CIVIL AERONAUTICS AUTHORITY

Technical Development Report No 19

THE ALFARO ENGINE

By K S CULLOM
Power Plant Section

Formerly Report No 4, Technical Development Division
Civil Aeronautics Authority

JANUARY 1939

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON 1941

CONTENTS

The Alfaro Engine

SUMMARY

The Alfaro engine built for the Bureau of Air Commerce (now Civil Aeronautics Authority) by Aircraft Development, Inc, Boston, Mass, passed its contract 2-hour acceptance test on May 16 1938 This engine was developed to its present stage with the assistance of the Bureau in an attempt to provide a more efficient power plant for commercial aircraft

The engine is of the crankless or so-called "barrel" type employing two cam plates which are actuated by double-opposed pistons, and operates on the two-stroke cycle with fuel injection and spark ignition The engine built for the Bureau was of the four-cylinder (eight piston) water-cooled type The average performance figures for the 2-hour test are 113 b hp (obs) at 2,030 r p m, 132 lb per sq in b m e p (obs), and a specific fuel consumption of 0 59 lb per b hp-hr The corrected values are 115 b hp at 2,000 r p m with a b m e p of 136 The specific dry weight of the engine, including generator and starter, is 2 34 lb per b hp The frontal diameter is approximately 15½ inches

The results of the test prove the practicability of the design and indicate that, with further development there is considerable promise that the Alfaro engine can become a lighter, and more compact aircraft power plant than conventional types It is recommended that the development of this engine be continued

INTRODUCTION

In August 1935 tests were completed with a water-cooled, single-cylinder engine of the crankless, two-stroke cycle, fuel injection spark ignition, double-opposed piston type, designed by Heracio Alfaro, of Aircraft Development, Inc, of Boston, Mass, and built with the cooperation of the Indian Motorcycle Company of Springfield, Mass

The tests were conducted at the engine laboratory of the Massachusetts Institute of Technology The engine was, as far as is known, the first of this type and was made to investigate the possibilities of Mr Alfaro's design This single-cylinder engine was of 3¾-inch bore and 5-inch stroke (111 cu in displacement) and developed 80 b hp at 2,000 r p m on 72 octane fuel A 9 5 1 compression ratio was used, and the scavenging pressure was 6½ inches Hg A b m e p of 145 lb per sq in and a specific fuel consumption (at a power output corresponding to cruising) of 0 435 lb per b hp-hr were obtained, with the scavenging air supplied by an independent air compressor With full load the air consumed was approximately 145 percent of the piston displacement

These results were considered promising, since they indicated that a lighter and more compact engine than the conventional type could be developed advantageously Accordingly, designs were prepared for an engine of suitable size for light commercial airplanes This design was submitted, together with the data obtained on the single-cylinder tests to the Development Section of the Bureau of Air Commerce of the Department of Commerce The data and design appeared so promising that specifications were written for an engine of this type to be used in small, privately owned airplanes, and on October 16, 1935, the Bureau ordered from Aircraft Development, Inc, the construction of such an engine The contract required, in part, that the engine should deliver 90 b hp for a period of 2 hours at a speed of not over 2,000 r p m, and that the specific fuel consumption should not exceed 0 65 lb per b hp-hr It was further

required that the engine develop 0 4 b hp for every pound of its weight including generator and starter

