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TEST OF PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE.(U)

MAR 49 A R SCHRADER

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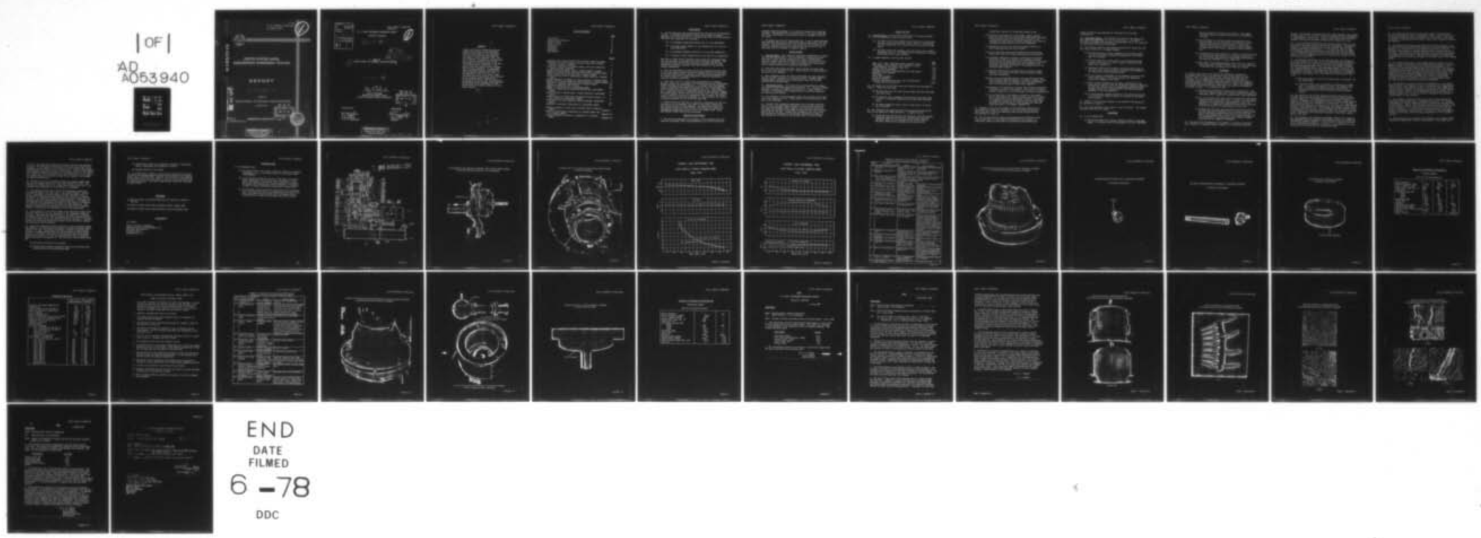

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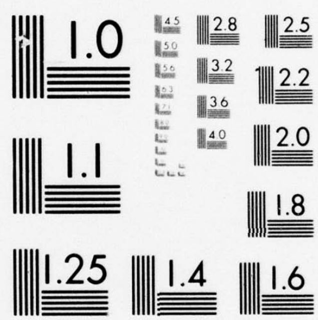

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E.E.S. REPORT C-3599-A(1)
25 MARCH 1949

UNITED STATES NAVAL ENGINEERING EXPERIMENT STATION

REPORT

TEST OF

PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE

- NS-623-071 -

NEES
C-3599-A(1)

ANNAPOLIS, MARYLAND

88/78

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U. S. NAVAL ENGINEERING EXPERIMENT STATION

Annapolis, Maryland

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6 TEST OF
PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE,

by

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ABSTRACT

A Model 1/4D Philips external combustion engine was delivered 18 May 1943 under Contract NObs-34195 for test. Variable load tests were conducted and attempts were made to obtain endurance runs. The test operation was generally unsatisfactory due to numerous casualties and to the inadequate delivery capacities of the gasoline nozzle and air compressor. The test of the first engine was discontinued after 86 hours operation. A replacement engine embodying numerous modifications was subsequently furnished for test. It was operated a total of 79 hours. Test operation again was generally unsatisfactory due to numerous minor casualties and operating difficulties, such as fouling of the gasoline or air nozzles, carbon deposits on the burner head, deformation of the burner grate and improper operation of the burner control.

TABLE OF CONTENTS

INTRODUCTION

1. The Stirling cycle was devised during the early part of the Nineteenth Century. It aroused considerable interest and a number of engines employing this operating cycle, or its variations, were built and operated. The basic cycle comprises the following:

(a) An isothermal compression carried out at a low temperature.

(b) A constant volume transfer of the working fluid to a zone of high temperature.

(c) An isothermal expansion carried out at the high temperature.

(d) A constant volume transfer back to the zone of low temperature.

Heat must be added from an external source during the isothermal expansion and heat must be rejected during the isothermal compression. Net work results from the fact that the available energy from the high temperature expansion is greater than that required for the low temerature compression.

2. With the development of better steam power machinery and the invention of practicable internal combustion engines during the latter part of the Nineteenth Century, interest in the Stirling cycle engines died out because they were no longer competitive from the standpoints of size and operating reliability.

3. About 1937, the N. V. Philips Gloeilampenfabricken, Eindhoven, Holland, started the development of a Stirling cycle engine using modern design knowledge and modern materials. In January 1946, development work on a Stirling cycle engine was started in this country under Navy contract NObs-34195 by the Philips Laboratories, Inc., Dobbs Ferry, N. Y., employing a group of technicians loaned by the Eindhoven Company. The present engine was the first unit delivered under the Navy contract. It was intended not only as an experimental unit to permit the investigation of the Stirling cycle as applied to a modern engine, but also as a portable generator set for front-line radio use.

4. Authorization for this test is contained in references (a) and (c). Priority A-3 in the February list, Small Diesel Engine Branch, and cost classification "W" were assigned. The engine was delivered to this Station 18 May 1948 under Contract NObs-34195; this engine was subsequently replaced by a second unit on 16 December 1948. Tests were started 19 May 1948 and are continuing.

DESCRIPTION OF MATERIAL

5. The unit was constructed as a portable electric generator set and comprised the engine, dual voltage generator, air and fuel tanks and

necessary auxiliary equipment. All parts were mounted on a skid-type sub-base. The generator was direct-connected to the engine shaft and had a total rated output of 125 watts at the two voltages of 500 and 6.3 volts.

6. The engine was rated 1/4 bhp at 2500 rpm. It was a single-cylinder model having a power piston and displacer piston operating in the same cylinder. The cylinder bore was 2-1/2 inches and the strokes of the power and displacer pistons were respectively 1-7/32 and 3/4 inch. A sectional view of the engine is shown on Plate 1.

METHOD OF TEST

7. Original Engine. The engine was completely disassembled for inspection and wear measurements. After re-assembly, variable load tests were made at power outputs ranging from no load to maximum power. Repeated attempts were made to operate the engine continuously for 24 hours at a power output of 125 watts; the attempts were unsuccessful due to various casualties and operating difficulties.

8. Tests were made using both Shell rubber solvent and Amoco water white (lead free) gasoline as fuel. Shell Albis No. 22 lubricating oil was used in the crankcase.

9. Fuel consumption tests were made by measuring the time required to consume the fuel contained in a calibrated flask. Standard types of pressure gages, thermometers and thermocouples were used for the observation of pertinent data.

10. Replacement Engine. The engine was not disassembled for inspection prior to test in accordance with reference (c). Repeated attempts were made to operate the engine for 500 hours at a power output of 125 watts. The attempts were unsuccessful due to various casualties and operating difficulties.

11. All operation of the replacement engine was with Amoco water white (lead free) gasoline as fuel. Shell Albis No. 29 lubricating oil was used in the crankcase.

12. Accurate fuel consumption measurements were not made during the tests of the replacement engine because of the possibility that the fuel measuring equipment might interfere with the engine fuel flow. The engine was operated on fuel taken directly from the self-contained supply tank of the unit. Average fuel consumption over two to four hour periods was determined by periodically measuring the amount of fuel required to fill the tank to the same level for each filling.

RESULTS OF TEST

13. Original Engine. The pre-trial disassembly of the engine showed it to be in satisfactory condition except that:

(a) The inner race of the crankpin needle bearing was spalled near the edge of the bearing roller travel, Plate 2. The bearing race was replaced by the contractor before re-assembly of the engine.

(b) The lower end of the cylinder, below the ports, had a scuffed appearance, Plate 3. The damage was not sufficient to indicate the probability of piston seizure.

14. A weight analysis of the dry unit follows:

	Lbs.
Base, incl. tanks, instrument panel, gasoline filter	53.0
Bare engine, less flywheel, fan, compressor, burner head assembly, fan casing, base, etc.	27.4
Flywheel and fan assembly	9.6
Compressor assembly, including chain and chain guard	5.0
Regulator block assembly	3.4
Fan casing	2.5
Burner head assembly	5.6
Generator assembly	16.3
Complete engine-generator unit, dry, including base, tubing, and all auxiliaries	122.9

15. The results of the variable load tests conducted are presented on Plate 4. These data show that:

(a) The fuel rate was 0.64 lb/hr with the Amoco fuel and 0.60 lb/hr with Shell Fuel.

(b) The specific fuel consumption at rated power, 125 watts, was 5.2 and 4.8 lbs/kw-hr, respectively, for the Amoco and Shell fuels.

(c) The speed regulation from no load to rated power, 125 watts, was 3.5 percent.

16. The casualties and operating difficulties encountered during the test of the engine are listed on Plate 5. A summary follows:

(a) During the first 56 hours of test operation, there was chronic difficulty with loss of power and reduced heater head temperatures (1100°F or less instead of the desired 1200°F). The basic cause was the slightly faulty operation and insufficient capacity of the gasoline burner nozzle.

(b) Following installation of a new design, larger capacity gasoline nozzle at 56 test hours, there was chronic difficulty in maintaining proper air tank pressure because of the increased air requirements of the new gasoline nozzle and the inadequate delivery capacity of the air compressor.

(c) Throughout the test, the engine was usually difficult to start, requiring from two to ten trials.

(d) On two occasions, heavy carbon deposits were found on the heater head, Plate 6, causing interference with combustion.

(e) Compressor difficulties included: cracking of two suction valve discs, Plate 7; sticking of the compressor piston; fouling of the discharge valve with carbon deposits; loosening of the suction valve neoprene seat; and breakage of the compressor crankshaft by failure of the brazed joint of the two-piece shaft, Plate 8.

