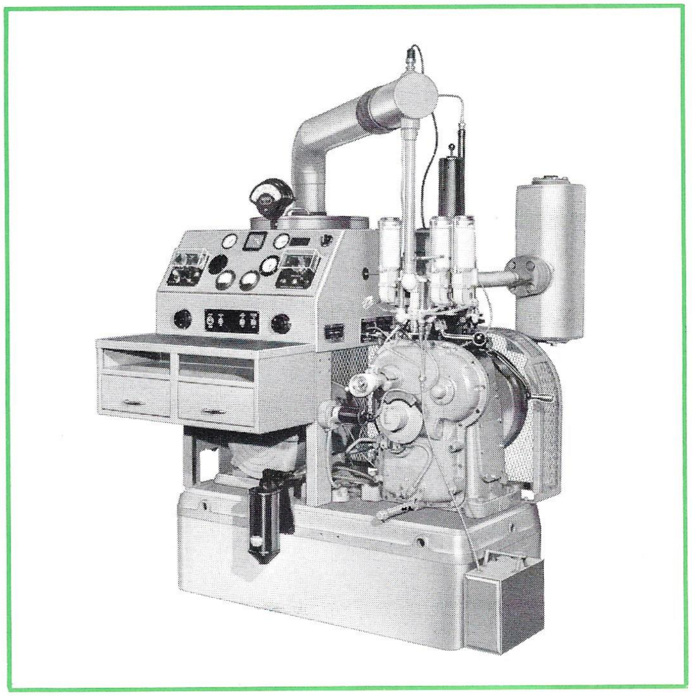


Motor Method Unit

Engine Lubrication: Full pressure lubrication to all bearings. Crank pin drilled at 90 degrees to provide oil before and after the high pressure area. By-pass type waste filter.

Cylinder: Variable compression cylinder of one piece cast construction which assures freedom from cylinder head gasket leakage problems and cylinder head and barrel distortion from stud clamping pressure. Valve rocker arm carrier linkage automatically maintains constant valve clearance when raising or lowering the cylinder to change compression ratio. 18mm spark plug opening on the side, and 7/8-inch spark plug opening in the top for knockmeter pick-up element. Uniform metal thickness of cylinder barrel and port wall thickness held within close limits to assure uniformity of cooling and cylinder rating characteristics.

Research Method Unit



Piston: Five-ring, cast iron, heavy construction.

Cooling: Gravity return evaporative cooling with surge chamber and condenser attached to the cylinder. Due to open free flowing water jacket space unobstructed by stud bosses, evaporative cooling automatically maintains uniform jacket temperature within close limits and with no tendency toward unstable cooling conditions at high compression ratio.

Ignition: Special 110 volt condenser discharge type ignition. This system completely eliminates influence of breaker point arcing, as spark occurs at the make of contact instead of the break. Neon indicator on the crankshaft indicates exact spark angle. Linkage to variable compression cylinder automatically adjusts spark with compression ratio.

Intake Manifold: Intake manifold is equipped with blade type electrical mixture heater, 110 volt AC. For higher voltages, a step-down transformer is required. Heater circuit opens automatically when engine stops to prevent accidental overheating.

Carburetor: Three-bowl variable level carburetor with single venturi and fixed jets. Mixture ratio is regulated by varying the fuel level. A special horizontal air bleed tube in the venturi reduces the suction, thus permitting large jet sizes free from clogging tendencies. This feature also makes the mixture adjustment by fuel level extremely sensitive. Since fuel level is always visible, the carburetor adjustment cannot shift without the operator's knowledge. Four-bowl carburetor instead of three-bowl can be provided on special order.

Ice Tower Humidity Control: Standard ASTM ice tower is supplied. It is required by laboratories not air conditioned sufficiently to provide engine inlet air within the limits of 25 - 50 grains of moisture per pound of air. The tank is 21 inches in diameter and 54 inches high, rockwool insulated, with a central air duct which draws air from the bottom of the ice pack. An easily removable trap drains off the water from the melted ice.

Power Absorption: Special synchronous induction motor; 1200 rpm, 4 hp, 220-440 volt, 60 cycle, three phase, mounted on adjustable slide rails and driven by double V-belt with pulleys for 900 engine rpm. Starting inrush current is approximately 220 amps for 220 volts and approximately 110 amps for 440 volts. Running current is approximately 22 amps for 220 volts and approximately 11 amps for 440 volts. Synchronous induction motors for other currents can be supplied on special order.

Ignition Power Supply: The direct current for ignition purposes is furnished by an ignition power supply unit operating from the 110 volt AC line current. This unit is mounted on the inside of the console panel.

Starting Switch: Remote control push button starting switch throws the synchronous induction motor directly on the power circuit. Main power failure automatically cuts engine ignition switch.

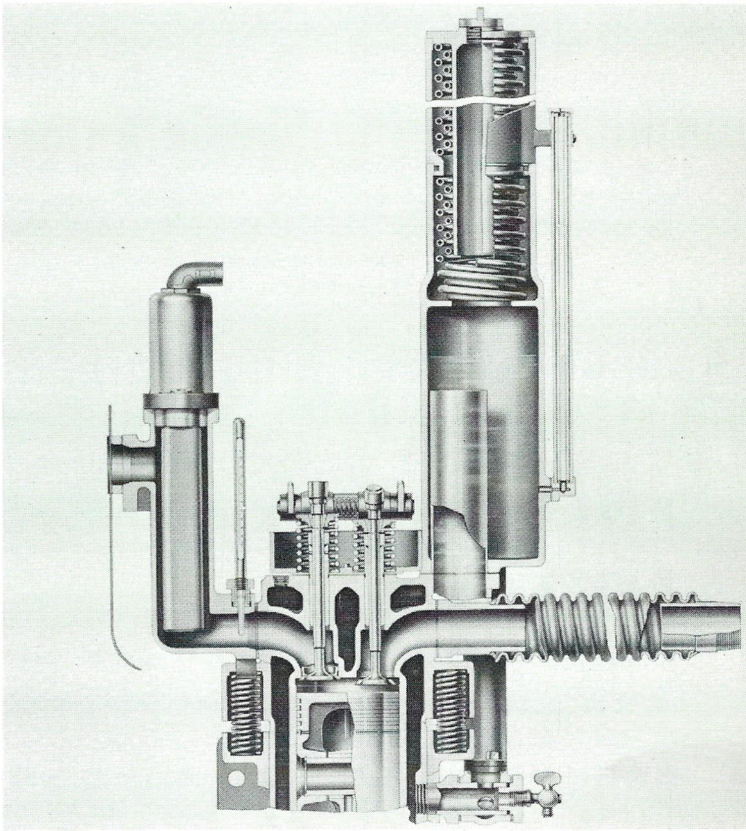
Knock Indicator: The electronic detonation meter is now listed by ASTM as the preferred instrumentation for knock indication. The apparatus consists of the electronic equipment mounted as a unit in a cabinet in addition to the magnetostriction type of cylinder pressure pick-up element for mounting the cylinder and the Weston milli-volt type of knockmeter indicator. Since the voltage from the 110 volt AC supply line may not be steady, a voltage regulator is furnished to assure constant voltage supply to the knockmeter.

Control Panel: A console type instrument control panel and desk is provided with mounting for attachment to the unit, above and in front of the synchronous induction motor. All instruments and switches are mounted in this unit. A hinged front provides convenient access to the interior for maintenance.