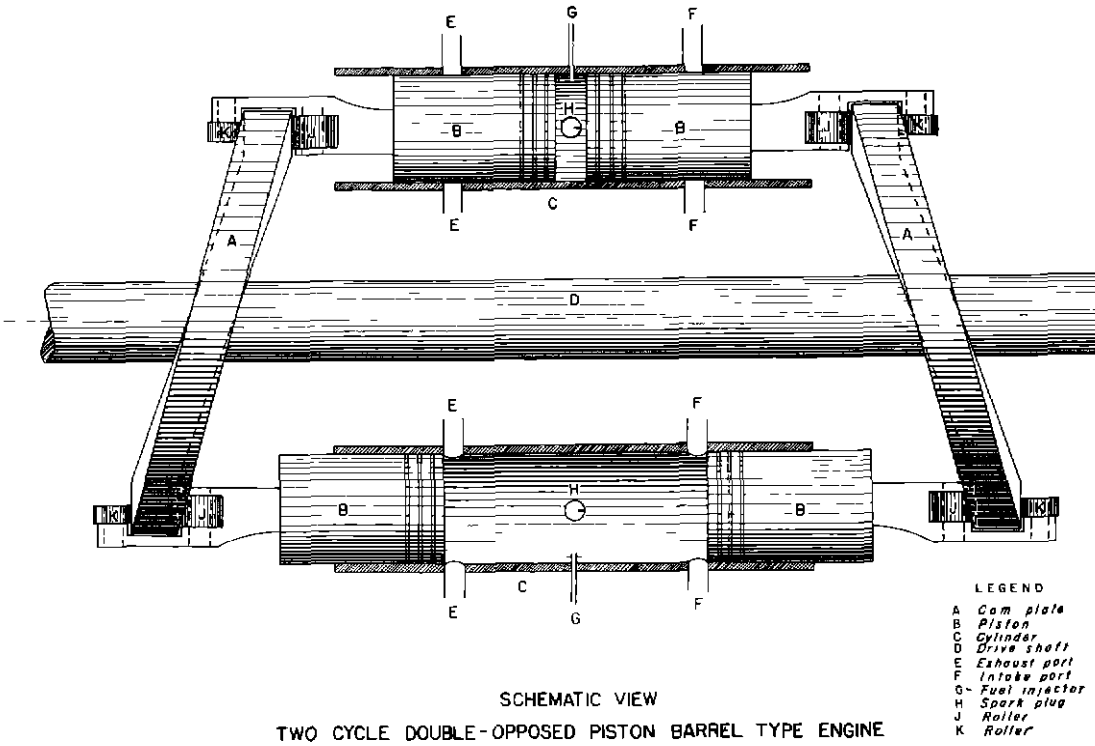
DESCRIPTION OF ENGINE

The engine built for the Bureau is a four-cylinder (eight-piston) execution of the same type as the original single-cylinder engine except that it was constructed of lighter materials and had a bore of $2\frac{11}{16}$ inches and a stroke of $3\frac{3}{8}$ inches per piston (167 cu in total displacement) and the engine shaft was designed to fit a standard propeller hub

The cylinders are parallel to the drive shaft and disposed at equal distances and angles about the shaft (See figs 1, 2 and 3) There are two pistons operating in each cylinder with heads opposite each other, thus forming a common combustion chamber The pistons act directly on two cam plates by means of roller bearings The cam plates are integral with the drive shaft and located one at each end The drive shaft is equipped with single-row annular ball bearings

With the exception of the fuel-injection valves there are no mechanically operated valves, the intake and exhaust being accomplished by the pistons uncovering the ports, one piston controlling the intake ports and the other piston controlling the exhaust ports The fuel injection takes place under a pressure of 2,000 lb per sq in The pump comprises two units with two plungers each, of the Bosch type placed 90° from each other on a cam casing which contains also a drive for the primary fuel pump and another for the tachometer connection The camshaft drive has an adjustable coupling which permits accurate injection timing Each cylinder has a fuel discharge nozzle of the Bosch differential type

The scavenging air is supplied by a centrifugal blower built within the engine and driven through an intermediate gear at approximately ten times engine speed Calibration of the blower showed that at an engine speed of 2,000 r p m, and a delivery of 350 cu ft per min at 6½ inches Hg pressure, the power required