(f) Generator difficulties included: Shorted internal wiring; rubbing of the rotor on the field coils and stator insulation; and overheating.

(g) Loose scale was generally found on and near the heater head when the burner head was removed. A chemical analysis of the scale indicated that its apparent source was the stainless steel of the heater head or burner head, Appendix I.

(h) Cracking of the heater head occurred after 77 hours operation, resulting in a loss of air pressure. The results of a metallurgical examination of the failed part are given in Appendix II.

(i) In the inspection of the engine, incident to the replacement of the heater head, black and white deposits were found on the metal wire of the regenerator, Plate 9. The results of a chemical analysis of the deposits indicated that they contained oil and corrosion or wear products of steel and copper materials in the engine, Appendix III.

17. Analyses of new and used samples of the crankcase lubricating oil are presented on Plate 10. Analyses of the Shell rubber solvent and Amoco water white (lead free) gasoline used as fuels during the test are presented on Plate 11.

18. Test of the original engine was discontinued after 86 hours operation at this Station. The longest continuous run was 20 hours. A replacement engine incorporating the improvements and modifications

listed on Plate 12 was submitted for continuation of the test, reference (b).

19. Replacement Engine. The observed fuel rates for the engine with Amoco gasoline ranged from 0.71 to 1.03 lb/hr (avg., 0.85 lb/hr). The engine performance was generally unsatisfactory due to the casualties and operating difficulties encountered.

20. The observed casualties and operating difficulties during the test are listed on Plate 13. A summary follows:

(a) On three occasions, partial plugging of the gasoline and/or air nozzles occurred, causing the temperature of the heater head to be reduced.

(b) On three occasions, carbon deposits on the heater head and related parts, Plates 14 and 15, caused a reduction in the heater head temperature.

(c) Compressor difficulties included: stretching and/or wear of the drive chain, causing excessive looseness; and breakage of the chain idler pulley mounting bracket.

(d) On one occasion, replacement of the neoprene seal ring at the lower flange joint of the cooler section was required to prevent air leakage at that point.

(e) After 12 hours operation of the engine, deformation of the burner grate occurred, Plate 16, resulting in improper combustion. The part was replaced by a re-designed part having a tapered section; there was no further similar difficulty during the remainder of the test operation.

(f) On two occasions, improper operation of the burner control due to fouling of the leak-off orifice or sticking of the needle valve occurred.

21. Analyses of new and used samples of the crankcase lubricating oil are presented on Plate 17.

22. The total operation of the engine to date is 79 hours. The longest continuous run was 18-1/2 hours.

CONCLUSIONS

23. It is concluded that:

(a) The Philips Model 1/4D external combustion engine is not suitable, in its present state of development, for use in the Naval

Service because of its lack of reliability. The longest continuous period of operation that could be obtained was 20 hours.

(b) The performance of the basic engine was generally satisfactory except for the cracking of the heater head of the original engine after 77 hours operation. Most of the difficulties encountered were with the externally mounted equipment such as the burner, compressor, burner controls, etc.

(c) The engine is not well suited for a study of the practicability of the Stirling cycle because of its extremely small size and the relative complication and high power requirements of the auxiliary equipment of such a small unit.

(d) The weight of the engine-generator unit, 122.9 lbs., approximately one pound per watt of rated output, is much higher than is desirable for a portable unit of this power output.

DISCUSSION

24. Shell rubber solvent was used as fuel during the contractor's development work prior to the delivery of the original engine to this Station. This is a light gasoline type petroleum distillate and is considered to be a higher grade fuel with a lower end point and a considerably narrower distillation range than the Amoco water white gasoline used during most of the Station's tests, Plate 11. Much of the combustion difficulties experienced during the Station's tests may be attributed to the change in fuels. It is pointed out that:

(a) The Shell fuel burned more cleanly than the Amoco fuel. The Amoco fuel tended to have a more luminous flame and it gave off occasional puffs of smoke and a pungent odor during combustion.

(b) All of the heater head carbon deposit troubles were experienced during operation on the Amoco fuel. However, the total engine operation on the Shell fuel, approximately 67 hours, was insufficient to demonstrate conclusively that carbon formation difficulties would not be experienced with that fuel.

(c) A higher fuel flow rate was required with the Amoco gasoline. The gasoline nozzle furnished with the original engine did not have a sufficiently high delivery rate for the Amoco fuel. When it was replaced with a nozzle of increased capacity, the air requirements of the new nozzle were increased, thereby rendering the air compressor inadequate.

25. The specific fuel consumption of the engine 5.2 lb/kw-hr with Amoco fuel, appears to be somewhat high as compared with conventional gasoline

engines. The smallest conventional gasoline engine generator sets tested by this Station, 1.5 to 2.0 kw in size, had rated power fuel consumptions of approximately 1.75 lb/kw-hr. However, these units cannot be validly compared with the Philips engine because of the disparity in size.

26. It is considered probable that the observed carbon deposits on the heater head were caused by minor combustion derangements. The deposits occurred at irregular intervals and on some occasions they followed observed combustion irregularities. It is considered that the range of acceptable combustion conditions is too narrow and that the combustion is excessively sensitive to various factors such as burner nozzle pressure, partial plugging of fuel or air nozzles, and variation of the fuel nozzle suction lift.

27. The starting difficulties in the original engine are believed to be due principally to the use of too low a crankcase starting pressure. Initially, 25 to 30 psi was used as the starting crankcase pressure. This was subsequently raised to 50 to 60 psi in an effort to improve the starting characteristics. The replacement engine used 100 to 120 psi crankcase pressure for starting and no difficulty in starting was experienced at any time. The higher starting pressure is considered to be generally satisfactory but it does have the following minor objections:

(a) The force required to pull the starting rope is increased, but not excessively.

(b) A greater volume of air is required to pressurize the crankcase. This causes the engine air tank to be somewhat inadequate in capacity and sometimes the air supply must be replenished during the initial heating or initial running periods.

28. The compressor difficulties experienced during the test of the original engine occurred during efforts to obtain the maximum delivery from the compressor. The maximum delivery was required in order to supply the increased air requirements of the new design, larger capacity gasoline nozzle, which was installed at 56 test hours. The compressor difficulties may have been, in part, due to the efforts to obtain maximum delivery. The compressor is a single-stage unit normally operating at a delivery pressure of 140 psi. It is necessary that the clearance volume be adjusted to the minimum practicable in order that delivery of air can occur. Necessarily, the piston-head clearance is very small, approximately 0.002 inch.

29. The breakage of the compressor crankshaft, Plate 8, was caused by the compressor piston striking the head during operation as a result of insufficient adjusted clearance. A weak brazed, two-piece construction of the crankshaft contributed to the failure. The crankshaft was later replaced by a one-piece shaft of increased strength.

30. The compressor suction valve discs that cracked during the test of the original engine, Plate 7, were made of steel. Suction valve discs of beryllium copper were later furnished by the contractor. There were no failures of the new type valve discs, either in the original or replacement engines.

31. The scaling of the heater head and/or burner head, Appendix I, did not apparently cause any difficulty during the test period reported herein. However, it is considered to be an undesirable condition in that it indicates deterioration of the metal and may lead to eventual failure of the parts. The scaling is probably caused by the necessarily high operating temperatures of the parts. The observed scaling was not apparently connected with the failure, by cracking, of the heater head of the original engine.

32. The cracked heater head of the original engine, Appendix II, was a design in which the external fins were fabricated and brazed in position. While the cause of the failure was not definitely determined, it is possible that the brazing operation may have contributed to the failure. A replacement heater head for this engine had the external fins machined integrally with the head, although the internal fins were brazed. The heater head of the replacement engine was of similar construction. No cracking difficulties were experienced with either of these heads, although the length of operation, 79 hours on the replacement engine, was insufficient to demonstrate conclusive improvement.

33. The analysis of deposits found on the regenerator of the original engine after 81 hours operation, Plate 9 and Appendix III, suggests that corrosion and/or wear products of iron or steel and copper formed part of the material. Analysis of crankcase lubricating oil removed from the engines, Plates 10 and 17, show extraordinarily high ash content for a straight mineral oil, 0.14 to 0.45 percent, indicating the presence of unusual amounts of wear products.

34. The foregoing infers that the rate of wear in the engine may be excessively high, possibly due to inadequate lubrication. No internal disassemblies of the two engines were made following the test operation at this Station. However, the pre-trial condition of the cylinder of the original engine, Plate 3, would indicate that its lubrication was not fully satisfactory. It is pointed out that lubrication in this type engine is a difficult problem in that lubricating oil must be prevented, as far as practicable, from reaching the regenerator or heat transfer surfaces.

35. Deterioration of the crankcase lubricating oil was extremely rapid, although the temperature of the oil was generally in the range of 180

to 200°F. The rapid deterioration was probably caused by the agitation of the oil and the high air pressure, 90 to 100 psi, maintained in the crankcase. In two samples of oil operated 52 and 56 hours, the neutralization numbers were 3.40 and 2.44, respectively. There was some tendency for carbonaceous appearing deposits to cover exposed areas in the crankcase. However, in the relatively short operating periods of the engines, the deposits were not excessive and they did not appear to have caused any operating difficulty.

36. The fuel rate of the replacement engine was somewhat higher than that of the original engine, viz. 0.85 lb/hr versus 0.64 lb/hr. The increase was probably due to the larger capacity fuel nozzle and to the increased power requirements of the larger air compressor.

37. The compressor drive chain used on the replacement engine was considerably smaller than that used on the original engine. Through wear or stretching, the chain tended to develop excessive slack. A spring-loaded idler pulley was provided by the contractor to tighten the chain. The vibration of the spring mounting was so great that the mounting broke after approximately 21 hours operation. A flywheel for the compressor was subsequently furnished for the purpose of smoothing out the torque fluctuations of the single-cylinder compressor. The operation following this modification was not sufficient to determine whether it would cause any improvement in the chain performance.

38. The deformation of the burner grate of the replacement engine after 12 hours operation, Plate 16, was caused by the inadequate design of this part. The grate was supported only at its center and it operated at substantially red heat. The replacement grate had a thicker section at its center with the section tapering toward the periphery. This grate appeared to perform satisfactorily, without visible distortion, during the remaining 67 hours operation.