Unit Base: The complete unit, including engine power, absorption synchronous generator, control panel, and desk, is supplied mounted on a 24 x 48-inch cast iron bed plate.

Exhaust Surge Tank: Standard ASTM exhaust surge tank is supplied.

Tool Kit: Standard tool kit includes three tappet wrenches, two special wrenches, one adjustable wrench, three socket wrenches, one carburetor jet remover, one spark plug wrench, piston pin retaining ring pliers, piston pin remover, piston ring compressor, piston ring groove cleaner, crankshaft wrench, one valve grinding tool, one valve lifter tool, one breaker point stone, one thickness gauge and one Phillips screwdriver.



Intake Manifold, Condenser and Cylinder Head

Spare Parts: The standard assortment of spare parts includes two spark plugs with gaskets, one set of valves with springs and retainers, one set of piston rings, one manifold gasket, one set of gaskets for the cooling system, one valve rotator, one 5 amp and one 10 amp fuse.

Shipping Weight: Shipping weights are not uniform, but vary with customer specifications and requirements, and extra accessories ordered. Crated for domestic shipment, the standard unit will weigh between 2950 and 3150 lbs.

RESEARCH METHOD

Specifications

ASTM UNIT FOR KNOCK CHARACTERISTICS OF MOTOR FUELS BY THE RESEARCH METHOD ASTM D-2699

Method: The ASTM Research Method formerly known as CFR F-1 is considered to rate fuels under mild conditions, and the octane rating by this method correlates well for passenger car type of operation accelerating from low speed with a cool engine. The operating conditions are 600 rpm, 212^{O}F. jacket temperature, no mixture heater, inlet air temperature 125^{O}F., and spark advance fixed at 13 degrees.

Engine: The engine is identical to the Motor Method engine except that the manifold and mixture heater are removed and the carburetor is attached directly to the cylinder block. Also, the automatic spark advance linkage is disconnected and the spark fixed at 13 degrees.

Intake Manifold and Heater: Omitted on the Research Method. An inlet air heater is provided ahead of carburetor to maintain the inlet air temperature specified in the method.

Ignition: Fixed spark setting at 13 degrees.

Power Absorption: Same as Motor Method except to give 600 engine rpm instead of 900 rpm.

All other specification details are the same as the Motor Method unit.

MOTOR (L.P.) METHOD

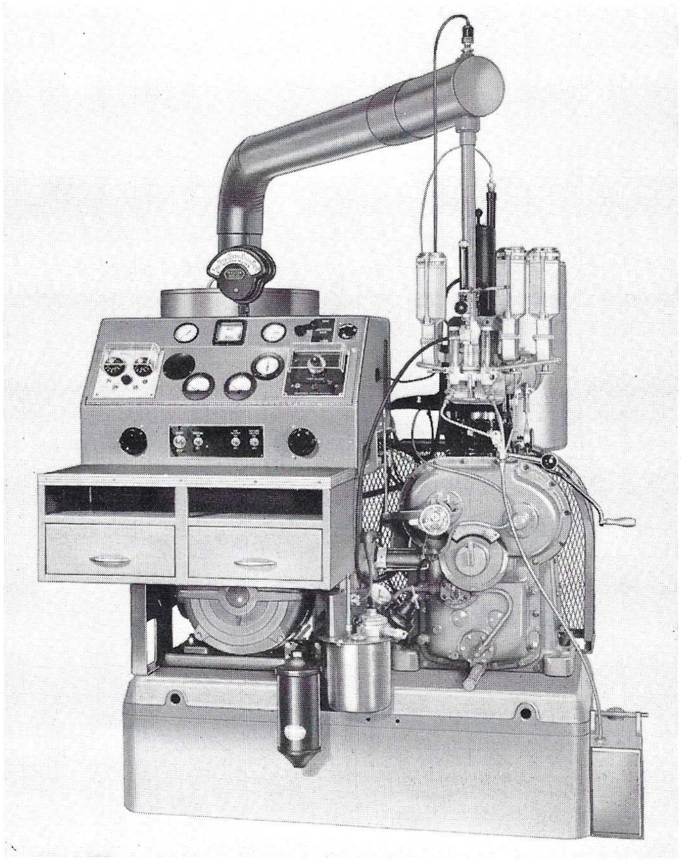
ASTM UNIT FOR KNOCK CHARACTERISTICS OF LIQUEFIED PETROLEUM (LP) GASES BY THE MOTOR (LP) METHOD – ASTM D-2623

All specification details are the same as the Motor Method D-2700 unit with the addition of the following special equipment for rating liquified petroleum (LP) gases. The equipment consists of a vaporizing and pressure regulating unit and a flow metering unit as shown in the picture.

The vaporizing unit consists of a tank filled with water containing a heating coil, a 115 volt immersion heater and a thermo-regulator to maintain the bath at a temperature of 180 ± 10F (82 ± 5.6 c). A thermometer is immersed in the bath for observation of water temperature and a mounting bracket is provided so that the bath may be attached to the right front panel leg of the console.

The flow metering unit is mounted on the special vertical intake air pipe at a point 1 inch below the intake air thermometer. This is the most convenient position for control of the flow regulator, and prevents the entering gas from disturbing the air-temperature thermometer.

Motor (L.P.) Method Unit



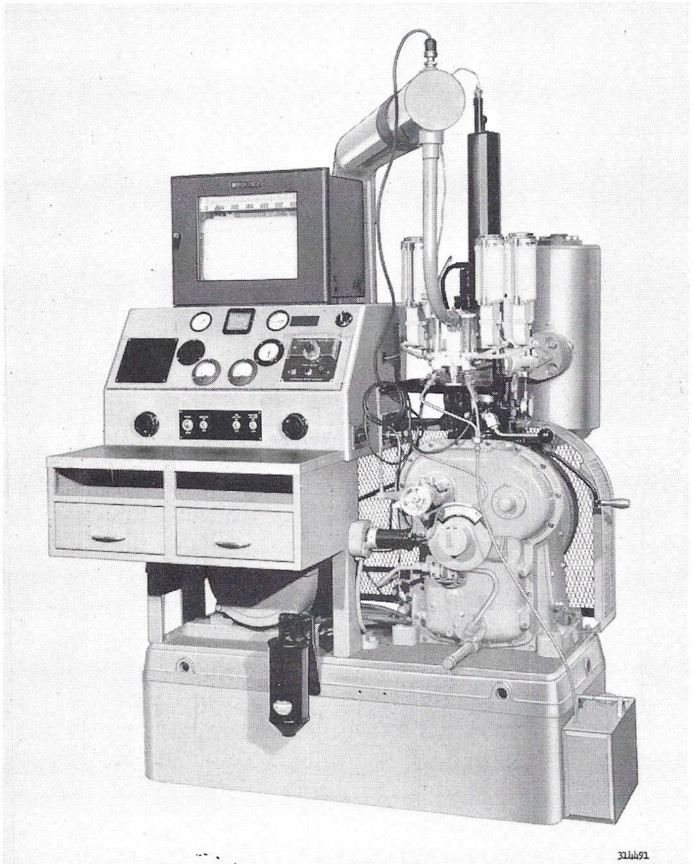
The Aviation Method utilizes the basic Motor Method unit, but involves a considerable change in engine equipment and instrumentation. The Aviation Method uses temperature in the combustion chamber as an indication of knock instead of the electronic knockmeter. At the time the method was developed it was felt that temperature was a more significant index for aviation engines than knock shock. Ordinarily it is not practical to convert from the Motor Method to the Aviation Method unless the switch is made at infrequent intervals. The Aviation Method requires 1200 rpm, an aluminum piston instead of cast iron, unshrouded inlet valve, long-bend air inlet pipe, larger carburetor venturi, a combustion chamber thermo-plug, and recording potentiometer for temperature indication. An oil cooler is also required.