SCHEMATIC VIEW
TWO CYCLE DOUBLE-OPPOSED PISTON BARREL TYPE ENGINE

Figure 1

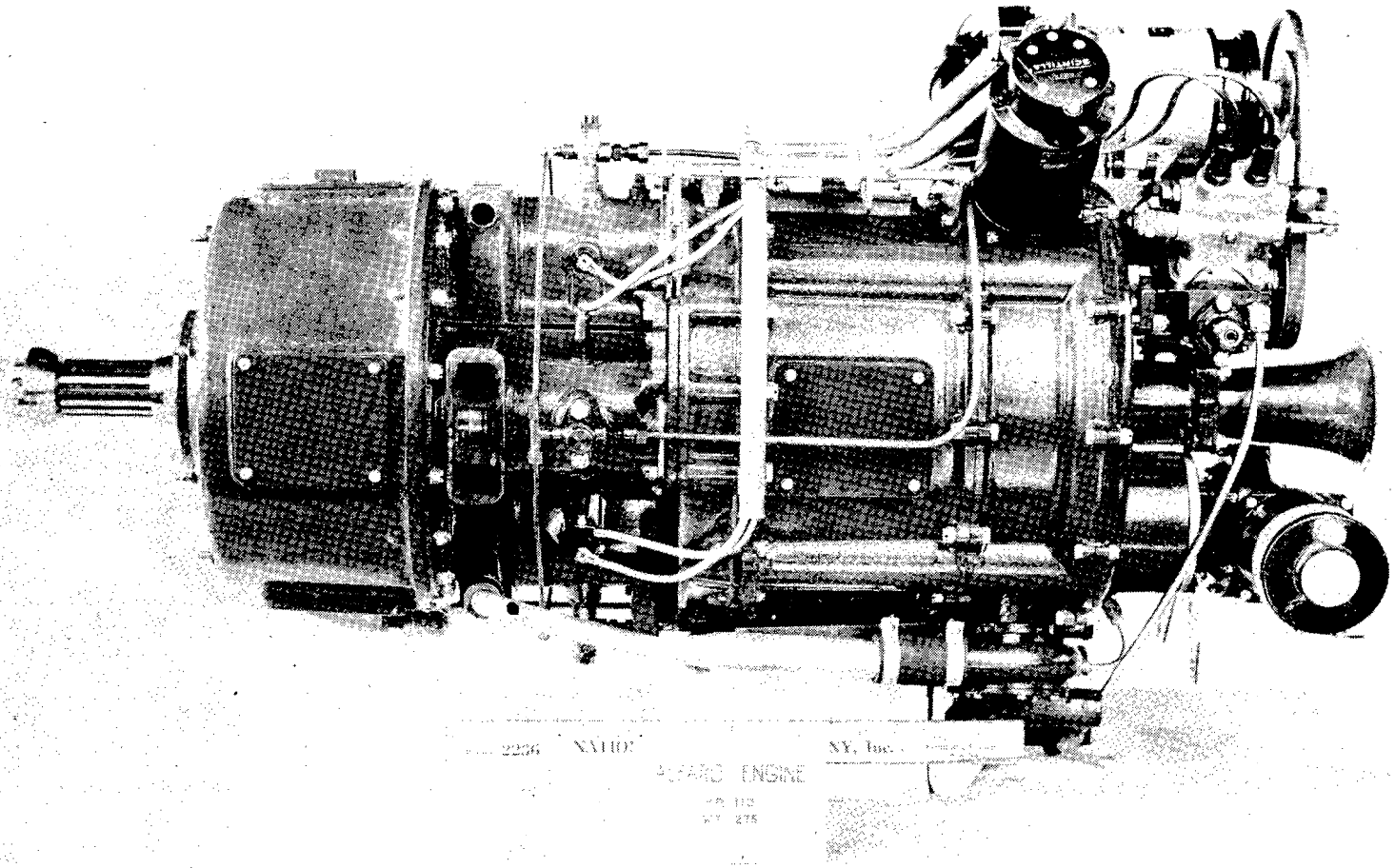


Figure 2.