39. During the attempted endurance operation of the replacement engine, the generator load was manually controlled to maintain a constant engine speed of 2500 rpm. Considerable variation of output voltage and load resulted. Voltages ranged from 91 to 108 and generator output ranged from 110 to 157 watts. Such wide variations might cause difficulties during service operation of the unit and additional control equipment might be required to counteract it. The variations were probably caused by:

(a) Non-uniform operation of the burner.

(b) Variable heat transfer through the heater head resulting from carbon deposits and varying flame shape.

(c) Varying heat losses to the atmosphere because of non-uniform ambient temperature and varying air currents.

(d) Varying friction in the engine.

40. In normal service operation, such output variations would be controlled by the flywheel-mounted governor weights which would dissipate excess power as friction heat. However, the variation in load capacity of the engine would cause the engine to operate at different speeds for the same power output. This would cause voltage variations that might be objectionable.

REFERENCES

(a) Bureau of Ships letter NObs-34195(643-330) over S41-5, dated 13 May 1948.

(b) Bureau of Ships letter NObs-34195(643c) dated 5 August 1948.

(c) Bureau of Ships letter NObs-34195(643c) dated 23 December 1948.

DISTRIBUTION

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Washington 25, D.C.

RECOMMENDATIONS

It is recommended that:

(a) The Philips Model 1/4D external combustion engine be considered unsuitable for use in the Naval Service in its present state of development.

(b) If the Bureau has definite need for a very small, low output engine operating on the Stirling cycle, development of the Model 1/4D engine be continued by the contractor to simplify and improve the auxiliary and control equipment of the engine in order to obtain satisfactory reliability of these parts.

(c) If the Bureau's chief interest in the engine is the investigation of the Stirling cycle, developmental and test work on the Model 1/4D engine be discontinued, and development work be concentrated on a larger unit having 15 bhp or more output.

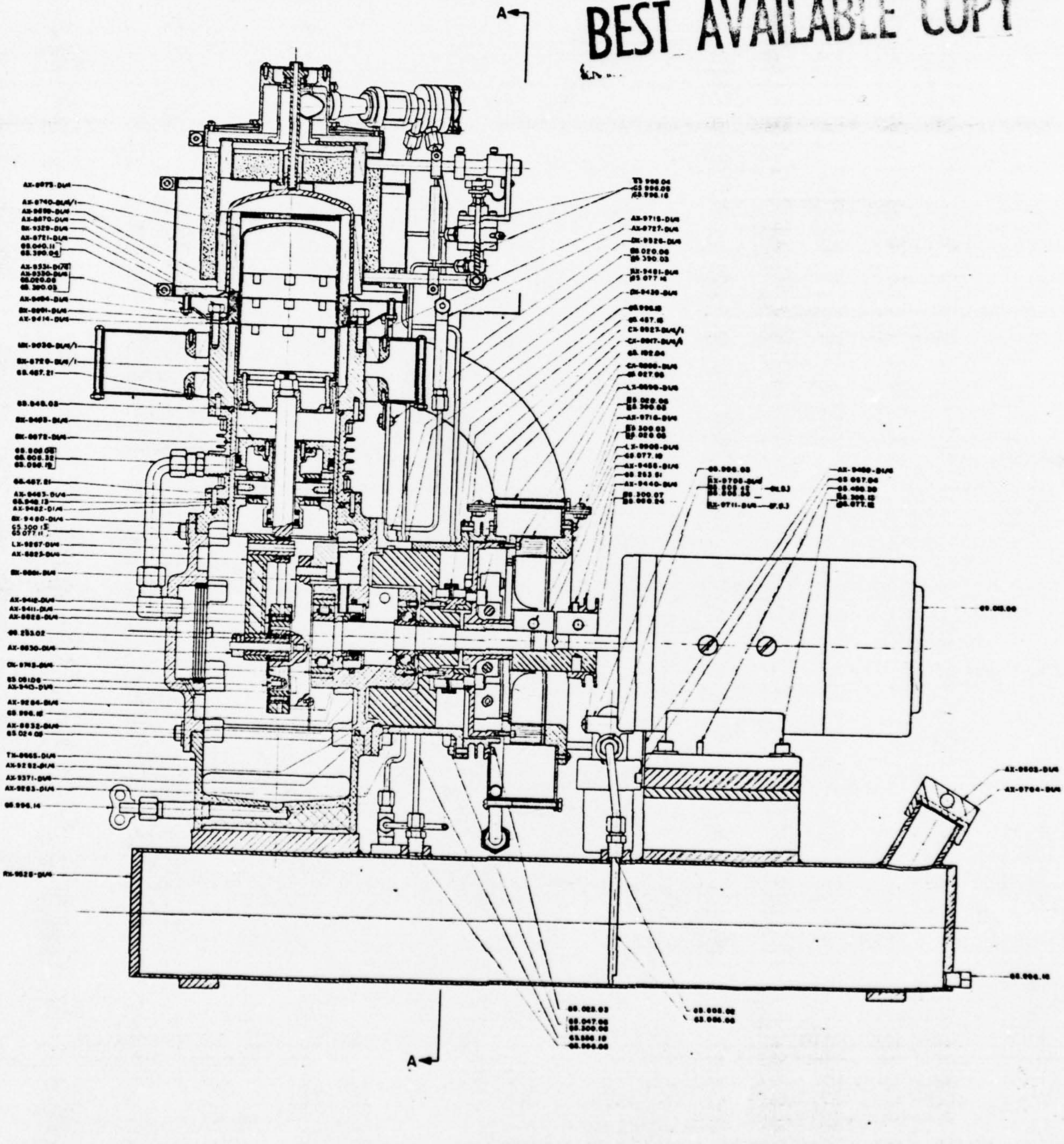
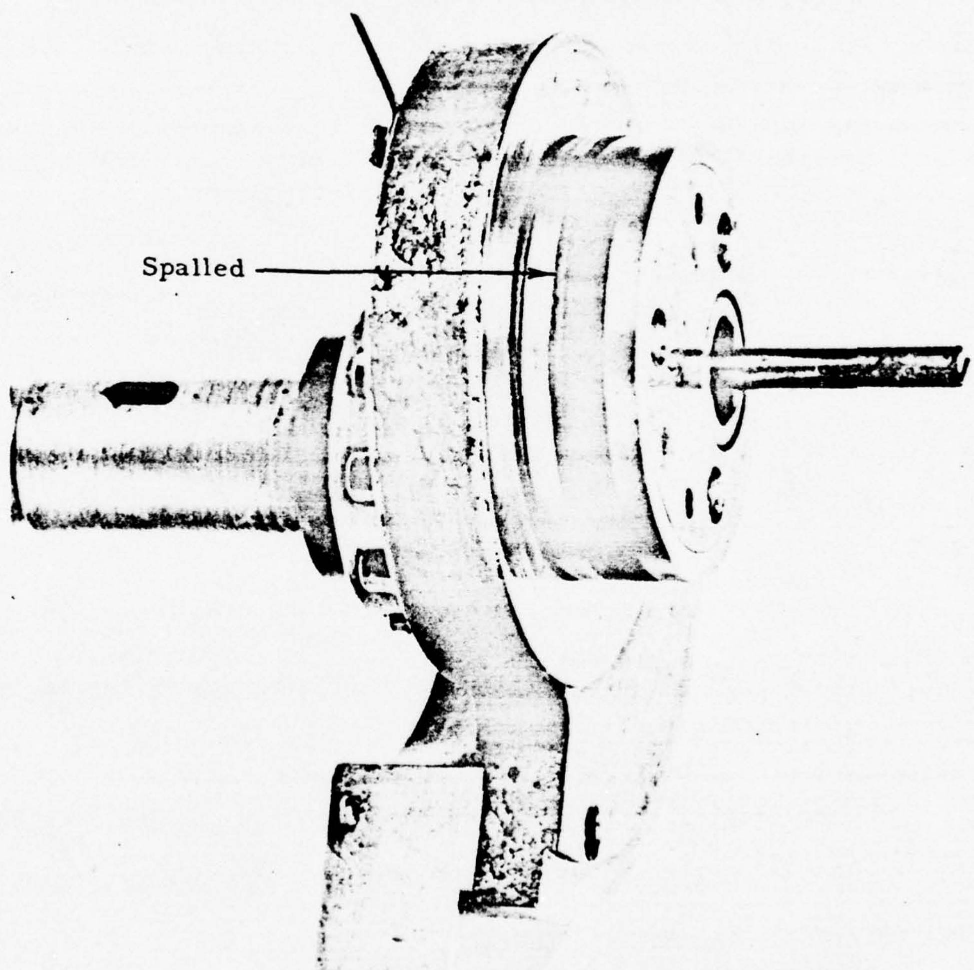
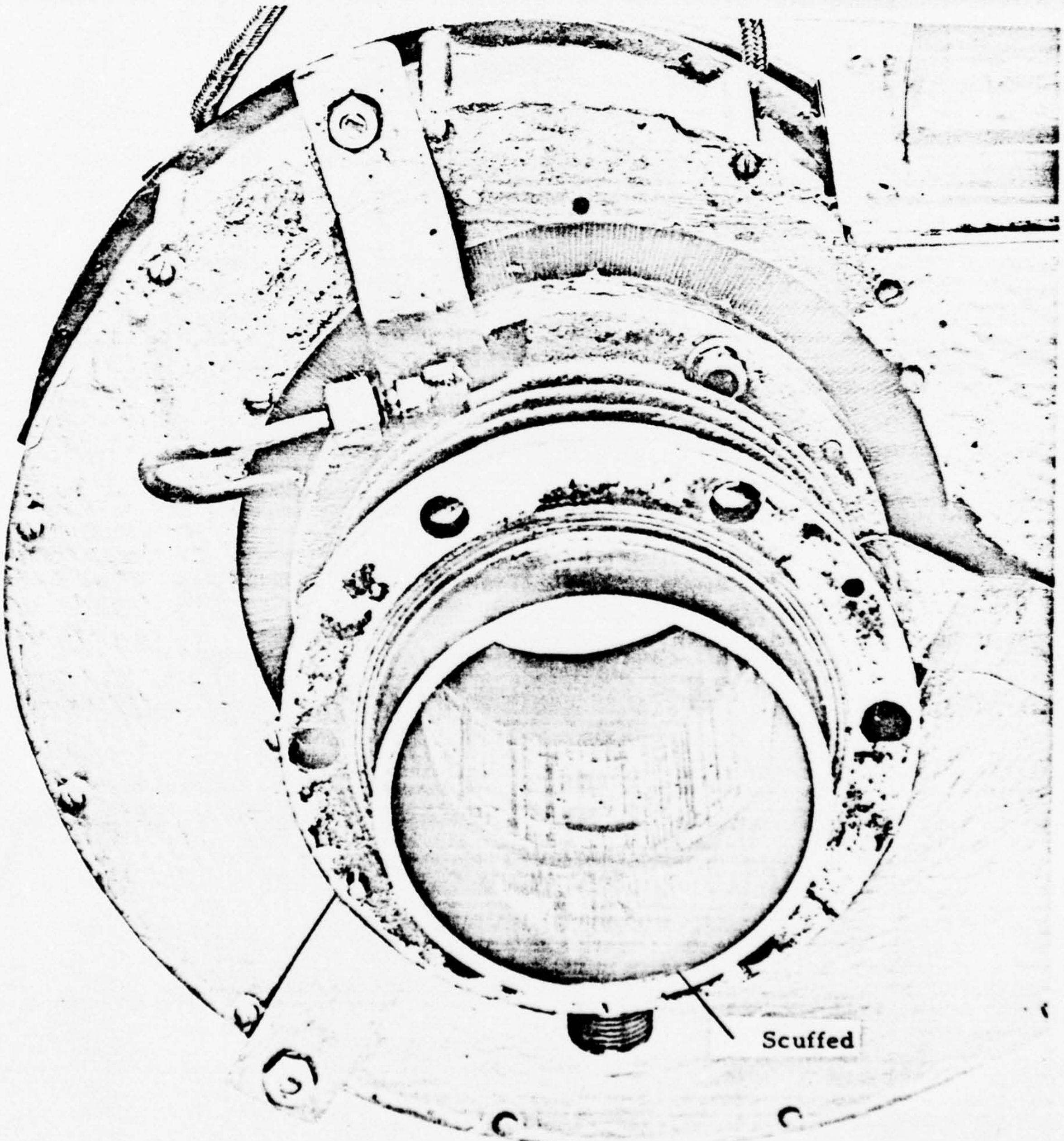