Specifications

ASTM UNIT FOR KNOCK CHARACTERISTICS OF AVIATION FUELS BY THE AVIATION METHOD — ASTM D-614-T

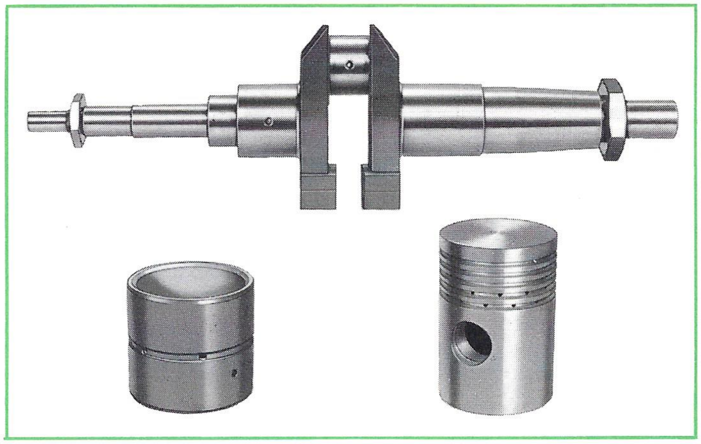
Method: The ASTM Aviation Method formerly known as the CFR F-3 Method is considered to rate aviation fuels under conditions which simulate aircraft lean cruise operation. A thermo-plug in the combustion chamber is used as an index of fuel knock intensity in contrast to the Motor Methods which use the electronic knock indicator. At the time this method was developed, temperature was considered a more significant index for aircraft service than combustion shock.

Aviation Method Unit



The operating conditions are 1200 rpm, 375°F. jacket temperature, 125°F. inlet air temperature, 220°F. mixture temperature, 3/4-inch carburetor venturi, aluminum piston, and unshrouded inlet valve. Spark advance is 35 degrees.

Engine: The engine is identical to the Motor Method engine except for a change from iron to aluminum piston, plain inlet valve instead of shrouded valve, and 3/4-inch venturi instead of 9/16-inch. Also a long-bend air inlet pipe is provided instead of the 90 degree carburetor elbow.



CFR-48 Crankshaft and Main Bearing and Aviation Method Aluminum Piston

THE AVIATION METHOD

Engine Lubrication: Engine lubrication is the same as in the Motor Method engine except that an oil cooler is provided.

Cylinder: The cylinder is the same as in the Motor Method engine except that it is equipped with an unshrouded inlet valve.

Piston: Aluminum piston, with wedge type piston rings to prevent sticking at high operating temperatures.

Cooling: Ethylene glycol coolant is used instead of water to obtain 375°F. constant jacket temperature.

Ignition: Champion RJ-11 spark plug. Fixed spark setting at 35 degrees.

Carburetor: Same as Motor Method carburetor, except it has 3/4-inch venturi instead of 9/16-inch.

Power Absorption: The power absorption motor is the same as the Motor Method motor except it is provided with pulleys for 1200 engine rpm instead of 900 rpm.

Knock Indicator: A thermo-plug and recording potentiometer, 600° - 1100°F. range, is used as the index of knock intensity instead of the electronic knock indicator.

All other specification details are the same as for the Motor Method Unit.

The apparatus for cetane rating of diesel fuels is an adaptation of the standard CFR gasoline octane rating unit. The CFR engine is modified by the application of a special variable compression diesel cylinder, injection equipment, and fuel ignition delay indicating apparatus.

The illustration is a section through the variable compression diesel combustion chamber, which is cylindrical in form. A high degree of compression swirl is obtained by means of the tangential location of the connecting passage to the main cylinder bore. The piston travels close to the flat surface of the head, thus forcing practically all of the combustion air into the combustion chamber. The compression ratio is varied by moving a piston plug axially in the chamber. The water jacketed injector is located at the end as shown, to inject along the length of the chamber near its periphery. Inherent compensation for change in density of the air with change of compression ratio is obtained as a result of the fact that, when the compression ratio is lowered by moving the plug out, the combustion chamber is made longer. Thus, for low density air charge when the fuel spray penetration will be great, the combustion chamber will be long, and vice versa.

Injection equipment consists of a standard Bosch injection pump provided with a variable injection advance and micrometer screws for setting fuel quantity and injection advance. Three fuel sample tanks and a special three-way valve permit switching conveniently from the test fuel sample to the reference fuels. Drain cocks located at the low points permit draining and flushing the lines. A graduated glass burette located at the sample tank level, but connected to the fuel pump, provides a vent and a convenient means of measuring the fuel injection rate. The injector is a standard Bosch pintle type with a manually operated by-pass valve which is convenient for turning injection on or off without moving the fuel pump rack position.

DIESEL CETANE METHOD

The ASTM Cetane Method compares fuels on the basis of the Ignition Delay. The instrumentation for this purpose is a transistorized Ignition Delay Meter. This is an electronic timing device utilizing signals from four pickups which are mounted on the engine as follows:

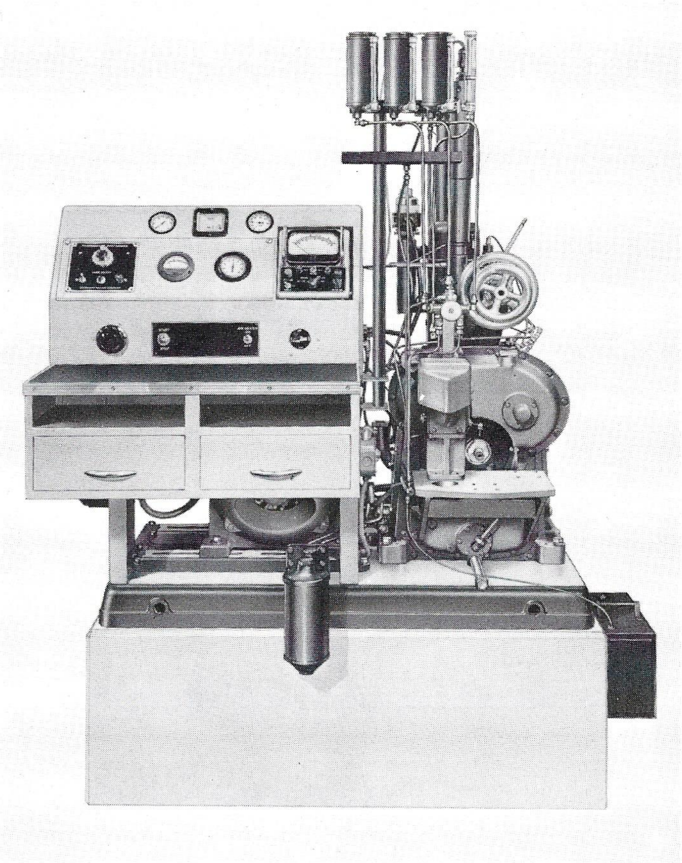
(1) A combustion pickup in the cylinder head having a diaphragm exposed to the combustion pressure.

