# PROGRESS REPORT

PR 91570-510-6

For the Period of December 1, 1963, through December 31, 1963

## DEVELOPMENT OF A HYDROGEN-OXYGEN SPACE POWER SUPPLY SYSTEM

NASA Contract NAS 3-2787

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## INTRODUCTION

This report is issued to comply with the requirements of NASA Contract, NAS 3-2787, and to report the work accomplished during the period December 1 through December 31, 1963. The objectives of this program are to conduct engineering studies, design, fabrication, and test work culminating in the design of an auxiliary power generation unit.

This contract, NAS 3-2787, is a continuation of NASA Contract NAS 3-2550.

## PROGRAM SCHEDULE

The program schedule is shown in Fig. 1.

## FLIGHT TYPE POWER SYSTEM DESIGN

No work was accomplished during this reporting period on the flight type power system design. Flight system design work has been postponed as a result of technical direction from the NASA Technical Program Manager.

## RELIABILITY AND QUALITY ASSURANCE

During December there were no program changes affecting the completion of reliability milestones. The only new milestone that had been scheduled for completion during December was the preparation of formal DRAWING CONTROL PROCEDURES. These procedures have been prepared on schedule and are submitted in Appendix A of this report. See Fig. 2.

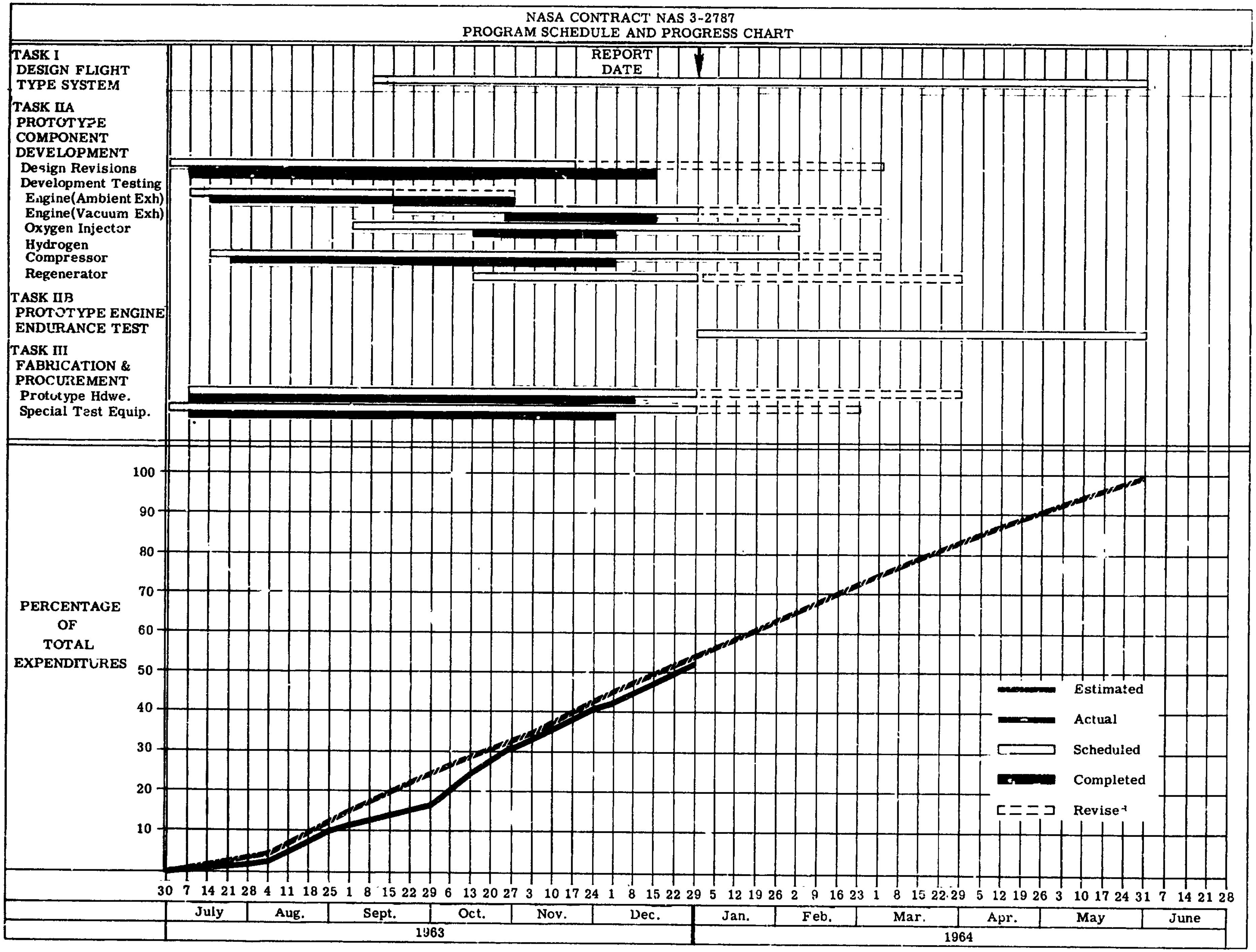


Fig. 1 - Program Schedule

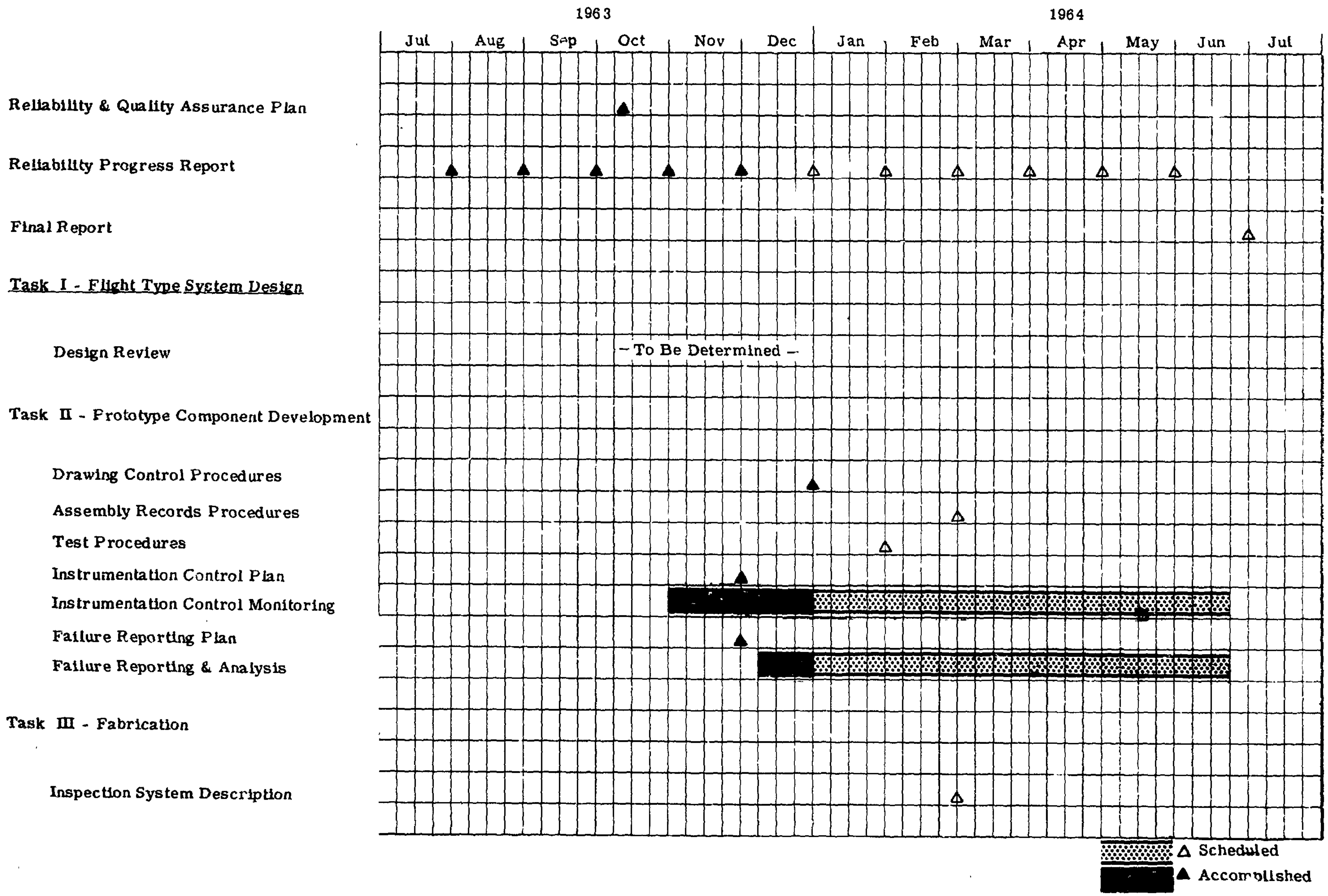


Fig. 2 - Reliability and Quality Assurance Program Plan Milestone Chart

During December, two meetings were held between the NASA Western Operations Office Reliability and Quality Assurance Monitor and Vickers Incorporated Reliability personnel. Reliability tasks and milestones in which particular emphasis was placed during the month are as follows:

a. Calibration of instrumentation and test equipment
b. Failure reporting
c. Prototype component buildup and parts records

Specific accomplishments in each of the above items are summarized in the particular task assignments listed on the following pages.

Reliability and Quality Assurance Function for Task 1 (Flight-Type Power System Design)

Design Review

No work was scheduled during this reporting period.

Reliability and Quality Assurance Function for Task II (Prototype Component Development)

Drawing Control Procedures

A detailed written description of drawing control procedures was completed as scheduled during the month of December. These procedures have been in use since the start of the program. See Appendix A.

## Assembly Buildup and Parts Records

A written description of the assembly and parts record procedures, now in use for the engine and compressor, will be prepared during the month of February and submitted in the February Progress Report. These records have been made available to NASA personnel and appear to be adequate.

## Test Procedures

There have been no changes in the planned format of test procedures as described in the November report. These procedures will be completed during January and presented in the January Progress Report.

## Instrumentation Control

The major Reliability and Quality Assurance effort during the month of December was the improvement of instrumentation control. The instrumentation control plan shown in November has been implemented and many substandard areas have already been corrected. Arrangements are being made to obtain duplicate gauges for those which cannot be calibrated in-house and must be sent to certified calibration agencies. This will permit testing to proceed without delay.

It is expected that the instrumentation control system will be completely in effect by the end of January. At that time, only continued monitoring will be necessary to maintain control.

## Failure Reporting and Analysis

A failure reporting plan for the NASA program was submitted previously and is now in effect. During December this task was brought up to date by summarizing all failures that have occurred since the beginning of the program (see Appendix B).

Also included (in Appendix B) is a list of the engine failure modes that have occurred to date. This list will be submitted in each Progress Report and will be updated as new modes are recognized. Also, it will be indicated when correction actions have been incorporated and failure modes eliminated.

Reliability and Quality Assurance Function for Task III (Fabrication)

There was no additional work accomplished by Reliability and Quality Assurance for Task III. A brief description of Vickers inspection and material review board procedures was made in the November report.

## PROTOTYPE COMPONENT DEVELOPMENT

### Engine

#### Design and Fabrication

The following design and fabrication was accomplished during this reporting period.