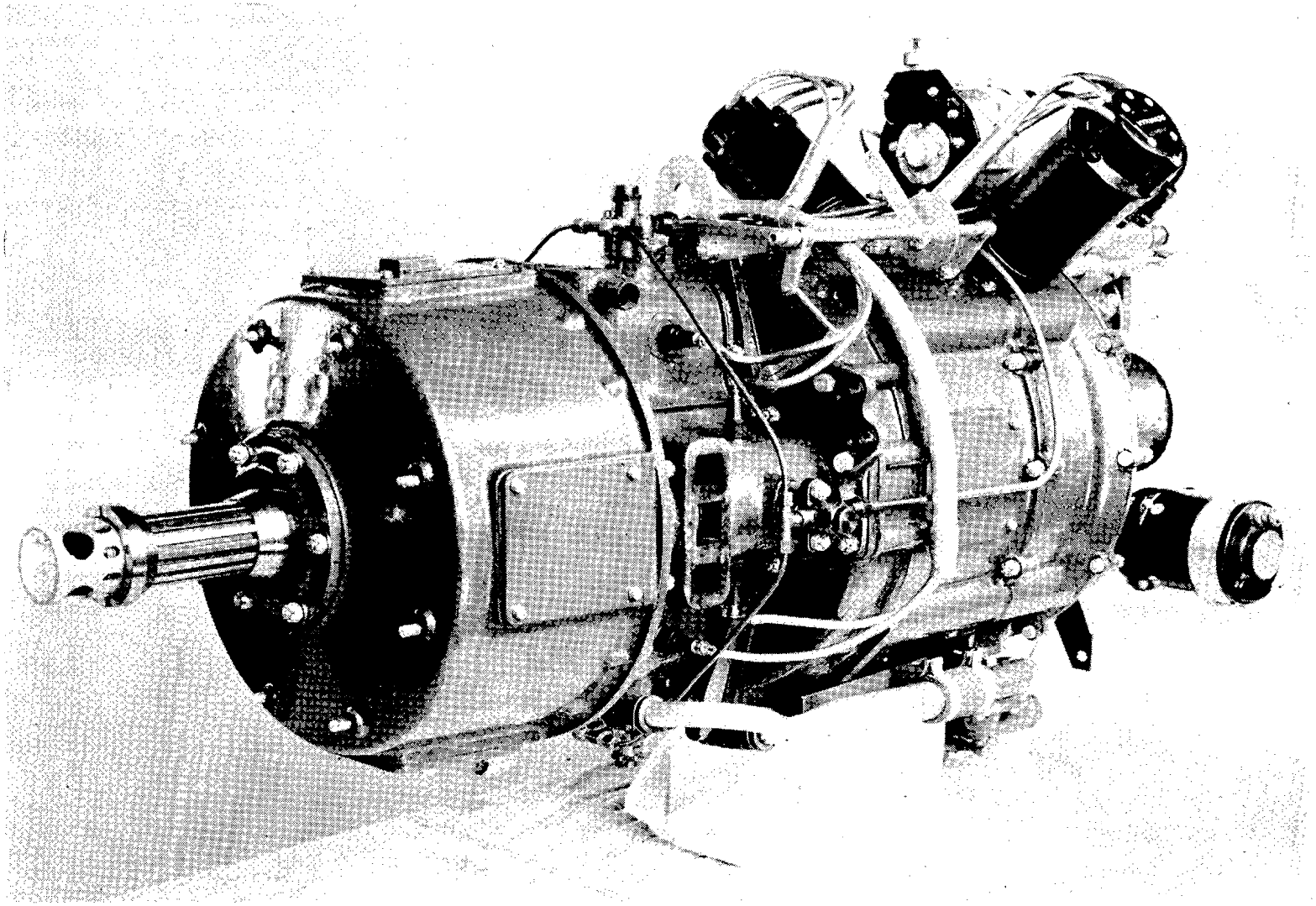


Figure 3.

was 8 34 hp , and the adiabatic efficiency approximately 60 percent

The engine has dual ignition, which was originally supplied by magnetos, but later changed to the timer and battery type in order to save bulk and weight The final arrangement included two special 12-volt Autolite coils Champion L M 5–C 14 mm spark plugs are used The generator is driven by a belt from the end of the cam shaft, and an "Eclipse' type electric starter is used

The engine is equipped with a centrifugal water pump, one oil pressure and two scavenger pumps Lubrication is accomplished by spraying oil through jets onto the cam plate, and the reciprocating units are lubricated by oil scooped from these elements

The compression ratio is 9 5 1 The dry weight of the engine is 269 lb , including generator and starter, which weigh 29 lb together The overall length of the engine is 44$\frac{9}{16}$ inches, and the diameter of the body approximately 15½ inches, excluding spark plugs and other protruding small accessories The total running time on the engine prior to the acceptance test was approximately 40 hours, about 10 hours of which were at or near full throttle