(2) An injector pickup attached to the fuel injector and actuated by motion of the pintle.

(3) A reference pickup mounted over the flywheel at T.D.C.

(4) A second reference pickup for calibration purposes mounted over the flywheel at 12-1/2° before T.D.C.

There is a steel pointer in the rim of the flywheel which energizes the reference pickups. There are three circuits in the Ignition Delay Meter. The first of these is for calibration to set the meter in accordance with the previously placed reference pickups which are 12-1/2° apart. With this setting established the engine is operated on the sample and the second circuit called INJECTION ADVANCE is used. At this time the micrometer screw on the mechanical advance mechanism is adjusted to give a deflection of 13° B.T.C. on the meter. Then the switch is turned to the third circuit which is IGNITION DELAY and the compression ratio of the engine is adjusted by means of the handwheel to give 13° on the meter. With the fuel rate adjusted to the specified 13 ml per minute a final adjustment of the compression ratio is made to maintain the 13° IGNITION DELAY reading. The handwheel setting for this condition is used with the handwheel settings for the higher and lower bracketing reference fuels to obtain the Cetane number of the sample by interpolation.



Diesel Cetane Unit

The index for ignition delay is the compression ratio required to produce the standard ignition delay of 13 degrees with combustion occurring at top dead center. The procedure in rating fuels, therefore, consists of determining the compression ratio to produce the standard 13-degree ignition delay period with the unknown sample and then running a pair of known reference fuels, one a little better and one a little worse than the sample. The exact reference fuel match for the unknown sample is calculated by interpolation from the relative compression ratios. The cetane number of the fuel, therefore, is the percentage blend of cetane with Alpha-methylnaphthalene which matches the test sample. In actual routine test work the primary reference fuel, cetane, is not used, but secondary reference fuels which have been calibrated against cetane are used.

Specifications

ASTM UNIT FOR MEASURING IGNITION QUALITY OF DIESEL FUEL BY THE CETANE METHOD – ASTM D-613

Method: The ASTM Cetane Method was previously known as the CFR F-5 Ignition Delay Method. It is considered to indicate a diesel fuel's ignition delay characteristic under engine operating conditions. Long ignition delay, or low cetane number, generally causes engine roughness or tendency to irregular firing at light loads. The ignition delay is also a good index of the cold starting ability of the fuel. Fuel with long ignition delay or low cetane number gives poor cold starting.

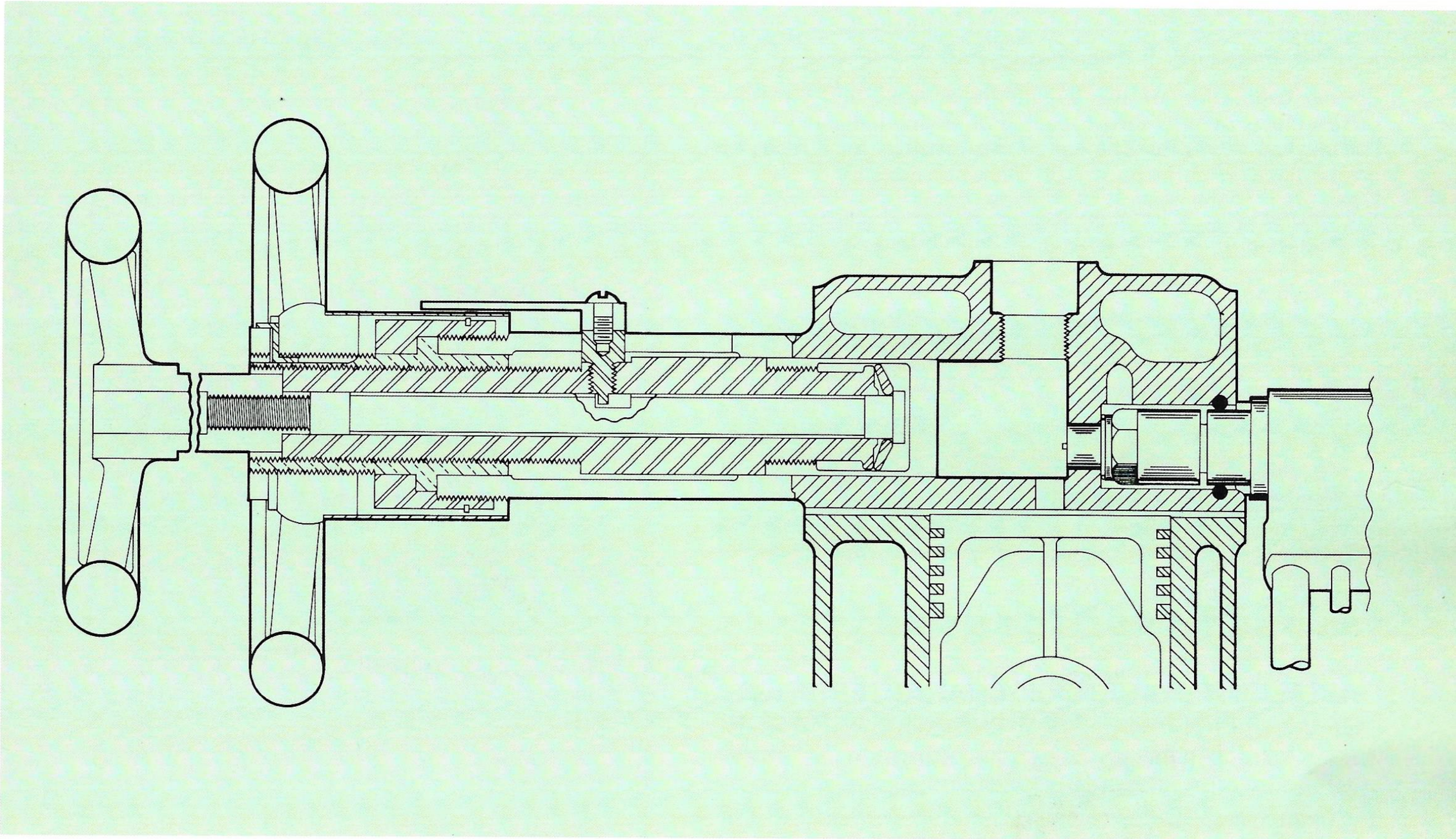
Engine: The Standard CFR-48 design rotating counterweight crankcase is used. It is equipped with an injection pump for diesel fuel injection.

Cylinder: The cylinder is 3-1/4 x 4-1/2 inches with a variable compression swirl type combustionc chamber. Compression ratio is varied by screwing an expansible plug in or out of the cylindrical combustion chamber. This design automatically compensates for change in air density with change of compression ratio, since the length of the chamber increases with a reduction of the compression ratio. Micrometer graduations are on the plug adjusting screw for indicating combustion chamber length. Compression ratio range is 7:1 to 28:1.

Piston: Cast iron, five-ring flat-top piston of heavy construction.

Cooling: Gravity return evaporative cooling with surge chamber and condenser attached to the cylinder.

Injection Equipment: Bosch injection pump provided with adjustable advance coupling. Bosch pintle type injector. Three fuel supply tanks equipped with strainer and sight gauge and three-way selector valve to permit switching from one fuel to the other. Graduated burette for measuring fuel flow rate. Fuel drain lines and waste fuel can.



Variable Compression Head and Cylinder of Diesel Cetane Unit

Intake Pipe: Intake pipe is equipped with electric heater for maintaining standard inlet air temperature.