1. Two additional hydrogen valves of the redesigned configuration (shown in Fig. 2 of PR 91570-510-2) are being fabricated. These new valves will include a heat shield to protect the valve guide from direct impingement of hot hydrogen.

2. Assembly of the split-housing oxygen injector (layout drawing shown in Fig. 2 PR 91570-510-4) has been delayed because the braze assemblies of the quill shaft, flange, and torque tube were defective. The flanges and quill shafts are being salvaged and new torque tubes are being fabricated.

   One (of two ordered) quill shaft has been flame plated with aluminum oxide.

3. Two more Oxygen injector cam blanks have been machined to the new configuration (described on Page 6 of PR 91570-510-2). One of these cams was returned to the vendor for rework and source inspection.

4. Fabrication of new X-609982 hubs to a drawing change, which requires a tolerance that will produce greater concentricity and squareness of the timing gear with respect to the crank shaft axis, is complete.

5. The drawings for the new piston and cylinder design (shown in Fig. 3 PR 91570-510-5) are being checked and corrected. They will be released for fabrication about January 8, 1964. An engine tolerance layout using the new piston and cylinder dimensions is being prepared to determine dimension for new cylinder head inserts.

6. Three piece compression rings, (two outer rings and one expander) have been designed. All three rings are of 17-4PH steel. The O.D. of the outer

rings are hard chrome plated. One set of rings was received December 31, 1963. These rings were light tight in a 1.5 diameter gage, but free gap dimension was less than specified and ring tension appeared to be low. Twenty-four (24) sets of these three piece rings have been ordered from another source, and will be received by January 15, 1964. The depth of the compression ring grooves of Engine No. 1 piston has been increased for use with these rings.

7. Three new oxygen injector poppets have been fabricated to the new design dimensions, but without flame plating.

<u>Assembly</u>

A summary of significant defects observed during the tear-down of Engine No. 1 after 22.2 hours of operation as follows:

1. A small hole developed in the hydrogen valve guide between the oil supply passage and the surface where the valve spring seats. The valve stems were scored because of loss of lubrication.
2. The top compression ring was [illegible] in the ring groove at the piston location opposite the oxygen injection port.
3. The silver plating of the "O" ring seal between the piston and piston dome had melted, and was adhered to the piston and dome.
4. The threads of the dome securing screw were heat siezed to the dome.

5. The dome edge was marked at one spot from contact with the head insert.

6. A pressure check of the piston prior to removal of the dome showed leakage past the dome seal at all pressures.

7. The top edge of the cylinder wall, opposite the oxygen inlet port, was erroded and warped to about 0.004" greater than the minimum bore diameter.

8. The bore diameter at the exhaust port bands was 0.0015" greater than minimum bore diameter.

The following modifications were made during the second build-up of engine No. 1.

1. Three piece compression rings were installed.
2. A cast iron compression ring was used in the oil ring groove.
3. New oxygen cam was installed.
4. The new design (inward opening) hydrogen valve was installed.
5. Timing gear hub fabricated to closer tolerances was installed.
6. A small diameter piston dome of LC 5 (Haynes 25) was used.
7. A secondary shim stock seal between dome seal piston was added.

8. The cylinder was honed to a courser crosshatched surface finish.

9. Larger oil drain ports were provided from the gear and cam chambers to the crankcase.

Engine No. 2 was removed from the test stand on December 30, 1963 and teardown is in process. The second buildup of Engine No. 1 will be mounted on the test stand on January 1, 1964.

The third buildup of the oxygen injector, using a flame plated poppet, was disassembled after 30 minutes of test stand operation with cold gas. The flame plating had failed in the seat area, in a manner similar to the failure shown in Fig. 4 of PR 91570-510-5. To date three flame plated poppets have been tested and all three have failed. During the fourth builaup of the injector an unplated poppet of the same dimensions will be used.

The oxygen injector, which is being used on the engine, was disassembled on December 12, 1963 after 17.8 hours of operation with redesigned (except for dimensions of poppet end and guide seat) parts. The flame plated bearing was in good condition. The clearance between the poppet and rocker arm had changed from 0.006" to 0.0097". The clearance between the poppet and seat guide diameters changed from 0.001" to 0.0083". This injector has not been disassembled for the last 8.8 hours of operation.