PLATE 1

CRANKSHAFT OF ORIGINAL ENGINE, PRE-TRIAL INSPECTION, SHOWING SPALLED SURFACE OF CRANKPIN



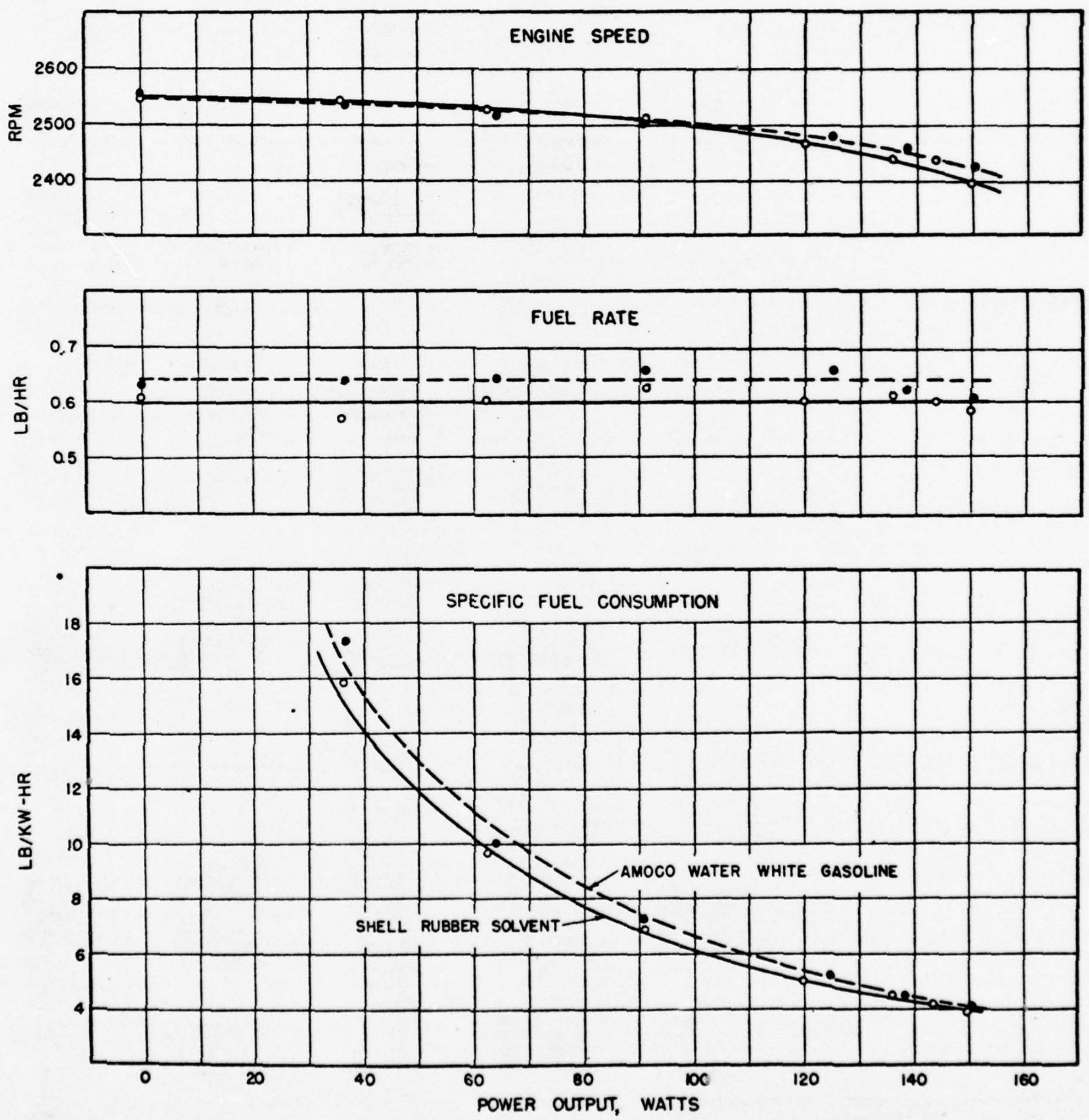
LOWER END OF CYLINDER, PRE-TRIAL INSPECTION
ORIGINAL ENGINE