Power Absorption: Special synchronous induction motor, 1200 rpm, 4 hp, 220-440 volt, 60 cycle, three phase, mounted on adjustable slide rails and driven by double V type pulleys for 900 engine rpm. Starting inrush current is approximately 220 amps for 220 volts and approximately 110 amps for 440 volts. Running current is approximately 22 amps for 220 volts and approximately 11 amps for 440 volts. Synchronous induction motors for other currents can be supplied on special order.

All other specification details are the same as those of the ASTM Motor Method Unit.

The Supercharge Aviation Method uses the standard basic engine and cylinder, but a completely different unit power absorption dynamometer, air induction system, and instrumentation. Conversion to any of the other test methods, therefore, involves extensive engine and equipment changes. However, it is possible to provide conversion equipment for the other methods by supplying the complete extra synchronous induction generator and control panel for the desired method. Some universities have equipment of this type where it is desired to cover as wide a range of test methods as possible for instruction purposes.

The Supercharge Method is run at 1800 rpm and requires measurement of the indicated power and fuel-air ratio at which knock occurs. A special 25 hp induction dynamometer is provided to maintain constant engine speed and rapid determinations of engine friction. Standardized ASME sharp-edged orifice type air flow meter and surge tanks with pressure regulators and electric heaters are provided to control and measure air flow to the engine accurately. An automatic fuel weighing device and time clock indicates the fuel delivery rate. High pressure fuel injection in the manifold is used instead of a carburetor. Knock is determined by ear.

Special calibration of the dynamometer scale and air flow orifice meter permits direct reading of engine indicated IMEP and air-fuel flow rate. The equipment provides for a range of engine inlet pressures up to 100 inches of mercury.

Engine inlet air requires an outside source of approximately 50 cu. ft. per minute of compressed air at 80 lbs. pressure.

SUPERCHARGE METHOD

Specifications

ASTM UNIT FOR KNOCK CHARACTERISTICS OF AVIATION FUELS BY THE SUPERCHARGE METHOD — ASTM D-909-T

Method: The ASTM Supercharge Aviation Method was previously known as the CFR F-4 Method. The Supercharge Method is considered to rate aviation fuels under conditions simulating maximum power with rich fuel ratio. Lean mixture ratings can also be made by this method since the knock limited power curve can be run over the full range of mixture ratio. However, the unsupercharged Aviation Method is ordinarily used as an index of the fuel's knock characteristics under lean cruise conditions.

Operating conditions for the Supercharge Method are 1800 rpm, 375°F. jacket temperature, 225°F. inlet air temperature, 45 degree spark advance and 7:1 fixed compression ratio.

Engine: Standard CFR-48 rotating counterweight crankcase with variable compression cylinder. Connecting rod drilled for jet cooling of piston. High lift camshaft with high speed timing. Water cooled exhaust manifold. Exhaust surge tank.

Oil Cooler: Oil cooler required for oil temperature control.

Cylinder: Variable compression cylinder equipped with sodium cooled exhaust valve, unshrouded inlet valve and enclosed valve gear.

Piston: Aluminum piston equipped with wedge-type rings to prevent sticking at high operating temperatures.

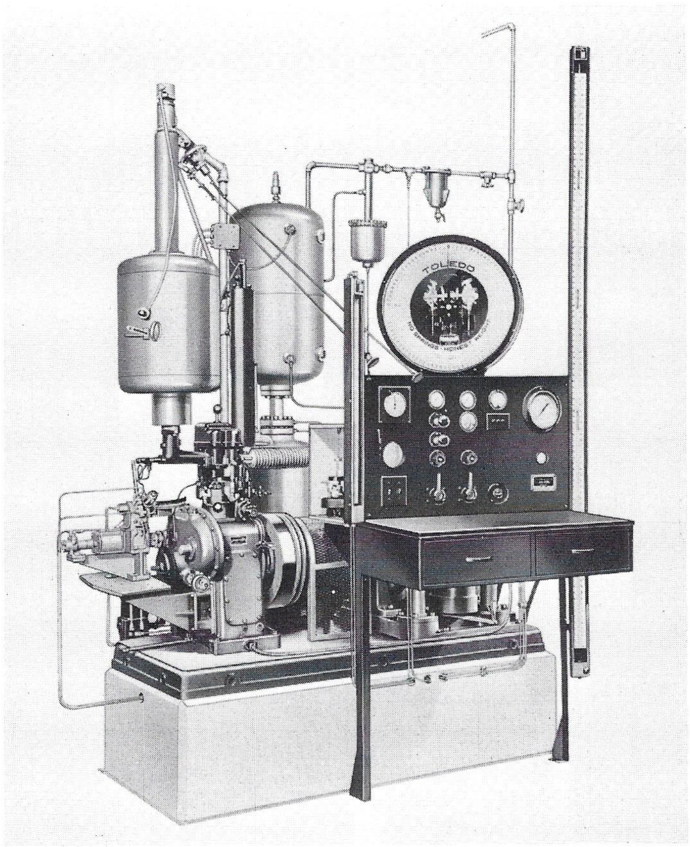
Cooling: Extra large condenser for evaporative cooling.

Ignition: Distributor and Champion RJ-11 spark plugs. Fixed spark setting @ 45°degrees.

Intake Manifold: Special tapered intake elbow with mounting arranged to carry injector for manifold injection.

Fuel Supply System: Bosch injection pump with micrometer stop for fuel control rack and special lubricating oil sump and circulator to prevent plunger wear when operating on gasoline fuel. Water jacketed fuel cooling plug is mounted in the end of the fuel sump. A Bosch pintle type injector is provided for manifold injection. Fuel weighing device equipped with control valves, fuel circulating pump, and electric time clock with automatic mechanical control switch for timing fuel flow rate.

Air Induction System: The air induction system includes filter,



Supercharge Method Unit

surge tanks, thermostatically controlled electric heaters, standard ASME sharp-edged orifice meter, pressure regulators, 100-inch mercury manometer for inlet pressure measurement, 30-inch air meter manometer graduated to read directly in minutes for one quarter pound of air and thermometers for temperature indication at orifice meter and engine inlet.

Safety Control System: An automatic safety control system is provided to shut off all electric power and engine ignition in case of oil pressure failure, excessive cylinder temperature, or main power failure.

Power Absorption: The power absorption unit consists of a 25 hp cradle type induction dynamometer, 440 volt, three phase, 60 cycle, 1800 rpm, with manual starting compensator. A Toledo dial scale is provided with dial calibrated for BMEP. An oil dash pot damps out cyclic impulses and maintains a steady scale reading. A double, fabric disc coupling is provided for engine-to-dynamometer connection.

For current characteristics other than 60 cycle, it is necessary to belt-drive the dynamometer in order to operate the engine at the standard 1800 rpm speed. With 50 cycle current, a 1500 rpm dynamometer with suitable pulley sizes is supplied.

Unit Base: Engine is dynamometer-mounted on a 28 x 70-inch cast iron base.