## Performance Testing

Performance data accumulated during the month of December, 1963, are given in Table I. All testing was accomplished with the second assembly of Engine No. 2. Table II gives the operating conditions used in these test runs.

## TABLE I

## ENGINE PERFORMANCE DATA

| Entry | Time Date | Time Hour | Oper. Cond. No. | $H_2$ Inlet Temp. °F | $H_2$ Inlet Press. psig | $O_2$ Inlet Press. psig | Speed rpm | BMEP psi | Power HP | BSPC lb/hp-hr | O/F lb/lb | % Heat Rejected | Vacuum in-Hg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12-3-63 | 2:54 | 1 | 470 | 300 | 800 | 3000 | 100 | 2.06 | 2.38 | 2.28 | 108 | 28 |
| 2 | 12-3-63 | 2:59 | 1 | 470 | 300 | 800 | 3020 | 101 | 2.09 | 2.33 | 2.28 | 96 | 28 |
| 3 | 12-3-63 | 3:08 | 1 | 485 | 300 | 800 | 4220 | 83 | 2.41 | 2.31 | 2.35 | 103 | 28 |
| 4 | 12-3-63 | 3:30 | 1 | 495 | 450 | 1000 | 3010 | 150 | 3.12 | 2.16 | 1.74 | 84 | 27 |
| 5 | 12-3-63 | 3:34 | 1 | 500 | 450 | 1000 | 4230 | 126 | 3.66 | 1.96 | 1.43 | 69 | 27 |
| 6 | 12-3-63 | 3:38 | 1 | 500 | 450 | 1000 | 4200 | 126 | 3.62 | 1.99 | 1.56 | 68 | 27 |
| 7 | 12-3-63 | 3:45 | 1 | 505 | 600 | 1055 | 4170 | 166 | 4.81 | 1.82 | 1.21 | 57 | 26 |
| 8 | 12-3-63 | 3:50 | 1 | 500 | 600 | 1005 | 3000 | 190 | 3.90 | 1.94 | 1.17 | 63 | 26.5 |
| 9 | 12-3-63 | 4:00 | 1 | 515 | 600 | 1050 | 4190 | 166 | 4.76 | 1.75 | 1.12 | 60 | 26.5 |
| 10 | 12-9-63 | 11:43 | 1 | 515 | 300 | 800 | 3030 | 86 | 1.78 | 2.49 | 1.69 | 122 | 26 |
| 11 | 12-9-63 | 11:50 | 1 | 500 | 300 | 900 | 4230 | 76 | 2.21 | 2.24 | 1.76 | 123 | 26.5 |
| 12 | 12-9-63 | 11:55 | 1 | 500 | 300 | 800 | 4190 | 76 | 2.19 | 2.24 | 1.74 | 107 | 26.5 |
| 13 | 12-10-63 | 10:35 | 1 | 500 | 300 | 800 | 3010 | 86 | 1.79 | 2.53 | 1.86 | 105 | 26 |
| 14 | 12-10-63 | 10:45 | 1 | 500 | 300 | 700 | 3020 | 87 | 1.81 | 2.42 | 1.77 | 107 | 26.5 |
| 15 | 12-10-63 | 10:53 | 1 | 500 | 300 | 700 | 4240 | 78 | 2.30 | 2.24 | 2.05 | 81 | 26.5 |
| 16 | 12-10-63 | 10:57 | 1 | 500 | 300 | 600 | 4270 | 77 | 2.24 | 2.24 | 1.94 | 83 | 26.5 |
| 17 | 12-10-63 | 11:04 | 1 | 480 | 300 | 640 | 3030 | 83 | 1.72 | 2.41 | 1.59 | 87 | 26.5 |
| 18 | 12-10-63 | 11:10 | 1 | 495 | 300 | 600 | 3010 | 89 | 1.85 | 2.41 | 1.84 | - | 26.5 |
| 19 | 12-10-63 | 11:16 | 1 | 490 | 300 | 500 | 3020 | 89 | 1.85 | 2.38 | 1.54 | 89 | 26.5 |
| 20 | 12-10-63 | 11:22 | 1 | 500 | 300 | 500 | 4190 | 80 | 2.30 | 2.12 | 1.72 | 86 | 26 |
| 21 | 12-10-63 | 11:27 | 1 | 485 | 300 | 400 | 3010 | 90 | 1.85 | 2.46 | 2.20 | 149 | 26.5 |
| 22 | 12-11-63 | 2:26 | 1 | 490 | 300 | 800 | 3000 | 83 | 1.71 | 2.73 | 2.09 | 120 | 27 |
| 23 | 12-11-63 | 2:42 | 1 | 490 | 300 | 800 | 2990 | 90 | 1.86 | 2.88 | 2.82 | 154 | 28 |
| 24 | 12-11-63 | 2:50 | 1 | 500 | 300 | 600 | 3020 | 87 | 1.81 | 2.61 | 2.21 | 127 | 27.5 |
| 25 | 12-11-63 | 3:07 | 1 | 500 | 300 | 600 | 3010 | 83 | 1.71 | 2.72 | 2.23 | 130 | 26.5 |
| 26 | 12-11-63 | 3:14 | 1 | 500 | 300 | 600 | 3030 | 82 | 1.72 | 2.63 | 2.03 | 142 | 26.5 |
| 27 | 12-19-63 | 11:00 | 2 | 700 | 300 | 1100 | 3050 | 73 | 1.53 | 2.82 | 1.97 | 127 | 26 |
| 28 | 12-21-63 | 3:05 | 3 | 490 | 300 | 1150 | 3080 | 76 | 1.60 | 2.84 | 1.67 | 110 | 24.5 |

The engine was operated for a total of 5.7 hours during this reporting period. In addition it was motored without combustion for 9.2 hours, (mostly for motoring friction and compression pressure tests). A BSPC of 1.75 lb/hp-hr has been achieved at 600 psi hydrogen pressure and 4200 rpm (Entry 9, Table I), repeating the best performance attained last month.

Much of the running this month was at low inlet pressures and moderate power levels to check the day to day reproducibility of results, and to check running stability. Pressure-time traces and photographs are given in Figs. 3 through 11 A discussion of these figures follows.

## TABLE II

## ENGINE OPERATING CONDITIONS

1. Cooled cylinder head, 5% clearance volume, outward opening hydrogen valves, Dowtherm "A" coolant, timing $H_2$ 10° BTDC - 20° ATDC, $O_2$ 4° ATDC - 44° ATDC.