VARIABLE LOAD PERFORMANCE TEST

PHILIPS MODEL $\frac{1}{4}$ D EXTERNAL COMBUSTION ENGINE

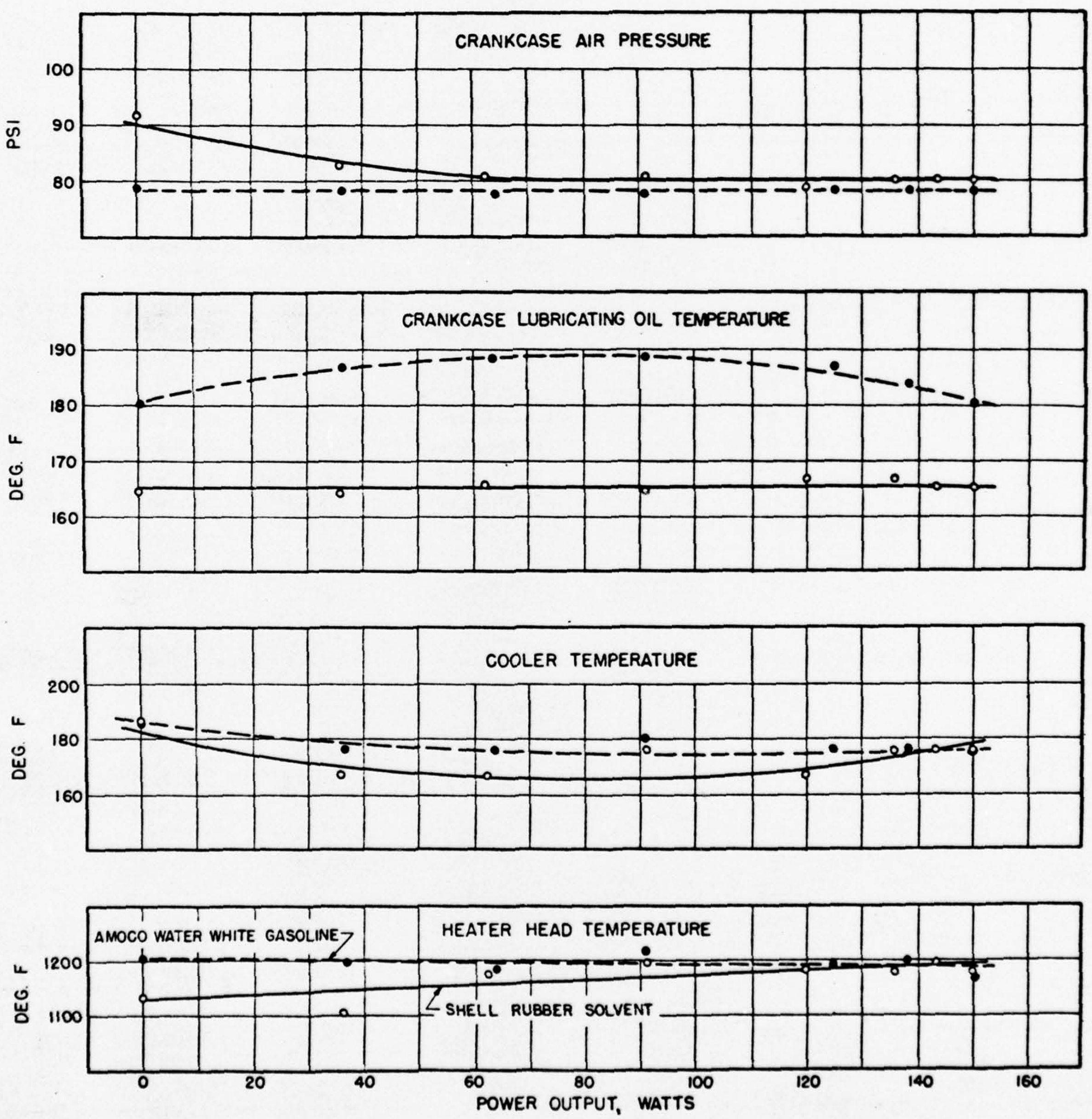
ORIGINAL ENGINE



VARIABLE LOAD PERFORMANCE TEST

PHILIPS MODEL $\frac{1}{4}$ D EXTERNAL COMBUSTION ENGINE

ORIGINAL ENGINE

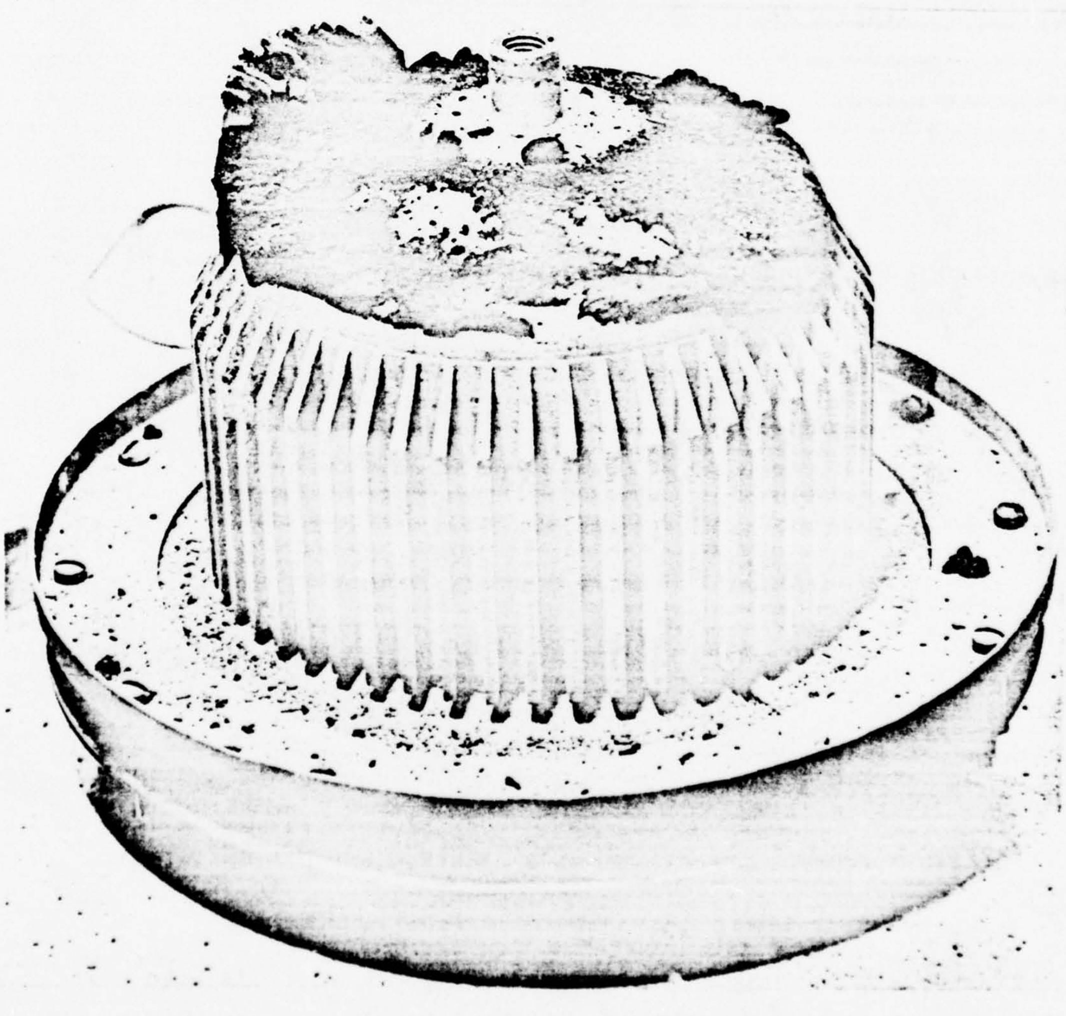


Summary of Casualties and Operating Difficulties
Original Philips External Combustion Engine

Eng. Hrs.	Casualty or Operating Difficulty	Cause	Action Taken
5	Burner fire tended to go out.	Insufficient burner pressure for low heat.	Increased low heat burner pressure.
8-85	Engine difficult to start.	Possible engine deterioration and low crankcase starting pressure.	Increased crankcase starting pressure from 30 to 50-60 psi.
11	Shut-off valve tended to stick closed; low head temp.; burner control operation erratic.	Shut-off valve rubber seat disc disintegrated; fragments of rubber fouled air lines.	Removed shut-off valve disc; cleaned out air lines.
16	Burner fire tended to go out.	Burner low heat pressure too low.	Increased low heat burner pressure.
18	Low heater head temp.	Insufficient gasoline delivery.	Adjusted burner gasoline nozzle.
31	Low heater head temp.	Carbon deposit on heater head crown.	Cleaned carbon from heater head.
35	Generator did not develop voltage.	Shorted wire in generator.	Repaired generator wiring.
38	Low heater head temp.	Insufficient gasoline delivery.	Modified fuel tubing; adjusted burner nozzle.
46	Generator did not develop steady voltage.	Overheating of generator.	Removed commutator-end cover plate of generator to improve cooling.
51	Low heater head temp.	Insufficient gasoline delivery.	Shielded and insulated gasoline and air tubing; modified fuel and air tubing.
56	Fan rubbing on entry ring; stud bolt in center of heater head broke.	Insufficient clearance for fan. Bolt thread seized.	Relieved fan entry ring to provide clearance. Installed new bolt.
56	Low heater head temp.	Insufficient gasoline delivery.	Installed new design larger capacity gasoline nozzle; installed float bowl in gasoline line to obtain constant fuel level; installed shielding and insulation on air and gasoline lines; removed insulation from center of lower side of burner head to improve gasoline vaporization.
57	Compressor not operating.	Piston stuck in cylinder; discharge valve fouled.	Freed compressor piston; installed new compressor head assembly.
59	Compressor not delivering air.	Suction valve disc cracked, Plate 7.	Replaced suction valve disc.
60	Compressor not delivering air.	Suction valve disc cracked.	Replaced suction valve disc.
61	Compressor not delivering air.	Compressor crankshaft broken, Plate 8. Suction valve neoprene seat loose.	Repaired compressor crankshaft; installed new compressor head with beryllium-copper suction valve disc.
77	Loss of air pressure.	Heater head cracked, Appendix II.	Installed new heater head and regenerator; compressor tappet surface machines to remove abraded surface; new one-piece compressor crankshaft installed.
81	Rotor of generator was tight in stator.	Rotor contacted field coils and insulating paper in stator.	Moved wiring as required to give rotor clearance.
86	Carbon deposit on heater head, Plate 6.	Imperfect combustion.	Cleaned heater head.

Plate 5

CARBON FORMATION ON HEATER HEAD, ORIGINAL ENGINE
4-1/2 HOURS OPERATION SINCE CLEANING



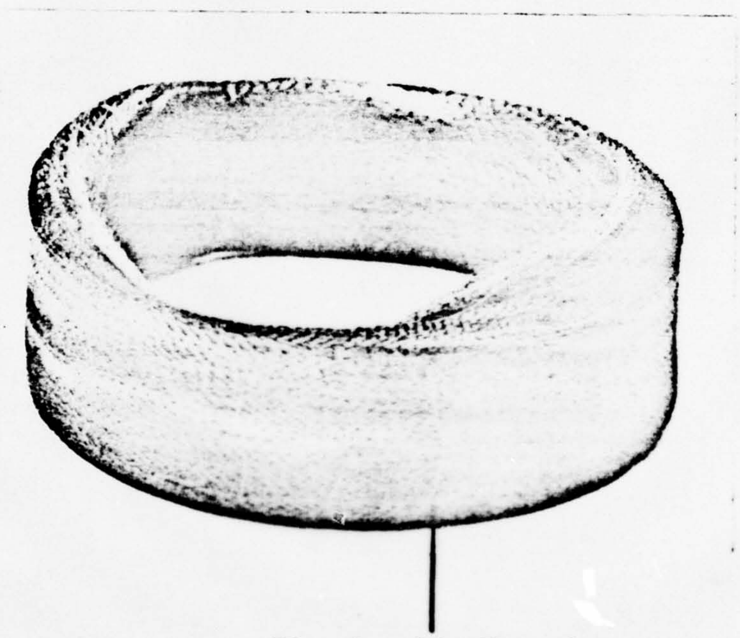
COMPRESSOR SUCTION VALVE, ORIGINAL ENGINE

59 HOURS OPERATION

BROKEN COMPRESSOR CRANKSHAFT, ORIGINAL ENGINE

61 HOURS OPERATION

REGENERATOR, ORIGINAL ENGINE
81 HOURS OPERATION



Analysis of Crankcase Lubricating Oil

Original Engine

Albis No. 22 Lubricating Oil

Hours Operation	0	56	24
Specific gravity, 60/60	0.870	0.881	0.869
A.P.I. degrees, 60/60	31.1	29.1	31.4
Flash point, open cup, °F	405	405	--
Pour point	+10	0	--
Viscosity, Secs.,SUV			
100°F	120	153	--
130°F	72.3	84	78
210°F	41.0	43	--
Viscosity index	98.2	90.0	--
Color, NPA	2.0	2.5	--
Reaction	Neut.	Neut.	Neut.
Neutralization number	0.02	2.44	0.05
Precipitation number	--	0.05	--
Carbon residue (ash free),pct	0.02	0.75	0.13
Ash, pct	None	0.14	0.17
Spect. of Ash	--	--	Fe and Cu

Analyses of Gasolines

	Amoco Water White Gasoline	Shell Rubber Solvent
Gum (air jet method), mgs/100 mls	6.0	12.5
Sulphur, pct	0.08	0.08
Vapor pressure, Reid, lbs/sq.in.	9.3	6.6
Specific gravity at 60/60 deg. F	0.744	0.708
A.P.I. degrees	58.69	68.36
Water tolerance, mls	pass	pass
Heat of combustion, gross value, Btu/lb	19915	20230
Lead content, T.E.L., mls/U.S. gal.	none	none
Aromatic content, pct by vol.	22.5	5.0
Olefins, pct by vol.	21.5	nil
Bromine number	39.0	nil
Distillation range		
Pct. evaporated at 167 deg. F.	--	42.5
Pct. evaporated at 221 deg. F	--	93.5
End point, deg. F	401	267
Residue, pct.	0.9	0.5
Evaporation loss, pct.	2.1	1.0
Distillation, uncorrected		
Initial boiling point, deg. F	92	112
5cc, deg. F	106	136
10cc, deg. F	127	143
15cc, deg. F	137	146
20cc, deg. F	149	150
30cc, deg. F	174	157
40cc, deg. F	203	166
50cc, deg. F	231	176
60cc, deg. F	256	186
70cc, deg. F	283	195
80cc, deg. F	315	204
90cc, deg. F	347	215
95cc, deg. F	380	230
Recovery, pct.	97.0	98.5

Modifications of Replacement Philips Engine, Model 1/4D.