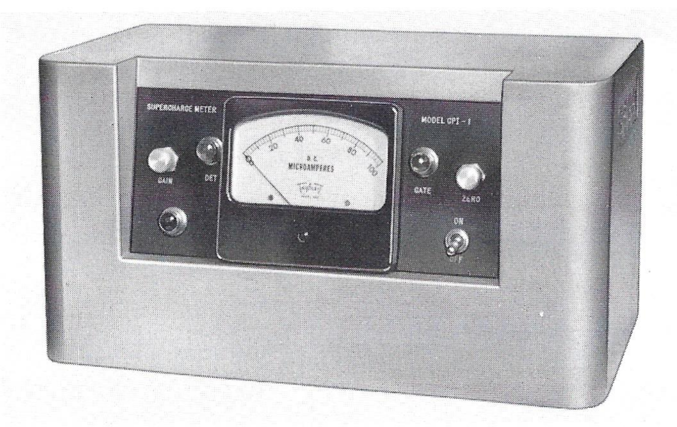
Instrument Panel: Instrument panel with two-drawer steel desk, 15 x 40 inches, is provided for mounting directly on the floor alongside the dynamometer.

Spare Parts and Tools: A standard group of spare parts and tools is supplied with the unit.

Supercharge Knockmeter Model GP1

This electronic instrument for evaluating the detonation of the Supercharge Method Engine was approved by ASTM in 1957 for use as an aid to the ear. It employs an external type E pickup mounted on the engine cylinder. The operating principle differs from that of previous instruments used with the Supercharge method and employs the functions of gating, and product integrating, from whence come the letters GPI. Basically, the instrument has counter, memory, and computer circuits enabling it to integrate continuously the product of the knock intensity on any cycle and the time interval in cycles since the previous knock. This is advantageous in the Supercharge method, wherein the knock is erratic in both frequency and intensity.

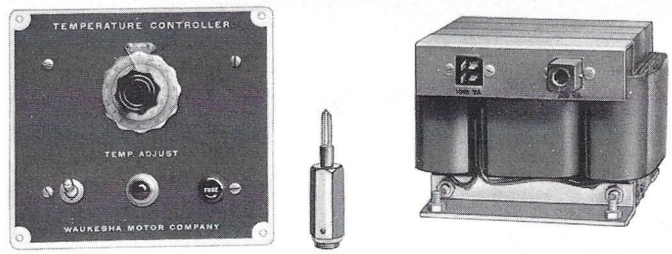
This meter is not supplied with Supercharged Packaged Unit, but must be ordered as an extra at additional charge.



Supercharge Knockmeter Model GP-1

Waukesha Temperature Controller

This simple, versatile instrument is applicable to the ASTM Motor, Research, Aviation and Cetane methods and general laboratory use wherever it is desired to control temperature within the range of 80°F. to 400°F. The controller employs a small thermistor sensing probe and a saturable reactor to provide continuously modulated proportional control of the current to the heating element without the use of any moving contacts or relays. It features high sensitivity and close control, with easy adjustment of the control point by the coarse and fine co-axial dials on the front panel. It is available for mounting in the console panel of ASTM fuel rating units, or in a portable cabinet for general use and for units without console panels. The controller operates on 110 volts AC and will handle heaters up to 1000 watts capacity.



Panel Type Controller — Temperature Sensing Probe — Portable Controller

Several special cylinder types, accessories, and special tools are available for laboratory use. A short description of these items is listed herewith. Consult the Waukesha Motor Company for additional details.

ACCESSORY SPECIALTIES

"L" Head Cylinder

(Not Illustrated)

For the study of ell head combustion chamber designs, a valve-in-side, ell head cylinder can be mounted directly on the standard crankcase. The fixed compression cylinder combination includes the cylinder together with heads for 5:1, 6:1, 7:1, 8:1 and 8.5:1 compression ratios, valve tappets, and guides to convert the overhead mechanism to ell head type, and evaporative cooling equipment to fit the ell head. This equipment has also been found valuable by oil companies for studies of oil control and ring sticking.

Multiple Hole Cylinder

(Not Illustrated)

Variable compression 3-1/4-inch bore cylinders similar to the standard ASTM knock rating cylinder, but with additional spark plug holes, are available for special research use. The cylinder of this type most generally supplied has two additional spark plug openings located in the horizontal plane opposite the standard spark plug location. Different thread size and hole arrangements can be furnished on special order.

Removable Dome Head Cylinder

A new model cylinder head of two-piece design is now available. Named the RDH Cylinder, it is a Removable Dome Head type, incorporating over-square bore/stroke relationship and extremely high volumetric efficiency. The main features of the RDH Cylinder are: variable compression ratio by means of a hand crank to move cylinder up and down; large diameter valves and free-flow parts for excellent volumetric efficiency at high speeds; a 3-3/16-inch bore and 3-5/8-inch stroke; a hemispherical contour domed cylinder head, with a dome-topped, 3-ring piston having a larger radius of curvature. The valves are set at a 30-degree angle from vertical on each side of the center line. There is a compensating linkage on the valve gear to maintain constant valve clearance while compression ratio is varied. Standard CFR valve tappets are used.

The cylinder assembly can be applied in the field to any CFR-48 crankcase. Since the engine stroke is reduced from the usual 4-1/2 inches to 3-5/8 inches, a new crankshaft is furnished as part of the conversion kit. It is this crankshaft which makes the assembly applicable only to the CFR-48 crankcase. The new crankshaft is directly interchangeable with the standard CFR crankshaft. Since the bore is larger than the standard CFR, the top deck of the CFR-48 crankcase must be bored out to accommodate the greater size, and two new stud holes drilled and tapped. These modifications to the crankcase do not prevent subsequent use with standard CFR cylinders.