2. Uncooled head, 8.5% clearance, inward opening hydrogen valves, timing same as No. 1.

3. Same as No. 1 except for inward opening valves.

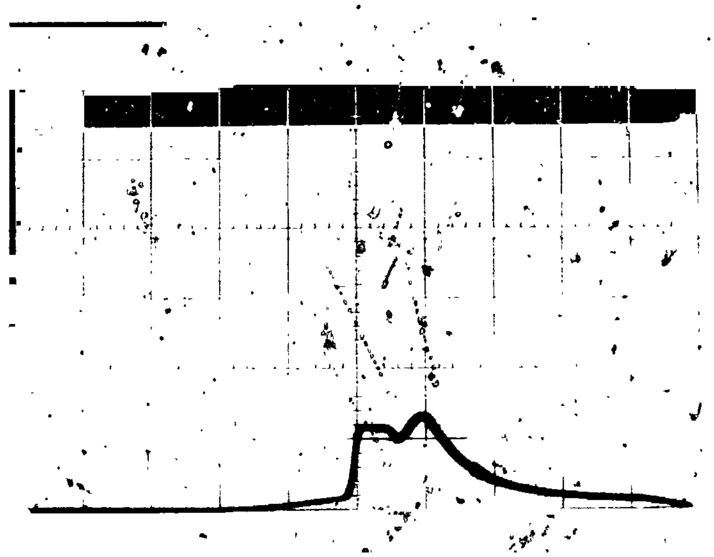

Fig. 3

12-3-63 3:08

Entry No. 3, Table I

$H_2$ Inlet pressure = 300 psig

$O_2$ Inlet pressure = 800 psig

Vacuum = 28 in. Hg

$H_2$ Inlet temperature = 485°F

Speed = 4220 rpm

Power = 2.41 hp

BSPC = 2.31 lb/hp hr

BMEP = 83 psig

O/F = 2.35

% Heat rejected = 103%

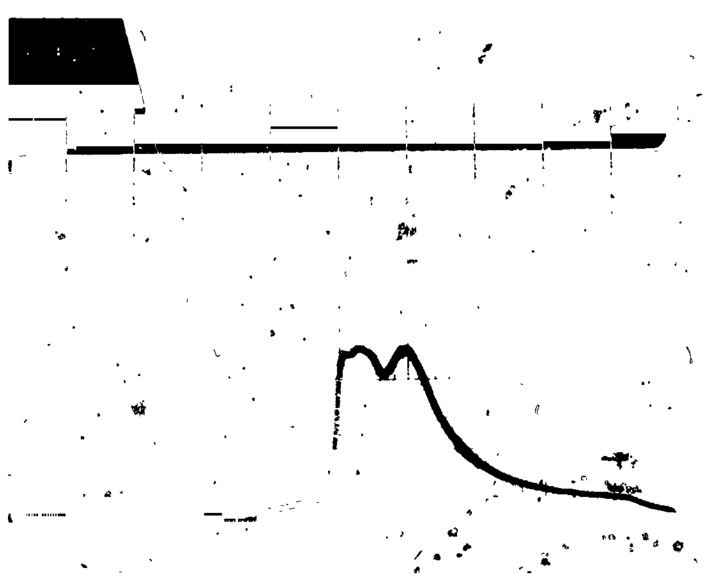

Fig. 4

12-3-63 4:00

Entry No. 9, Table I

$H_2$ Inlet pressure = 600 psig

$O_2$ Inlet pressure = 1050 psig

Vacuum = 26.5 in. Hg

$H_2$ Inlet temperature = 515°F

Speed = 4190 rpm

Power = 4.76 hp

BSPC = 1.75 lb/ hp hr

BMEP = 166 psi

O/F = 1.12

% Heat rejected = 60%

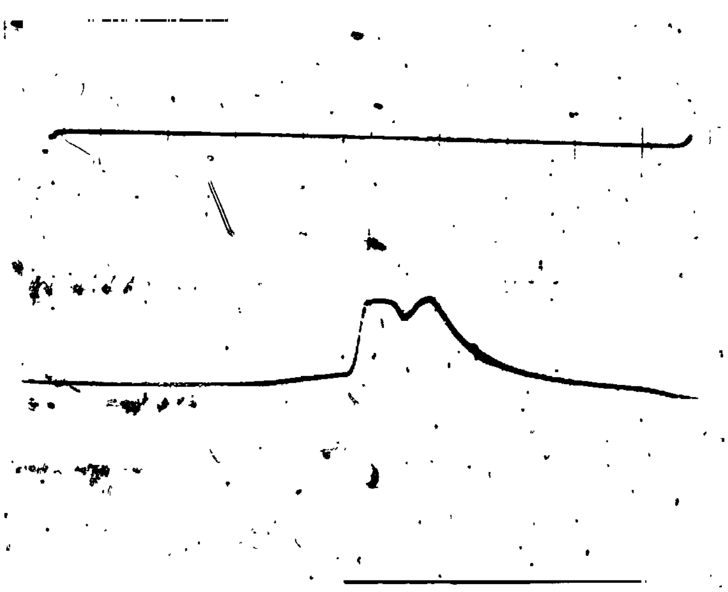

Fig. 5

12-10-63 10:53

Entry No. 15, Table I

$H_2$ Inlet pressure = 300 psig

$O_2$ Inlet pressure = 700 psig

Vacuum = 26.5 in. Hg

$H_2$ Inlet temperature = 500°F

Speed = 4240 rpm

Power = 2.30 hp

BSPC = 2.24 lb/hp hr

BMEP = 78 psi

O/F = 2.05

% Heat rejected = 81%

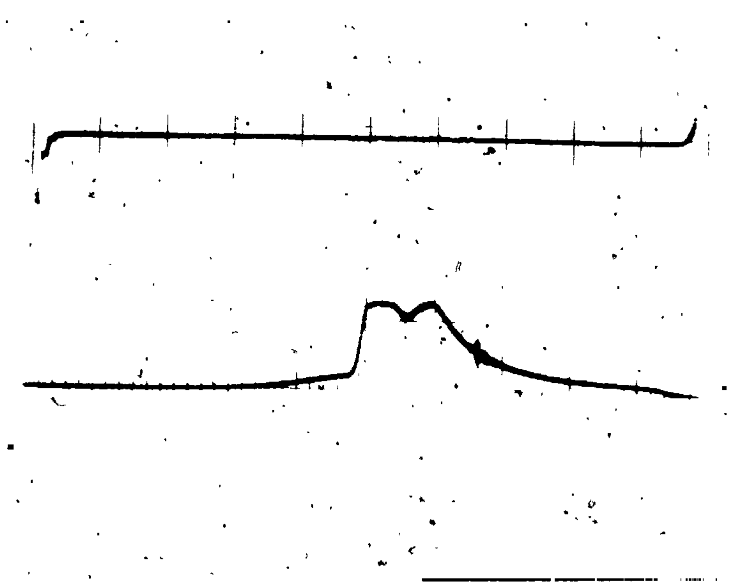

Fig. 6

12-10-63 10:57

Entry No. 16, Table I

$H_2$ Inlet pressure = 300 psig

$O_2$ Inlet pressure = 600 psig

Vacuum = 26.5 in. Hg

$H_2$ Inlet temperature = 500°F

Speed = 4270 rpm

Power = 2.24 hp

BSPC = 2.24 lb/hp hr

BMEP = 77 psi

O/F = 1.94

% Heat rejected = 83%

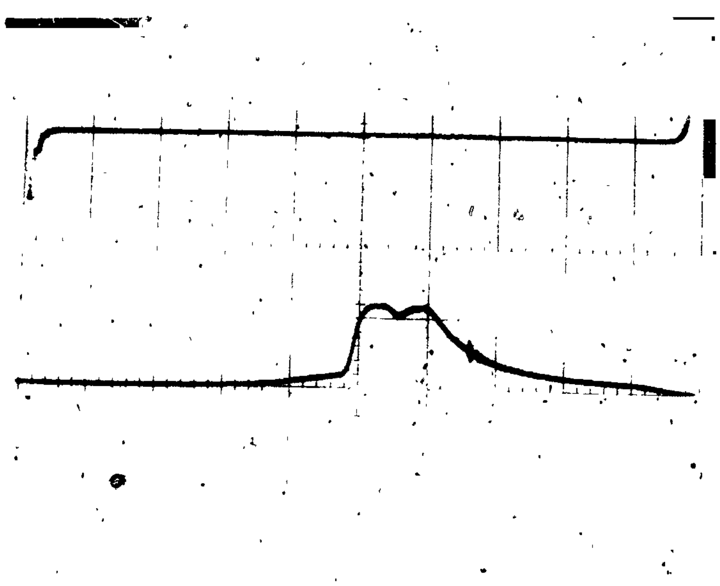

Fig. 7

12-10-63 11:22

Entry No. 20, Table I

$H_2$ Inlet pressure = 300 psig

$O_2$ Inlet pressure = 500 psig

Vacuum = 26 in. Hg

$H_2$ Inlet temperature = 500°F

Speed = 4190 rpm.