INSTALLATION

The power was absorbed by an electric cradle dynamometer connected to the engine by means of a short flexible coupling The engine was mounted on three rubber blocks of a natural frequency out of the range of operation of the engine The torque was measured on a beam scale

The fuel consumption was measured by the volume method, by timing the flow from a 215 cc pipette Carbon dioxide could be admitted to the pipette to force the flow The fuel was supplied from a tank under pressure of water from the city mains

The oil system consisted of an oil tank and an oil cooler, the latter being equipped with coils for use of water and steam for regulating the temperature

The water system was equipped with a tank placed about 10 feet above the engine The centrifugal pump driven by the engine circulated the water between the tank and the cylinder jackets Cold water could be added to the tank to maintain the proper temperature

The exhaust system included a manifold attached to the engine outlets and loosely connected to the exhaust main of the laboratory In this way the engine could freely oscillate due to the elasticity of the rubber blocks of its mount The laboratory's exhaust main was connected to a clearing blower which produced a suction of approximately $\frac{1}{10}$ inch Hg An auxiliary air blower was used to keep the exhaust manifold from becoming overheated

The electric current necessary for the ignition system was supplied by two regular automobile 6-volt batteries in series

The throttle control was arranged so that it was possible to operate the air inlet and the fuel delivery simultaneously, or independently

The instruments read during the test are indicated in the data

DESCRIPTION OF TEST

The 2-hour acceptance test required by the contract was run on May 16, 1938 The test was made at 2,000 r p m , at practically full throttle

The fuel used was gasoline with an octane rating of 87 (sp gr 0 73), although the designer states that the engine has operated successfully on 72 octane fuel without detonation Five percent of lubricating oil was added to the fuel in order to save the fuel pumps and injection nozzles from excessive wear Wolf s Head H O 120 oil was used Oil consumption was not specified in the development contract, but the consumption during the test was somewhat less than 0 025 lb per b hp -hr

The test was completed without difficulty The torque was steady throughout the test except when a certain irregularity could be heard This irregular sound, it is believed, was caused by unevenness in the injection nozzles which were of an experimental type, and may have caused slow or uneven burning in the cylinders, with corresponding explosions in the intake Small oscillations of the column of mercury could be observed coincident with these explosions

Near the end of the test the power dropped slightly, and it became necessary to open the throttle fully to maintain the power Exami-

nation of the engine after the test showed that the coupling between the engine and the injection pump was broken Although it was still in operation, the timing of the injection pump was substantially altered, which accounts for the drop in power

After completion of the acceptance test runs were made to ascertain the friction horsepower

RESULTS AND DISCUSSION

The engine met the contract requirements

The average performance figures for the test are 113 b hp (obs) at 2,030 r p m , 132 lb per sq in b m e p (obs) and a specific fuel consumption of 0 59 lb per b hp -hr The corrected values are 117 b hp at 2030 r p m , or 115 b hp at 2,000 r p m with a b m e p of 136 The test data and the computed results are shown on pages 7 and 8

The mechanical efficiency at 2,000 r p m was 86 percent at full throttle, and 90 percent with the throttle closed

The dry weight of the engine including generator and starter is 269 lb , which gives a specific weight of 2 34 lb per b hp

The tear-down inspection made after the test showed a broken Oldham coupling disc in the fuel pump drive, and one slightly fractured crosshead casting, all other parts were satisfactory

The dry specific weight of this first Alfaro engine (2 34 lb per b hp) is approximately in line with that of radial air-cooled engines of the same power The weight of the complete power plant, including the cooling system, which would add 0 4 to 0 5 lb per b hp , would therefore be greater than that of conventional engines of the same power However, it is known that the weight of this first engine can be reduced considerably by refinement of design, because the cylinder block including the water jackets is made of cast iron It has been estimated by the designer that an eight-cylinder execution of this engine would deliver approximately 265 b hp at 2,400 r p m with a total weight including ethylene-glycol cooling system, generator, and starter of close to 400 lb , which would give an estimated total specific weight of approximately 1 5 lb per b hp The diameter of the main body of the engine would remain approximately 15½ inches