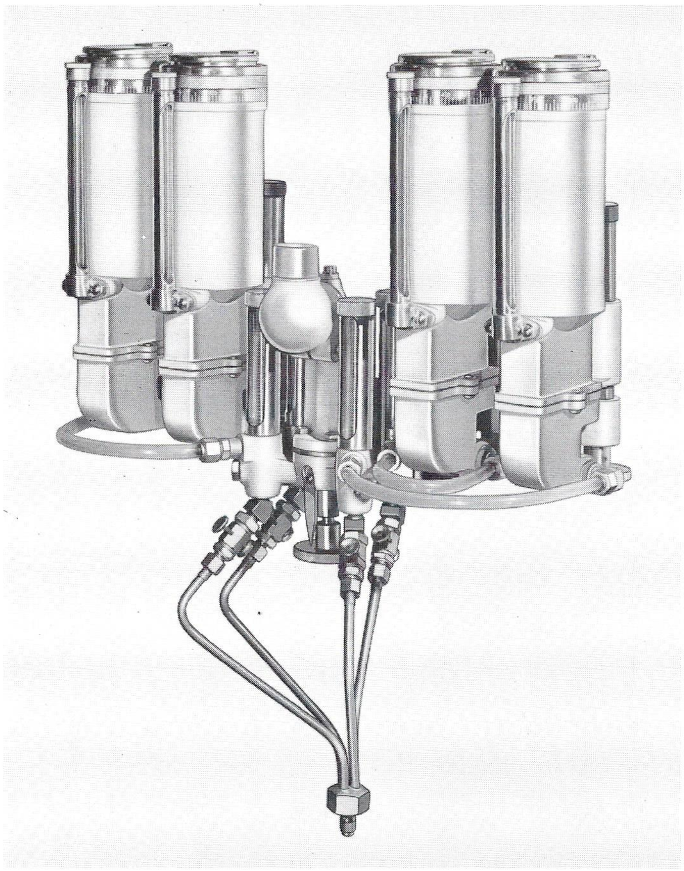
ACCESSORY SPECIALTIES

RDH Cylinder, Piston and Crankshaft

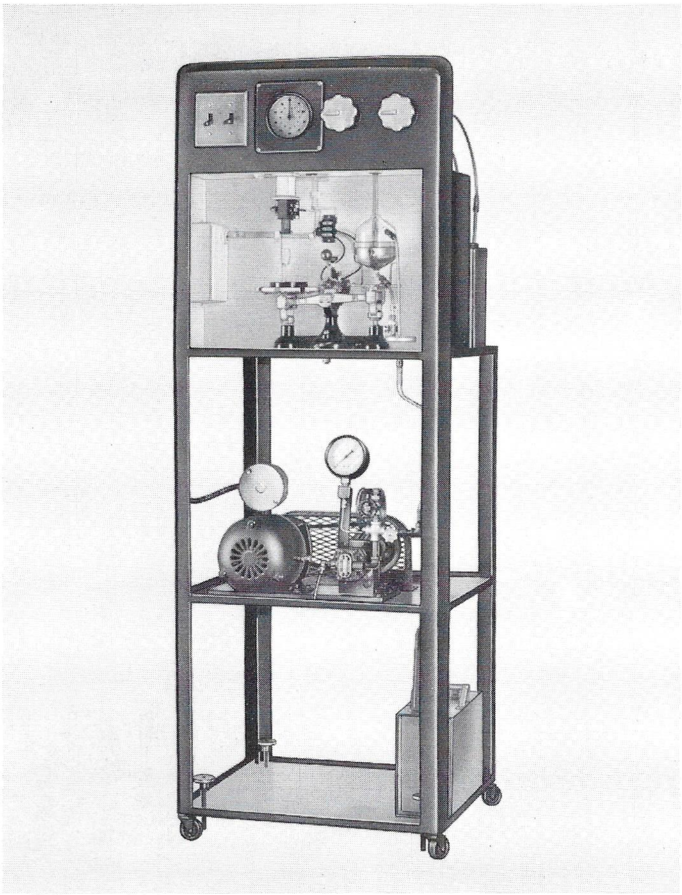
Variable Compression Removable Head Cylinder

A variable compression removable head cylinder has been designed and produced for a development program aimed at replacing the standard one piece ASTM cylinder. With this cylinder, valves can be reconditioned and combustion chamber deposit removed without disturbing the piston rings in the cylinder barrel. This eliminates the need of running in the piston rings after each cylinder reconditioning and saves at least 20 hours break-in time after each cylinder overhaul. These cylinders are not yet ASTM standard but are available on special order.

Variable Compression Removable Head Cylinder



Four-Bowl Carburetor



Fuel Weighing Device

Four-Bowl Carburetor

A four-bowl carburetor similar in all respects to the standard ASTM three-bowl carburetor is available on special order. By using four bowls instead of three, it is possible to operate with a wider range of bracketing reference fuels. This increases the speed of rating appreciably when testing a series of fuel samples which fall within the range of the three bracketing reference fuels.

Fuel Weighing Device

A fuel weighing device is available for use with manifold injection engines, with Diesel engines, or carburetor type engines. The complete unit, with scales, piping, 110 volt AC electric fuel circulating pump, control valves, electric timer, switches, and fuel sample cans, is mounted on a steel stand equipped with casters and leveling screws. Flexible fuel lines are provided for connection to the injection pump or carburetor. Control valves are arranged to permit operating with either a recirculating system or non-recirculating, as required

ACCESSORY SPECIALTIES

with carburetor operation. Electric fuel pump drive is provided with four-step cone pulleys to vary fuel flow rate from five to fifteen gallons per hour. A magnetic mercoid type switch on the fuel balance arm automatically starts and stops the time clock for a given fuel weight. A solenoid automatically lifts the scale weight, and a ratchet relay switch automatically controls the circuit for starting and stopping the time clock in sequence with the swing of the fuel scale beam. An electric socket connection is provided on the unit for use when it is desired to connect a standard electric time clock unit to the scale beam circuit. This permits measuring engine revolutions per unit weight of fuel. The standard beaker supplied with the unit has capacity to weigh one quarter pound fuel samples.

Exhaust Surge Tank

(Not Illustrated)

In order to eliminate resonant pulsations in the exhaust line which may occur with long lines, a surge tank should be located close to the engine. The standard 10-inch diameter by 24 inch length tank as supplied with the ASTM units is available. This tank is constructed of heavy-wall steel and provided with 2-inch stand-pipe flange connections at each end.

Cylinder Overhaul Stand

For convenience in overhauling the standard variable compression cylinder during reconditioning of valves and combustion chamber, a special overhaul stand is available. The stand is constructed with a swivel head to permit overhauling the cylinder at any desired angle. A telescoping pedestal permits adjustment to any convenient height. Casters on the base provide for moving the stand and leveling screws hold it secure while working on the cylinder. A bracket with hand screw adjustment is provided to hold the piston and connecting rod assembly whlle setting the compression ratio indicating micrometer.

Cylinder Overhaul Stand

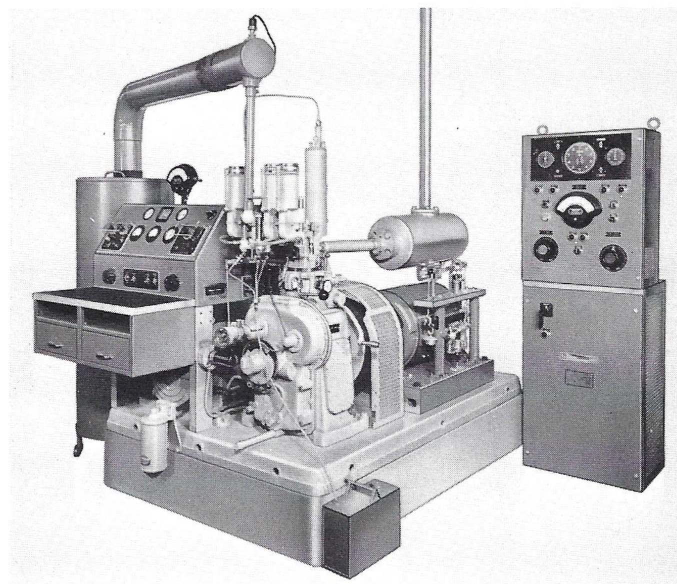
Valve Grinding Equipment

Because the CFR engine cylinder is equipped with hard Stellite valve seat inserts, and because the knocking characteristics are very sensitive to valve condition, it is necessary to have equipment available to the laboratory for reconditioning accurately valve faces and valve seats in the cylinder. An Albertson electric 110 volt AC grinder with a special spindle to reach into the CFR cylinder is available. This equipment also includes a dial indicator for checking the valve seat eccentricity.