Power = 2.30 hp

BSPC = 2.12 lb/hp hr

BMEP = 80 psi

O/F = 1.72

% Heat rejected = 86%

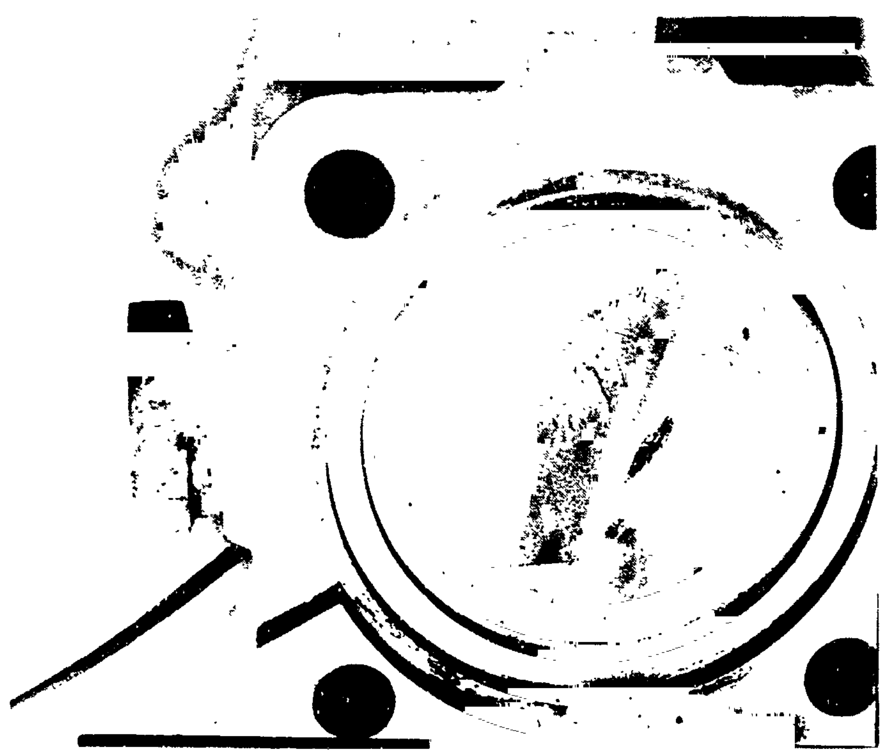

Fig. 8

12-19-63

Cylinder head after run with 7% combustion chamber, new hydrogen valves.