Engine Delivered 16 December 1948.

1. All needle bearings were replaced by sleeve-type bearings. Tin-base babbitt was used for the crankpin bearings, both bearings of the displacer connecting rod, and the central bushing in the lower piston (for passage of the displacer piston rod). The piston pin bearing of the main connecting rod was of SAE 64 bronze.

2. Meehanite bushings were used in the piston.

3. The crankpin bearing was made slightly smaller in diameter and slightly greater in length.

4. The displacer piston connecting rod design was changed so that the bearings were in the rod.

5. The burner head design was modified to use a different type of burner grate. The old accordian type grate was replaced by a flat perforated disc.

6. The bore of the compressor cylinder was increased from 3/4 to 13/16 inch in order to increase the air delivery.

7. The compressor drive chain was reduced in size.

8. The generator was of the single voltage type and it delivered approximately 140 watts at 95-100 volts. The original generator was of the dual voltage type and developed 500 and 6.3 volts.

9. The pulley for the starting rope was mounted on the free end of the generator shaft for improved accessibility. It had formerly been located between the engine and generator.

10. The burner control thermostat was designed around a quarts rod instead of the old system that used a lever motion-magnifying system.

11. A filter was installed in the air tube to the burner.

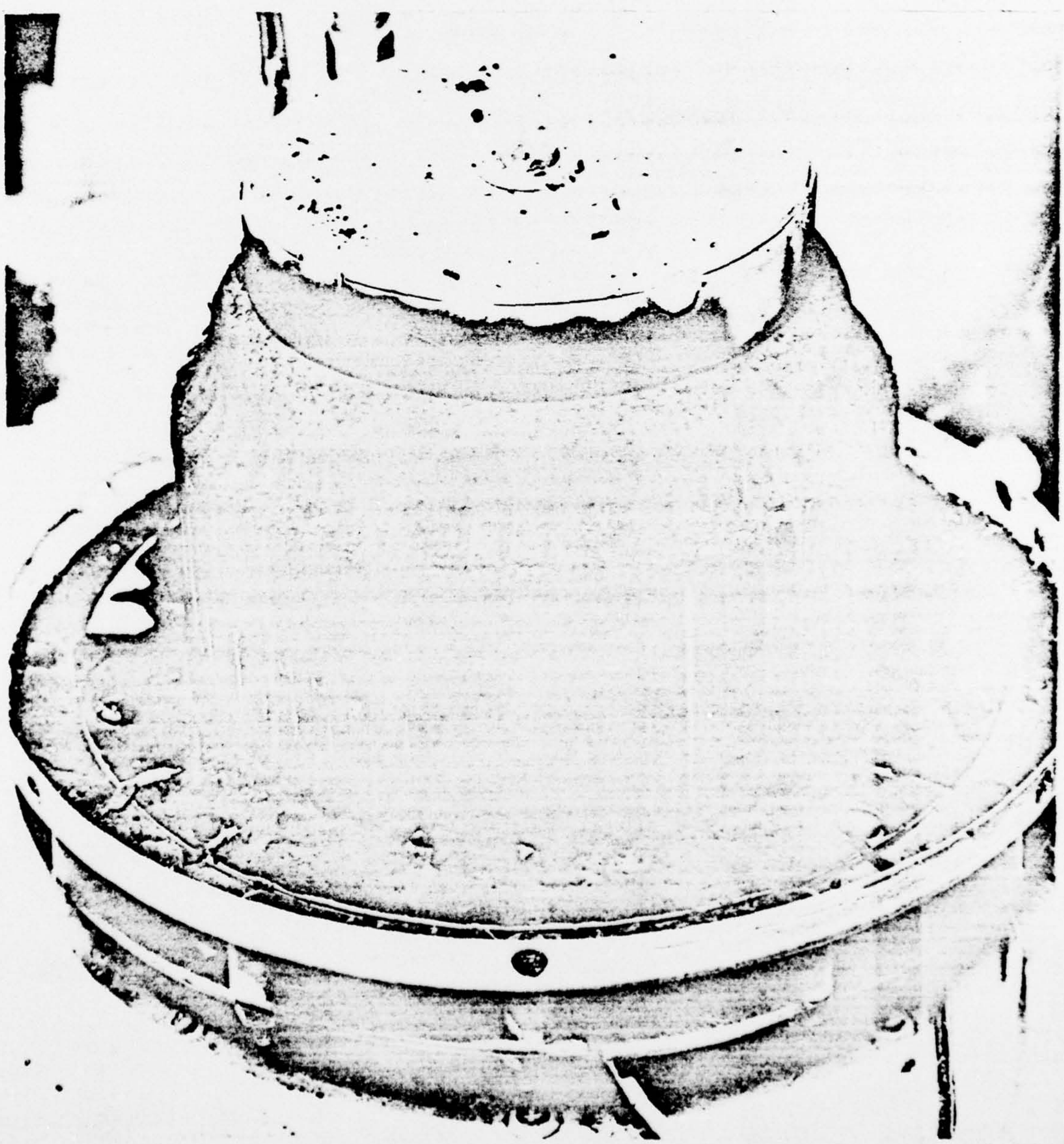
12. Radiation shielding was used to reduce the amount of burner head heat reaching the air and gasoline tubing.

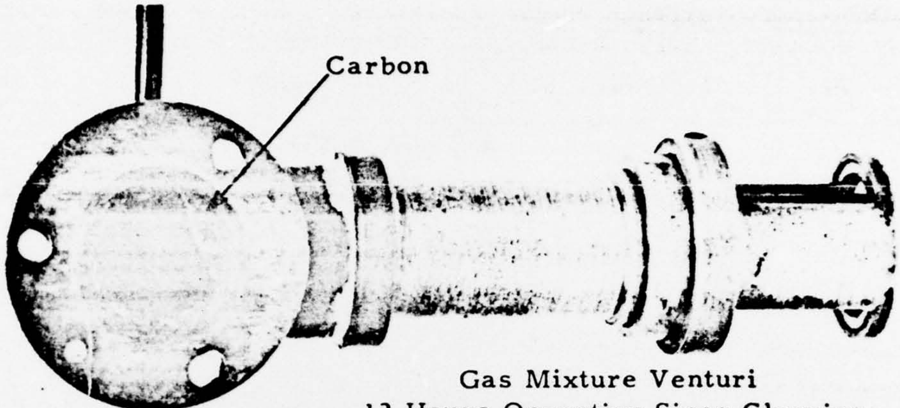
13. The air tubing system was modified to obtain a flow of air through the crankcase.

Summary of Casualties and Operating Difficulties
Replacement Philips External Combustion Engine

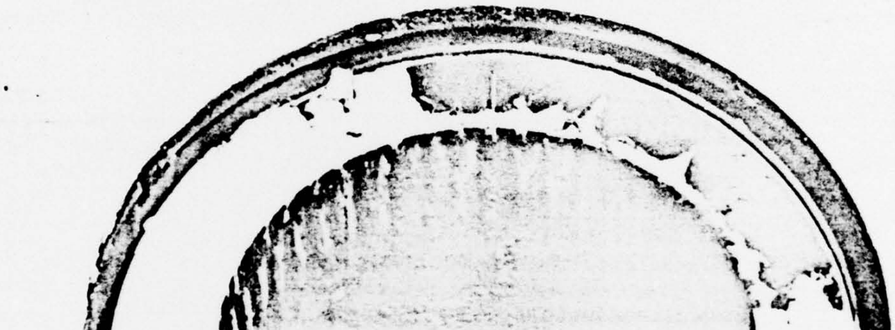
Eng. Hrs.	Casualty or Operating Difficulty	Cause	Action Taken
0.5	Improper burner combustion.	Air or gasoline nozzle plugged.	Cleaned air and gasoline nozzle.
12	Low heater head temp.	Carbon deposits on heater and burner heads, Plates 14 & 15. Burner grate deformed, Plate 16.	Removed fuel measuring equipment and modified tubing so engine operated directly from self-contained fuel tank. Cleaned heater and burner heads. Straightened burner grate.
19	Loss of generator load.	Generator terminal lug connection broken.	Repaired by re-soldering.
22	Loss of engine power.	Gasoline nozzle plugged.	Gasoline nozzle cleaned. Following modifications made: new design burner grate installed; burner air tubing modified; gasoline nozzle shielded; fiber idler wheel mounted on compressor to tighten drive chain.
41	Compressor chain came off sprocket.	Looseness due to wear and/or stretching.	Tightened chain.
43	Compressor idler pulley mounting broke.	Insufficient strength to withstand the normal vibration.	Removed idler pulley.
51	Loss of power.	Gasoline and/or air nozzles plugged.	Cleaned nozzles.
64	Low heater head temp.	Carbon deposits on heater head fins.	Cleaned heater head fins.
65	Loss of air from system.	Leakage at neoprene seal ring immediately below cooler flange.	Replaced neoprene seal ring. Modified compressor by addition of flywheel to reduce peak loads on chain.
71	Burner control operated improperly; burner remained in low heat position.	Plugging of burner control leak-off.	Re-adjusted burner control leak-off.
73	Burner control operated improperly as above.	Burner control pilot valve needle sticking.	Replaced pilot valve assembly.
79	Low heater head temp.	Carbon deposits on heater head fins.	Cleaned carbon deposits from heater head fins. Burner head and control block returned to Philips Lab. for modification.