The frontal diameter of this engine is close to half that of equivalent radial engines, which would give a frontal area about one-fourth as great This factor would prove a considerable advantage in minimizing power plant drag at high speeds, in addition to improving the visibility from single-engine aircraft

This engine embodies the important feature of two-cycle operation which is essential to large reductions in specific weight Also, it lends itself to the adaptation of compression ignition and the use of heavier fuels

CONCLUSIONS AND RECOMMENDATION

1 It was concluded that the results of the test indicate the practicability of the Alfaro engine design

2 It was further concluded that refinement of the design, together with additional testing, and development work, may be expected to produce a simpler, lighter, and more compact power plant than conventional types for aircraft use

3 It is recommended that the development of the Alfaro engine be continued

Alfaro Engine **Aircraft Development, Inc**

U S DEPARTMENT OF COMMERCE

GENERAL LOG SHEET

Friction Run

R P M	Load T C	Load T O	F H P-T C	F H P-T O
1,820 2 000	16 5 17 o	23 28 5	10 11 7	14 10

Alfaro Engine **Aircraft Development, Inc**

U S DEPARTMENT OF COMMERCE

GENERAL LOG SHEET

TEST—**Contract 2 hr acceptance** DATE—**May 16, 1938**
OBSERVER—**J H Geisse**

Run No	Counter r p m	Torque, lb at 21 inches	Dry bulb temp °F	Wet bulb temp °F	Barometer observed pressure cm Hg	Secs fuel 215 cc	S F C (lb per b hp hr)	B Hp	
								Obs	Corr
1	Ind 2000	165	79	60	7o 2			110	113 5
2	2040	167				17	(66)	111	114 5
3	2060	169				17 8	600	116	119 7
4	2020	170				18 2	o85	114.5	118.1
5	2040	169 5				18 6	o78	115 3	119 0
6	2030	169 5				18 6	581	114 8	118.4
7	2020	168 o				19 0	575	113 7	117 3
8	2030	166				18 6	o92	112.3	115.9
9	Ind 2020	165				18 5	604	111	114 5
Average	2030						59	113 2	116 8

Alfaro Engine **Aircraft Development, Inc**

U S DEPARTMENT OF COMMERCE

GENERAL LOG SHEET

TEST—**Contract 2 hr acceptance** DATE—**May 16, 1938**
OBSERVER—**J H Geisse**

Run No	Time, hr min	Counter r p m start-fin	Oil inlet temp °F	Water temp °F		Oil pressure, lb per sq in gage	Throttle setting	Spark setting degrees	Intake port pressure, In Hg
				In	Out				
1	11 10	Ind 2000	120	140	180	25	F T	12	6 1
2	11 30	S 2996 F 3200	110	140	180	25			6 1
3[1]	11 45	3200 3406	10o	140	180	25			6 0
4	12 00	3406 3608	100	140	180	25			5 7
5	12 15	3608 3812	100	140	180	25			6 0
6	12 30	3812 4015	100	140	180	25			6 0
7	12 45	4015 4217	100	140	17o	25			6 0
8	1 00	4217 4420	100	140	170	25			6 0
9	1 10	Ind 2020	100	140	170	25			6 0

[1] Generator pulley came off and was left off for balance of run

Tear-Down Inspection

Oldham coupling disc for fuel pump broken (Accounts for drop in power last 5 min) One cross head casting fractured All other parts—O K

Engine Weight

269 lb including generator and starter Starter weighs 19 lb, generator 10 lb

Installation

Elec Dyn—Rubber engine mount Fuel system under 20 30 lbs pressure Fuel consumption by volume (215 cc)

Settings and Other Data

Ignition 12°	Nozzle Alfaro
Injection 74° BTC	Phase Angle 20°
Exhaust Open 66°, Close 66°	Comp Ratio (Nom) 9 5 1
Intake Open 55°, Close 55°	Spark Plugs Ch LM5C
Inj Pres 2,000 lb -sq in	Oil Wolfshead H O 120

Fuel 87 Octane (sp gr 73)

○