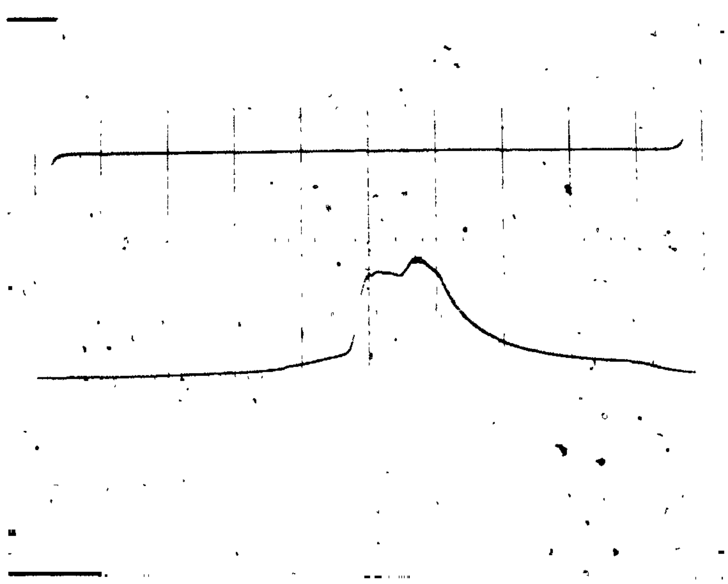

Fig. 9

12-21-63 3:05

Entry No. 28, Table I

$H_2$ Inlet pressure = 300 psig

$O_2$ Inlet pressure = 1150 psig

Vacuum = 24.5 in. Hg

$H_2$ Inlet temperature = 490°F

Speed = 3080 rpm

Power = 1.60 hp

BSPC = 2.84 lb/hp hr

BMEP = 76 psi

O/F = 1.67

% Heat rejected = 110%

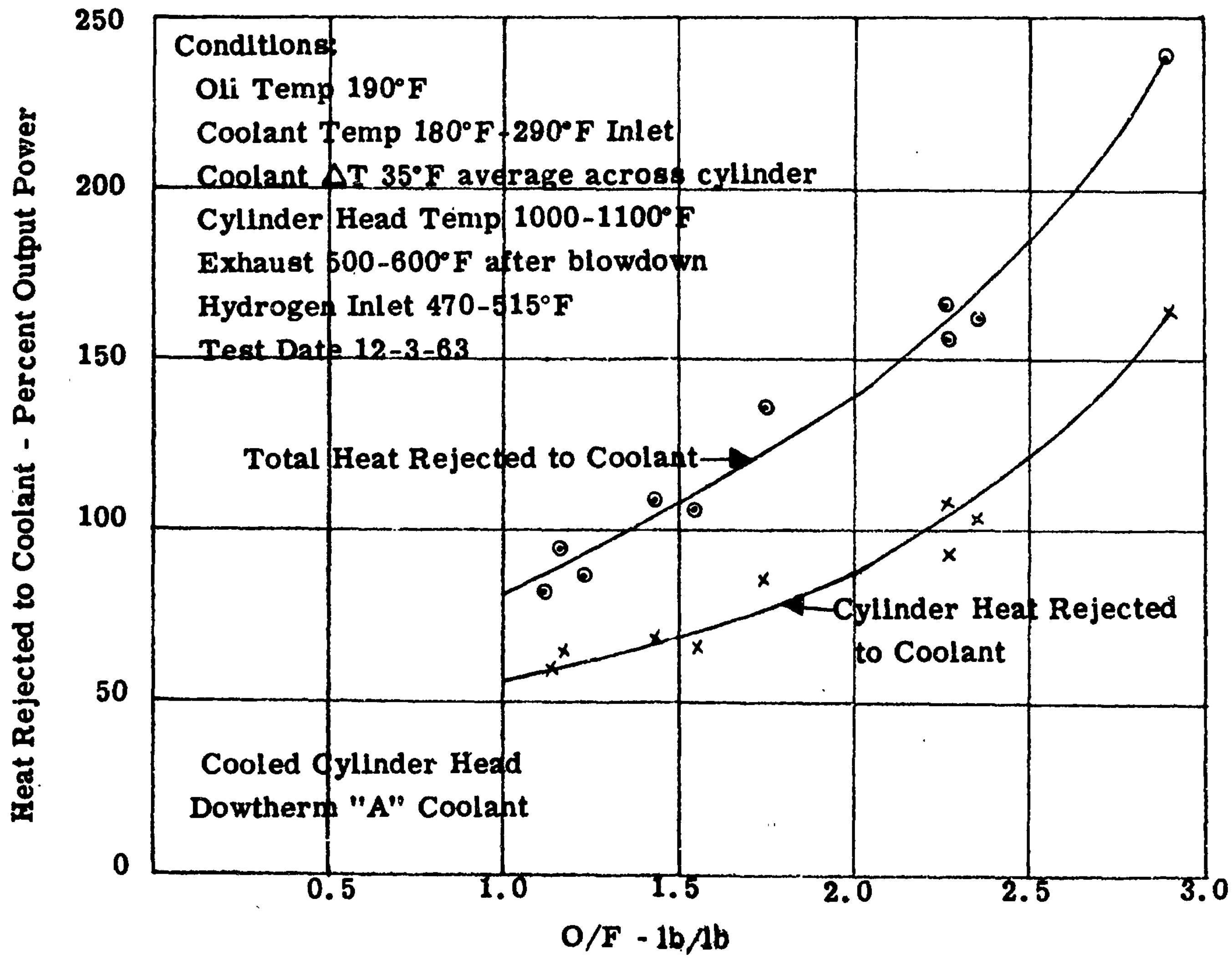


Fig. 10 - Heat Rejected to Coolant vs O/F Ratio

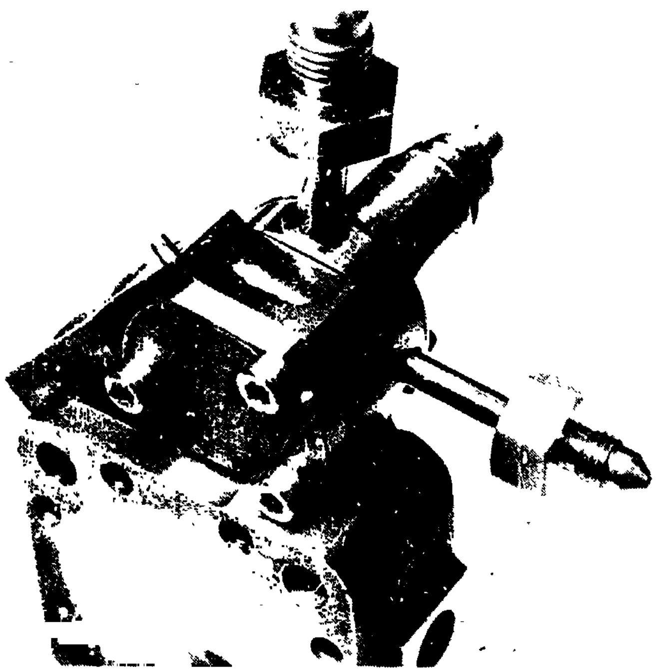

Fig. 11 - New Hydrogen Valve Assembly
Mounted on Cylinder Head

The tests on December 3, 1963, were run with a cooled head for the purposes of gathering information on cylinder and head heat loss. Verification of previous performance data was also sought. The results are given in Entries 1 through 9 of Table I and in Figs. 3 and 4. In these tests, coolant flowed through the cylinder walls and cylinder head in series. Dowtherm "A" was used as the coolant. Coolant temperature was raised by circulation through the coolant pump, to over 300°F. Cylinder wall temperature stabilized between 400 and 450°F. Oil temperature stabilized at 180°F after 30 minutes of hot running. Heat rejection data is plotted in Fig. 10 and agree with previous results obtained on Dowtherm "A" and water. Heat rejection to the coolant does not appear to be sensitive to the nature of the coolant, the coolant temperature, or flow rate.

Entries 7 and 9 on Table I represent identical operating conditions with a slight improvement in BSPC for Entry 9. This improvement was noticeable by the operator as the engine ran smoother.

With a cooled cylinder head, variations in head temperature as a function of mixture ratio were greatly damped, and it became possible to explore the effects of mixture ratio on performance. This was done in the tests of December 9 and 10. Three pressure-time traces from these runs are shown in Figs. 5, 6, and 7. The only difference in these runs is the oxygen inlet pressure. It can be seen that while mixture ratio decreases with decreasing oxygen pressure, no other parameters appear to be affected. Even heat rejection remains the same. (Cylinder wall and head temperatures were held constant.) BSPC is better in Fig. 5, but there is nothing to account for this except the long running time.

Two facts are apparent from all data gathered in this program:

1. The best performance figures are taken after the engine has been running for a considerable time.

2. While past data is reproducible given the same timing and the same mixture ratio, oxygen flow as a function of oxygen inlet pressure is not reproducible. Variations within a run and between successive runs have always been considerable and unpredictable. Mixture ratio must be set by observing temperatures, and adjusting oxygen pressure for the desired oxygen flow rate.

The engine was run for two half-hour stability checks. In these runs data was recorded at five minute intervals. Some data are shown in Entries 22 through 26 of Table I. Oxygen pressure was held to 800 psi for 30 minutes and dropped to 600 psi for another 30 minutes. No other changes were made. Flow changes were linear with time between points 22 and 23, points 24 and 25, and points 25 and 26. While drift usually occurs in the direction of increasing oxygen flow and therefore increasing O/F mixture ratio, it will also occur in the other direction.

The best explanation for changing oxygen injector characteristics during a run and between runs is the change in dimensions due to thermal and wear effects. A change of 0.001" in cold clearance of the oxygen injector causes a marked change in flow vs. pressure.

Note that BSPC in these stability runs was inferior to the repeated results achieved earlier on this engine. This was the first indication of a degradation in engine performance due to ring leakage and wear. This degradation became more evident later. At this time there were 10.5 hours of hot running time on this buildup.

Later tests were attempted using an uncooled combustion chamber giving 7% clearance volume, and a slot injector nozzle configuration. Four cast iron piston rings were used to improve compression. The slot injector nozzle did not have enough flow area to permit operation on a vacuum, and misfiring and loss of combustion occurred. A photograph of the combustion chamber after this run is shown in Fig. 8. This test also used the new hydrogen valves, which are shown mounted on the cylinder head in Fig. 11.

Power and BSPC were poor and the engine did not run well during this test.

A check was made with the cooled cylinder head and the slot injector. A P-T trace taken during this run is shown in Fig. 9. Power and SPC were poor. However, the new hydrogen valves were observed to give better chamber filling than the old valves.

Compression tests using the photocon cylinder head were made using hydrogen and nitrogen under a variety of conditions with two and four rings. While the results have not yet been completely analyzed there is conclusive evidence of excessive blowby and inadequate sealing. This primarily accounts for the poor performance of the last runs. A switch to four cast iron piston rings did not help since these rings did not seat in properly, due to inadequate ring tension and a worn cylinder barrel. Further investigation of ring and bore combinations, and allowable tolerances is needed.

During disassembly of this engine, friction tests were run on the engine at several stages of teardown. The 0 - 50 lb BLH load cell was used to measure torque. Since readings of less than 1 lb were recorded this data must be considered accurate only within limits of ± 20%. However, differences between two readings are likely to be more accurate than this. Further friction data will be taken when a low range load cell with adequate protection against overload is available. A summary of friction test results is given in Table III.

## TABLE III

## FRICTION TEST RESULTS

| Operating Condition | RPM | FMEP psi | Oil Temp. °F |
|---|---|---|---|
| 1. Four piston rings, | | | |
| $H_2$ valve operating | 2000 | 13.2 | 135 |
| | 3000 | 16.2 | ↓ |
| | 4000 | 23.1 | ↓ |
| | 4500 | 37.0 | ↓ |
| 2. Four piston rings, | | | |
| $H_2$ valve inoperative | 2000 | 10.6 | 120 |
| (cam follower removed) | 3000 | 16.9 | ↓ |
| | 4000 | 19.2 | ↓ |
| | 2000 | 9.7 | 160 |
| | 4000 | 15.0 | ↓ |
| | 4500 | 30.1 | ↓ |
| 3. Same as No. 2, oil | 2000 | 9.2 | 160 |
| supply off | 4000 | 9.2 | ↓ |
| | 4500 | 23.1 | ↓ |
| 4. Two piston rings, | | | |
| $H_2$ valve inoperative, | 2000 | 11.1 | 130 |
| oil flowing | 4000 | 8.1 | ↓ |
| 5. Same as No. 4, oil | 2000 | 9.2 | 130 |
| supply off | 4000 | 8.1 | ↓ |
| 6. All rings removed, | 2000 | 11.3 | 130 |
| $H_2$ valve inoperative, | 4000 | 8.1 | 140 |
| Oil flowing | | | |
| 7. Same as No. 6, oil | 2000 | 8.8 | 130 |
| supply off | 4000 | 3.5 | 140 |
| 8. All rings removed, cam | 2000 | 8.1 | 120 |
| gear off, Oil flowing | 4000 | 6.5 | 135 |
| 9. Same as No. 8, Oil | 2000 | 6.5 | 120 |
| supply off | | | |

Test Equipment

1. A gas sampling manifold has been added to the engine exhaust duct.

2. A Wallace & Fierman Model FA 160, 0-280 millimeter, of Hg absolute pressure gage has been connected to the engine exhaust manifold for more accurate measurement of exhaust pressure.