CARBON FORMATION ON HEATER HEAD, REPLACEMENT ENGINE
12 HOURS OPERATION SINCE CLEANING





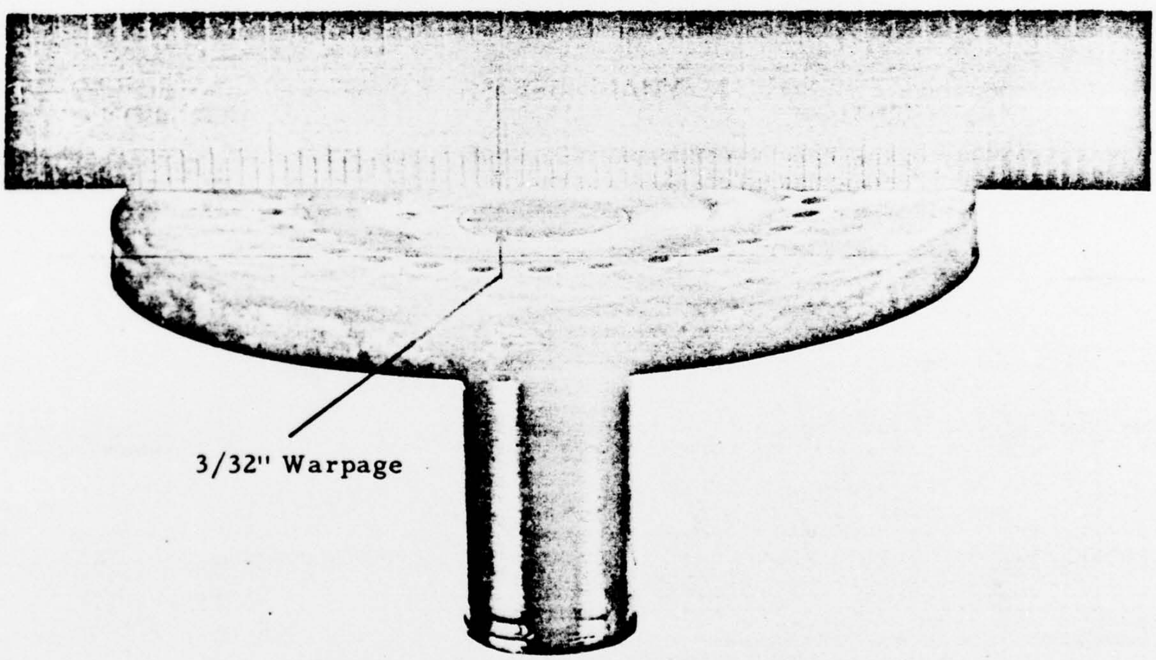
Gas Mixture Venturi
12 Hours Operation Since Cleaning



Carbon Formation in Burner Head, Replacement Engine
12 Hours Operation Since Cleaning

PLATE 15

BURNER GRATE - REPLACEMENT ENGINE
12 HOURS OPERATION



Analyses of Crankcase Lubricating Oil

Replacement Engine

Albis No. 29 Lubricating Oil

Hours operation	0	52
Specific gravity, 60/60	0.877	--
A.P.I. degrees, 60/60	29.8	--
Flash point, open cup, °F	425	--
Pour point, °F	+15	--
Viscosity, Seconds, SUV		
100°F	222	339
130°F	113	--
210°F	47.6	--
Viscosity index	96.5	--
Color, NPA	3.0	--
Reaction	Neut.	Neut.
Neutralization number	0.02	3.40
Precipitation number	None	0.75
Carbon residue (ash free), pct.	0.04	1.42
Ash, pct.	--	0.45

E.E.S. Report C-3599-A(1)

COPY

U. S. NAVAL ENGINEERING EXPERIMENT STATION

Annapolis, Maryland

21 July 1948

MEMORANDUM

From: Superintendent, Chemical Laboratory
To: Superintendent, I.C.E. Laboratory

Subj: Analysis of Scale from Heater Head of Phillips Engine - Test C-3599

1. This Laboratory received a three-quarter-gram sample of loose scale from the heater head of the subject engine. The sample was subjected to spectrographic, X-ray diffraction, and wet chemical analyses. The results are given below.

Constituent	Percent
Iron Oxide, Fe_2O_3	20.2
Iron Oxide (Ferrosoferric), Fe_3O_4	57.5
Chromium Oxide, Cr_2O_3	12.9
Nickel Oxide, NiO	6.6
Silica, SiO_2	2.3

2. The concentration ratios of the metallic constituents suggest that the scale originated from stainless steel.

/s/ J. G. O'Neill
J. G. O'Neill
Superintendent

- -

Appendix I

COPY

28 September 1948

MEMORANDUM

From: Superintendent Metallurgical Laboratory
To: Superintendent ICE Laboratory

Subj: Phillips External Combustion Engine, Examination of Heater Head for - Test C-3599

Ref: (a) ICE Lab. Memo to the Metals Lab. dated 15 July 1948.
(b) Copy of Par. 12 from Progress Report No. 20 of Phillips Laboratories, Inc., to BuShips, dated 8 Sept. 1948.

1. The Metallurgical Laboratory received for examination a half section of a failed heater head from the Phillips external combustion engine. Information received from the manufacturer indicated the head to be fabricated from Type 310 austenitic stainless steel with 8% aluminum bronze fins on the inside and outside. The fins had been silver plated and then brazed on with a Mn-Cu (30% Mn with possibly some Zn) brazing alloy, the operation having taken place at 1300°F in an hydrogen atmosphere.

2. Reference (a) stated that the outside fins were exposed in service to a burner flame using unleaded gasoline. The outside of the head reached a temperature in the neighborhood of 1200°F. The inside carried heated air at pressures up to about 200 psi. In use, the heater head was observed to leak at the cylindrical surface covered by the fins.

3. The photographs shown on page 3 illustrate the appearance of the head as received. A photomacrograph (X7) of a polished and etched section through the failure is shown on page 4. Details of construction are clearly evident, and the main crack was found to be surrounded by secondary cracks. Subsequent sectioning and dismantling revealed the crack to be about 1-1/4" long, extending to within 5/16" of either end of the fins.

4. The microstructure of the stainless shell is shown on page 5. The structure consisted of coarse grained austenite containing many twins. Carbides were precipitated at the grain boundaries and twin planes. The structure is not unusual for this type of material. The bond between the shell and fins was found to be strong.

5. The cause of the crack in the stainless shell is rather obscure and uncertain. Analysis of similar failures by the Eindhoven Laboratories, as reported in reference (b), indicated that failure may have been caused by overheating, resulting in an unfavorable reaction between the shell and the brazing material. Certainly the outer fins

attained temperatures near the melting point of the brazing alloy, and liquid brazing material is known to attack 25-20 Cr-Ni steel under prolonged exposure. On the other hand, the failure examined at the Station does not confirm the failure to have been caused by this mechanism. Such a conclusion is based largely on the fact that the attack was so local in nature, and no penetration of the brazing alloy into the uncracked stainless shell could be found.

6. Photomicrographs taken in the cracked areas are shown on Page 6. All of the cracks followed intergranular paths and contained foreign matter which may be oxides of steel or penetration of brazing alloy oxides. However, for the reason stated in the previous paragraph, if the foreign matter is brazing alloy residue, it is believed that the penetration did not occur until after the crack had formed. The photomicrographs seem particularly interesting since the three cracks illustrated show the life history in the crack development. It is especially noteworthy that the cracks start in the steel shell, then subsequently open up through the brazing alloy and bronze fins to produce a leak.

7. The intergranular nature of the attack and the complete lack of ductility around the rupture would indicate that creep at elevated temperatures was the cause of the failure. The development of an intergranular crack then could be accelerated by the presence of liquid brazing compound. The possibility of a crack formed during fabrication of the shell, even before service, should also be considered, particularly since reference (b) states "X-ray examination of three shells as machined, before brazing the fins in place, located a vertical crack about 5/16" high in one head."

8. Reference (a) requested recommendations as to means of prevention of this type of failure. Obviously, if the cracks formed during fabrication of the shell, these should be located with a hydrostatic test or other non-destructive means. It is understood that the manufacturer plans to make future heater heads by machining the outer fins and shell from a single piece of Type 310 steel. This approach is a wise one, because the possibility of damage from liquid brazing alloy is eliminated in service. Furthermore, the use of a single piece should add strength to the shell itself. Certainly some means of strengthening the shell should be devised, without impairing heat transfer, so that stresses leading to creep failure will be reduced.