Valve Grinding Equipment

Dynamometer Research Unit

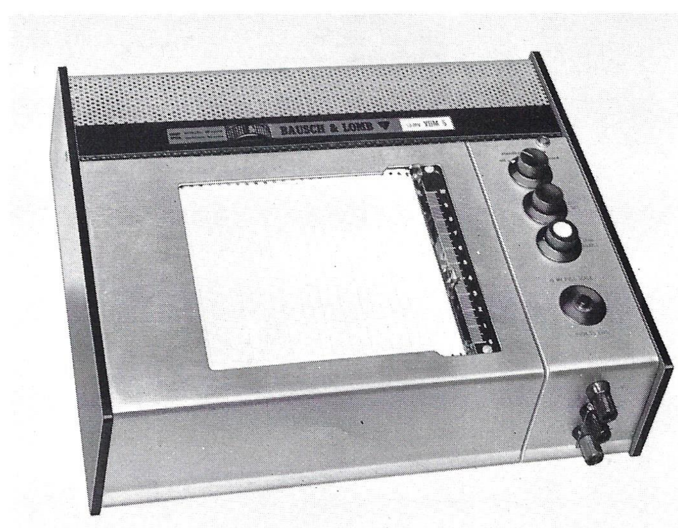
Each of the standard types of units listed previously (except supercharged unit) may be supplied as a complete laboratory set with cradle type electric 250 volt DC dynamometer. The dynamometer unit, in addition to the standard fuel rating unit, includes a special electric dynamometer complete with engine coupling, load resistors, revolution counter mounted on an independent panel, and a separate control panel for the dynamometer containing all necessary meters, switches, circuit breakers, resistors, and connections. A large ell-shaped cast iron base supports the dynamometer and rating unit. The dynamometer unit permits a complete study of fuel and engine characteristics at variable speeds and loads together with power measurement.



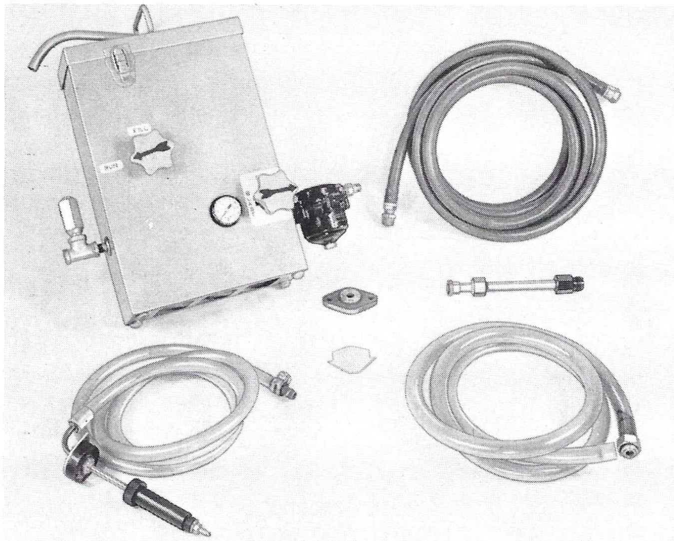
Standard Unit with Cradle Type Electric Dynamometer

Strip Chart Recorder

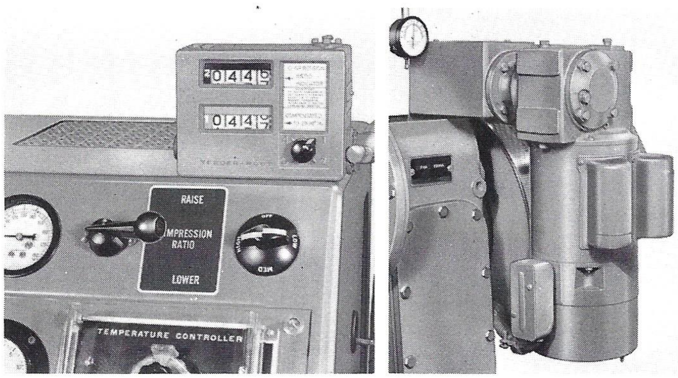
The strip chart recorder is a self-balancing potentiometric recorder designed for use in addition to, or in place of the standard indicating knockmeter, for recording knockmeter readings. Greater engine operating efficiency and improved rating precisions are benefits gained from the use of this instrument. The recorder, which measures 14-1/2 x 11-3/4, can be used in three positions — flat on bench, 30° desk tilt, or wall mounted. The pen writes a clean, sharp line and is easily removed for filling and thorough cleaning. Also, the pen lifts automatically from the paper when not recording to prevent wicking. The chart paper is low cost and its high quality assures clear, non-feathering recording lines which are easily reproducible on most copy equipment. The recorder has been approved for use by ASTM Committee D-2, Research Division I.



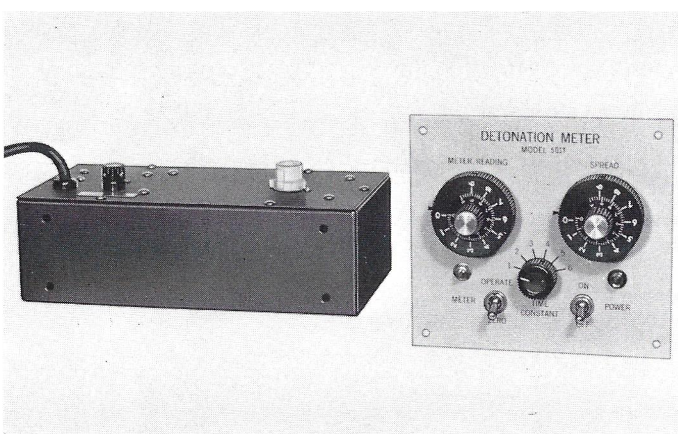
Strip Chart Recorder



Carbon Blasting Equipment

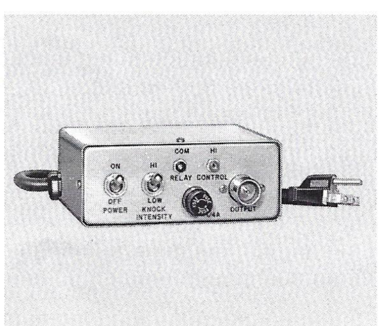


Motorized Compression Ratio Changer



Panel Mounted Transistorized Detonation Meter

Transistorized
Detonation Meter



Transistorized
Signal Generator

Carbon Blasting Equipment

The carbon blast equipment is a fast and effective way for removing dry carbon deposits without removing the cylinder from the engine. In the blasting operations, the discharge is made through the pickup hole. A special nozzle and adapter is available for use in carbon blasting split-head cylinders. Also, a special tool is available that will safely and conveniently hold open either valve while carbon blasting. Usually, a cylinder can be blasted in about thirty minutes.

Motorized Compression Ratio Changer

Equipment is available for changing the compression ratio of the CFR engine by means of an electric motor and reading the cylinder height remotely by a digital counter. This equipment may be specified for factory installation on new Motor, Research, and Aviation Units or ordered in kit form for field installations. It is not applicable on Cetane Method Units, and is of no value on Supercharge Units since it operates at a fixed compression ratio.

Transistorized Detonation Meter

The new transistorized meter is a solid state version of the 501A and 501AP meter which uses no vacuum tubes, requires no warm-up, and occupies a far smaller space. Dependability, stability, and freedom from operational problems are gained by the use of this new meter. The preferred D-1 pickup is used with this meter. At the time of this printing, the meter is [redacted] ASTM approved.

Transistorized Signal Generator

The signal generator provides a reference signal which will permit adjustment of the spread on the Detonation Meter, independent of the engine. The signal also permits a quick operational check to the Detonation Meter if malfunctioning is suspected.

Multiple Speed Power Absorption Motor

(Not Illustrated)

Two-speed induction motors can be provided for power absorption where it is desired to run more than one constant engine speed. Two-speed motors are generally used to permit switching between 600 and 900 rpm for Research and Motor Methods. When using an induction type motor for power absorption, exact synchronous speed is not obtained. The difference between speeds when motoring or absorbing engine power may be as great as two to four percent. However, speed control when operating at engine full load is maintained constant within less than one percent.