3. Use of the new vacuum system engine exhaust manifold adaptor has resulted in a pressure reduction at the engine of over a psi during vacuum operation.

4. Fabrication of the new oxygen injector test block has been delayed due to schedule slippage of the vendor fabricating the cam shaft.

5. Drawings are being detailed and parts procured for a system to measure engine exhaust gas flow rate. The system consists of:

   a. A sealed water tank with an emersed water cooling coil.

   b. A water level sight glass

   c. A Rotameter flow meter

The engine exhaust will be bubbled through the water tank to condense the steam content. The hydrogen flow will be measured with the flowrater. The steam rate will be measured by timing the level change of the water level in the sight glass. The water cooling coil will maintain the water at constant temperature.

## Regenerator

No work scheduled this reporting period.

## Compressor

### Design & Fabrication

1. Fabrication of Rulon A step gap rings for the Koppers configuration piston is complete.

2. A standard check valve has been machined to cartridge into the first stage cylinder head as an alternate discharge valve design.

3. One first stage head has been reworked for a larger diameter inlet valve seat diameter, and a larger diameter valve is being fabricated.

4. The new piston configuration, shown in Fig. 12 , is being fabricated. Piston cups of both Rulon A and Rulon LD are being fabricated. It is anticipated that this design will reduce leakage, due to better conformance of the seal to the cylinder wall, and by the elimination of ring gaps. The integral lip type seals should result in lower friction than can be achieved with piston rings. The force exerted on the cylinder wall by the seals can be controlled by the dimensions of the seal under cut. In addition the lip seal should perform better over a range of temperatures because they are an integral part of the piston and can not shrink into, expand out of, or stick to a ring groove.

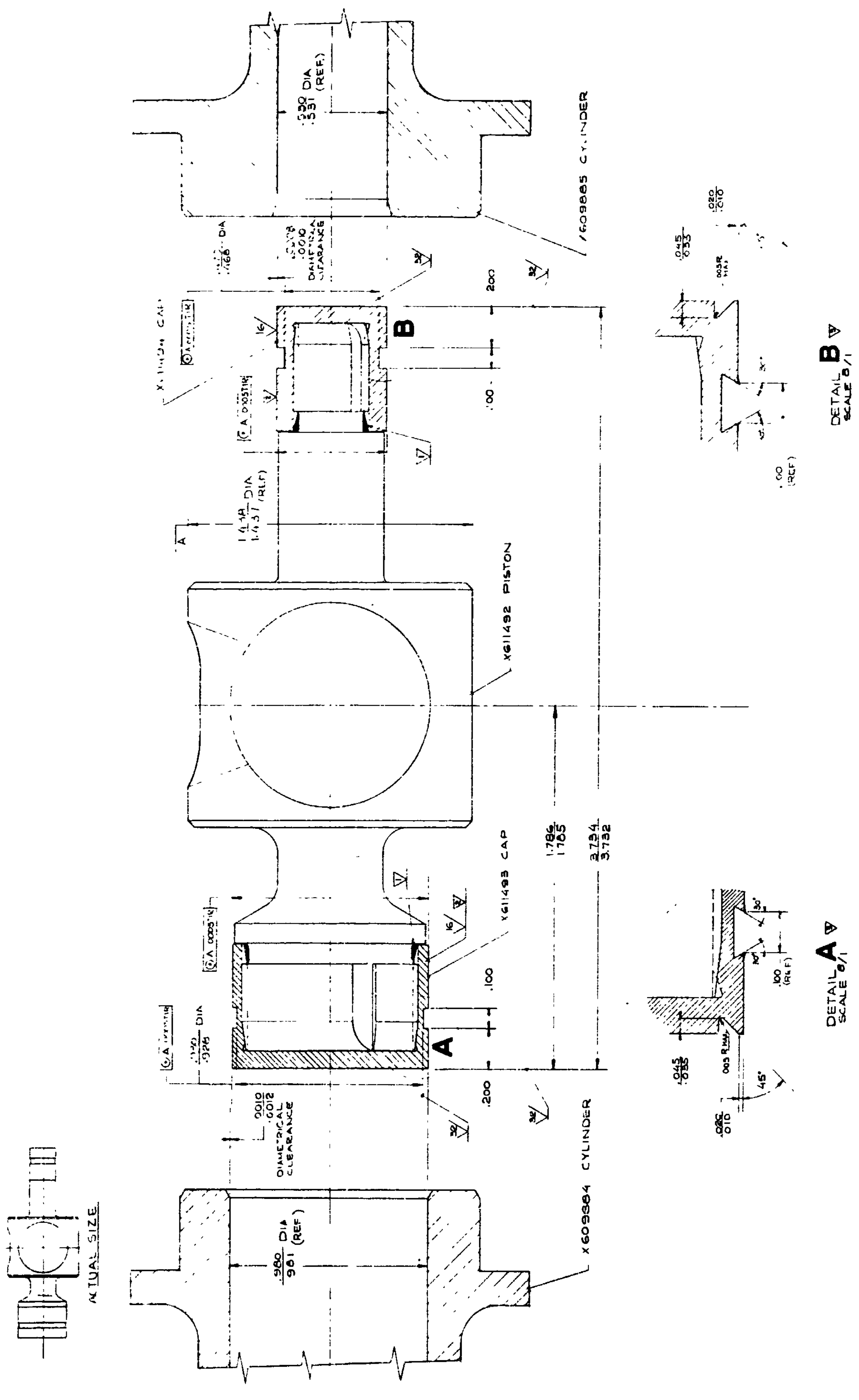


Fig. 12 - New Piston Configuration

5. A design study of a first stage inlet valve in piston is being made. A dynamic analysis of the valve configuration is in process.

Assembly

The Koppers piston rings were removed from compressor No. 2 and were replaced with Rulon A step gap rings.

The discharge valve was removed from one first stage cylinder head and replaced with a standard check valve.

Performance Testing

The Rulon A drive linkage bearings have continued to function satisfactorily, both with and without cooling. During one test the drive was exposed to liquid nitrogen without ill effects. A total running time of 5 hours and 51 minutes has been accumulated on the Rulon drive bearings in compressor No. 1 and about 3-1/2 hours have been accumulated on the bearing in compressor No. 2.

Teflon grease recommended by Dixon Corporation to reduce friction and wear of Rulon A was run on the surfaces of the bearing of compressor No. 2 and appeared to function satisfactorily. This grease will also be evaluated on the surface of the new piston design shown in Fig. 12.

The Rulon A step gap piston rings were run in for a total of 1-3/4 hour (one hour without heads and 3/4 hour with two stage compression). Friction torque using the Rulon rings was approximately one half of that experienced with the Koppers and Mace rings. First stage cylinder cooling was not required.

During this month all valves were statically flow tested to evaluate pressure drop vs. flow. These tests led to design changes of first stage valving.

During performance testing performed to date, flow has been measured with sonic orifices which have not been calibrated. These orifices will be calibrated against rotometers with certified calibrations during the week ending January 11, 1964.

During future tests, flow will be measured with the rotometers.

A standard test data sheet and a data reduction sheet have been prepared and put in use. During the month of January both the compressor and test stand will be developed to the point that accurate quantitative performance data will be taken.