/s/ W. C. Stewart

W. C. Stewart

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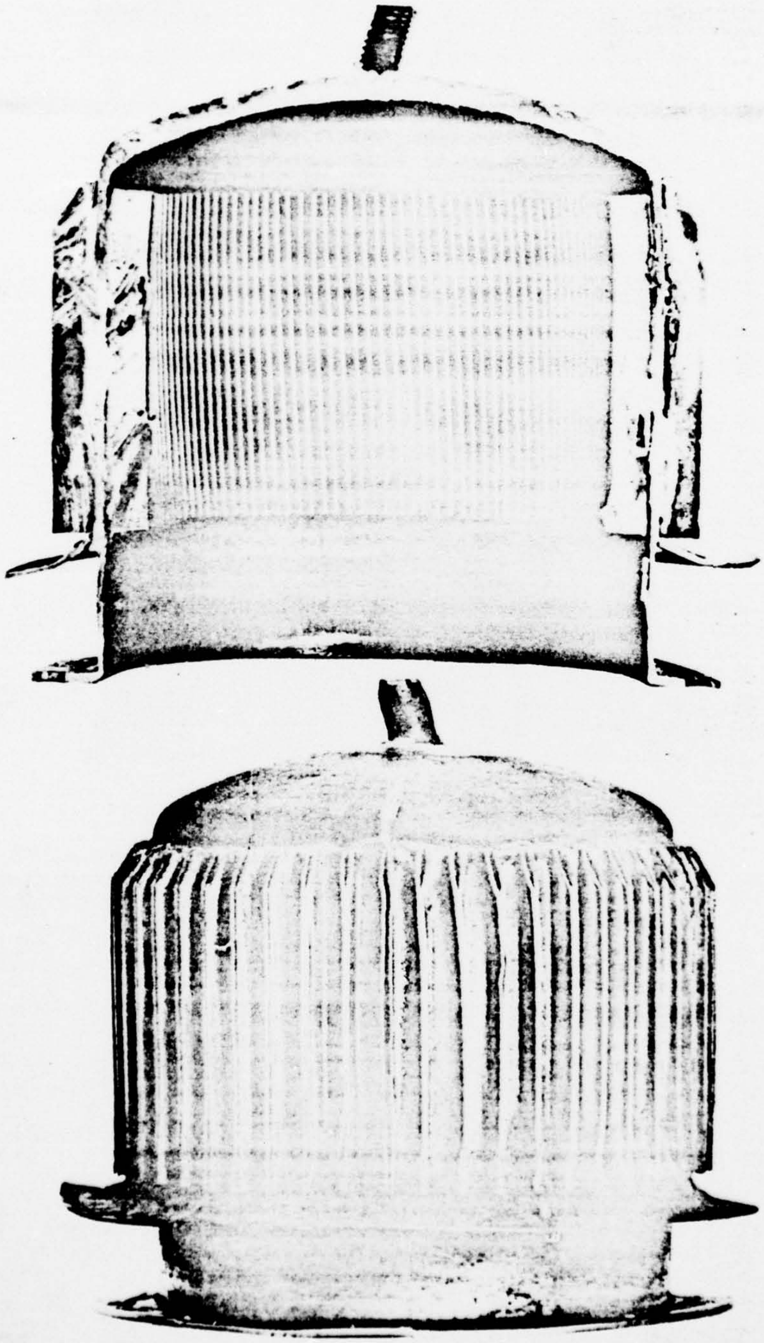
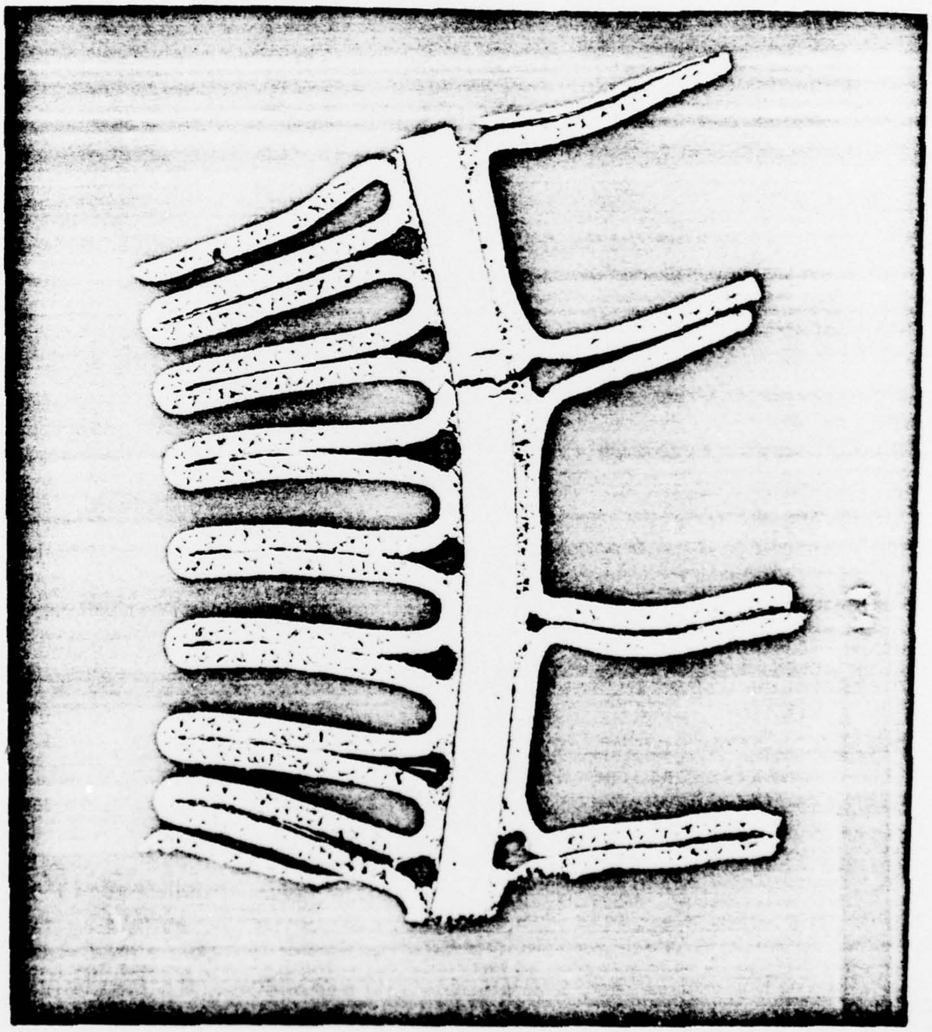
METALLURGICAL EXAMINATION OF
CRACKED HEATER HEAD OF ORIGINAL ENGINE



Actual Size

METALLURGICAL EXAMINATION OF
CRACKED HEATER HEAD, ORIGINAL ENGINE



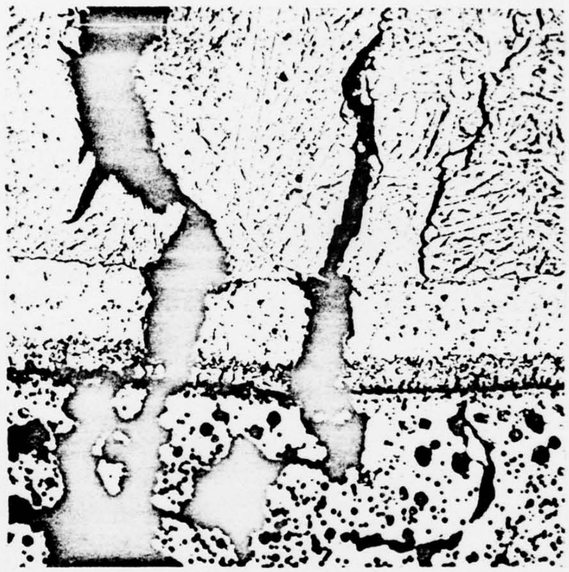
X 7

METALLURGICAL EXAMINATION OF CRACKED HEATER HEAD, ORIGINAL ENGINE

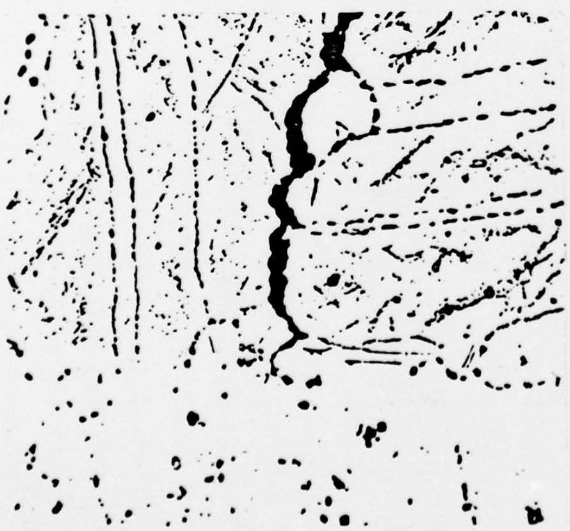
1
X 100

2
X 500

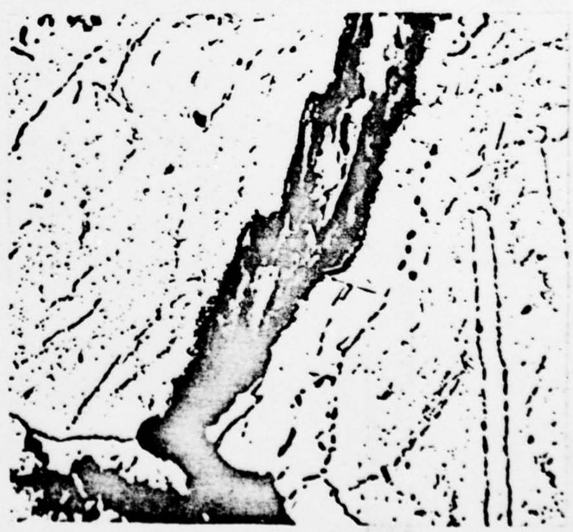
METALLURGICAL EXAMINATION OF CRACKED HEATER HEAD, ORIGINAL ENGINE



1
X 100



2
X 500



3
X 500

E.E.S. Report C-3599-A(1)

COPY

2 August 1948

MEMORANDUM

From: Superintendent, Chemical Laboratory

For: Superintendent, ICE Laboratory

Subj: Analysis of Regenerator Deposit from Philips External Combustion Engine, Test C-3599.

1. This laboratory received a regenerator from the subject engine on 16 July. The deposit was mechanically separated from the base metal wire. The 140 milligrams of deposit thus obtained were analyzed. The results of the analysis are given below:

Constituent	Per Cent
Copper Oxide, CuO	9.6
Iron Oxide, Fe_3O_4	42.3
Nickel Oxide, NiO	22.4
Chromium Oxide, Cr_2O_3	7.5
Carbon	5.2

2. The regenerator was cut open and the layers of wire examined. The white deposit around the midsection penetrated approximately 40% of the distance to the center layer. The black deposit present on the upper-half of the regenerator showed 100% penetration. The black deposit was uniformly distributed throughout the layers and followed the same pattern as appeared on the outside layer. The white deposit was extremely fine and powdery and tended to disperse into the air when the layers were pulled apart. It proved impossible to separate the black and white deposits.

3. The nichrome wire contained an oily material which was extracted by chloroform. The percentage of oil present in the deposit was approximately equal to the percent of carbon given in Paragraph 1. The presence of nickel, chromium and iron in the deposit was characteristic for nichrome wire corrosion; however, it should be noted that the iron concentration was far beyond what would be normally expected in nichrome corrosion. This suggests that there was accompanying steel corrosion or wear products accumulating within the regenerator. The presence of excessive amounts of copper in the deposit likewise suggests corrosion of either copper or copper-bearing materials within the system.

/s/ J. G. O'Neill
J. G. O'Neill
Superintendent
Chemical Laboratory
By direction

- -

[illegible]-25-49/ ls

U. S. NAVAL ENGINEERING EXPERIMENT STATION
Annapolis, Maryland

File No. NP16/L5/[illegible]1-5

Serial (1[illegible]1[illegible] (2[illegible]) Test C-[illegible]-A(1) 25 [illegible]

From: Director
To: Chief of the Bureau of Ships (Code ~~337~~ 362

Subj: E.E.S. Test Report C-[illegible]-A(1) Test of Philips Model 1/4D External Combustion Engine

Encl: Eight (8) Copies of subject test report

1. Eight copies of the subject report are forwarded herewith.

W D Leggett Jr
W. D. Leggett, Jr.

- -

[illegible]. G. School
Office of Chief of Engineers,
Engineer Research & Devl. Div.,
Room 2029, Bldg. T-7, Gravelly Point,
Washington 25, D.C.
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