Test Equipment

1. A one piece first stage inlet manifold with braze connected pressure, thermocouple and bleed ports has been fabricated. This manifold eliminates a number of possible leakage points and places instrumentation closer to the compressor inlet valve.

2. The rotometers, for measuring discharge flow, have been procured and calibrated by a certified laboratory.

PROTOTYPE ENGINE ENDURANCE TEST

No work scheduled during this reporting period.

# APPENDIX A

## DRAWING CONTROL PROCEDURES

# APPENDIX A

## DRAWING CONTROL PROCEDURES

## 1.0 DRAWING PROCEDURES FOR NASA PROGRAM

To insure that drawings exhibit accurate and precise information which if followed exactly will insure that fabricated parts meet the intent of the design, the procedures described below will be followed by the Engineering Project group.

### 1.1 Types of Drawings

Two classifications of drawings (those with X prefix numbers and those with SK prefix numbers) will be used. All drawings with X prefix numbers will be on vellum. Drawings with SK prefix numbers may be on vellum, C.B., brown line or may be blue prints marked with a red pencil.

#### 1.1.1 Use of Drawing with X Prefix Numbers

Drawings (details subassemblies, and assemblies) with X prefix numbers and parts lists will be used to represent the basic configuration of the development components (engine, compressor, and regenerator). Drawings with X prefix numbers will also be used for newly designed parts which are believed to be superior to existing parts; however, the basic assembly drawings and parts list will not be changed to show the newly designed parts until these parts have been proven by test to be superior.

#### 1.1.2 Use of Drawings with SK Prefix Numbers

Drawings with SK prefix numbers will be used for:

1. Rework of existing parts
2. Identification of layout drawing from which detail drawings are made.
3. Interim assembly drawings (when required) for alternate parts.
4. New parts which are of interim nature and which will definitely not be used in the final component configuration.
5. Cases where a number of different new approaches are being taken for a particular function, only one or none of which will ultimately be selected as a basic part.

1.2 Drawing Number Assignment and Inventory

One engineering project group design engineer designated as "Design Control Engineer" will be assigned the duties of reserving blocks of X and SK drawing numbers, and issuing all drawing numbers used for development hardware. He will record the drawing number and name on a master list at the time the number is issued. When an SK prefix number is issued for a drawing which will be used to rework an existing X number part the X number of the part to be reworked will be listed to the side of the SK number. When the drawings are released for fabrication of new parts or rework of old parts, he will add the drawing numbers to the procurement status form vellum. Copies of this list will be used for follow-up of fabrication.

All reproducible drawings (vellums, C. B., and brown lines) will be kept in the company file when they are not in use.

Rework, SK prefix drawings which are blue lines marked with a red pencil will be prepared in duplicate. One copy of the SK drawing will be filed in the engineering office in a folder labeled with the drawing number of the basic part being reworked. Maintenance of the file will be the responsibility of the Design Control Engineer. The other copy of the SK drawing will accompany the part through rework and inspection and will then become part of the assembly buildup records of the test component in which the parts are used. The assembly buildup records are the responsibility of the Test Engineer assigned to the test component.

1.3 Design Support and Liaison

The designer assigned a particular design task will:

1. Perform and maintain records of all necessary calculations, tolerance studies and liaison with vendors, the Production Planning Department, Staff Metallurgist, the Purchasing Department, etc., to insure the proper fabrication and function of parts.

2. Prepare a layout drawing

3. Prepare detail drawings or supervise and check the work of the draftsman assigned the detailing task.

4. Deliver a set of checking prints to the checking department and to another design engineer in the engineering project group.

## 1.4 Design Checking Procedure

After the design engineer responsible for a design is satisfied that all drawings are complete and correct, the drawings will be checked by both the checking department and by another design engineer within the engineering group who has not worked directly upon the particular design project. When corrections have been made to the satisfaction of the in group designer, he will sign the drawing. When corrections have been made to the satisfaction of the checking group designer, he will also sign the drawing. The Design Control Engineer will keep all checking prints until parts are fabricated.

Parts which are not urgently needed for the test program will not be released for fabrication until after all suggested corrections (by the other project group designer and the Checking Department) have been made. In cases where parts are urgently needed for the test program, the drawings may be released for production after the corrections indicated by the in-group designer have been made. In this case, only those changes requested by the Checking Department which are necessary to assure proper fabrication of the part will be made while the parts are in process; however, the Checking Department checking prints will be kept by the designer until such time that another change to the particular drawing is required. At this time the previously suggested non-critical changes will be incorporated. Non-critical changes are defined as those which do not directly affect the proper fabrication of the part such as compliance with specific company formats, requirements for micro-filming, etc.

## 1.5 Design Approval & Release

Layout drawings and background material from which detail drawings are to be made will be approved by both the Project Engineer and Program Manager prior to preparation of detail drawings.

All new and changed X prefix drawings parts and release notices will be approved and signed by the project engineer and Program Manager. All drawings (X and SK) will be released by the design engineer assigned duty of issuing drawing numbers and maintaining the procurement status form.

SK prefix drawings for new parts will be approved by the project engineer prior to release. Requests for rework of existing X number parts to an SK drawing configuration may be released by the test engineer after the SK number has been added to the procurement status list and after the request for rework forms has been approved and signed by the project engineer.

# APPENDIX B

## FAILURE REPORT AND SUMMARY SHEETS

## ENGINE FAILURE MODES

1. Oxygen Injector

    A. Broken flex pivot
    B. Haskel seal leak
    C. Bushing to shaft seizure
    D. Leak spring retainer deformed
    E. Flame plated valve worn

2. Engine

    A. $H_2$ valve assembly leakage
    B. Catalyst plug gasket leak
    C. $H_2$ valve retainer ring broke

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3 2787
MARK I $H_2$ $O_2$ ENGINE MODEL EA-1570-515

SHEET NO. 1 of 3

Note: 1. Initial and Date items you fill in, 2. Rework SE No.'s. can be used as Serial No.'s.

| Failure No. | Data Sheet No. Time & Date of Failure | Part Name | Part No. & Serial No. | Description of Failure (The Part Condition) | Description of Conditions (Active on Part prior to Failure) | Failure Mode No. | Cumulative Time on Part in Minutes | Action Taken |
|---|---|---|---|---|---|---|---|---|
| 1 | D.S. 18 | $O_2$ Injector Flex Pivot | X610104 | Broken Flex Pivot | Engine shut down due to tendency of oxygen valve to stick open. | 1A | 70 Cold 41 Hot | New flex pivot installed |
| 2 | D.S. 21 | $O_2$ Injector Flex Pivot | X610104 | Broken flex pivot | Engine cylinder head temperature was low and could not be increased. | 1A | 257 Cold 75 Hot | New flex pivot installed; poppet refinished and lapped; seat guide lapped. |
| 3 | D.S. 23 | $O_2$ Injector Face Seal | X610113 | Leaking haskel seal | Engine stopped because $O_2$ $\Delta P$ gauge showed increasing flow. | 1B | | New seal installed. |
| 4 | D.S. 23 | $O_2$ Injector Flex Pivot | X610104 | Flex pivot broken | Cylinder head temperature could not be raised to 1400°F and $O_2$ flow fluctuated excessively. | 1A | 88 Hot | Pivot removed and replaced with a new stainless flex pivot. |
| 5 | D.S. 27, 28 - 10-12-63 | $O_2$ Injector Flex pivot | X610104 | All three bands of $O_2$ injector flex pivot broken. | Engine stopped when $O_2$ flow fluctuated excessively. | 1A | 142 Hot | New flex pivot installed. |
| 6 | 10-18-63 | $O_2$ Injector Bushing | X611376 | Flame plated bearing seized in bushing. Bushing had started to come out of body. | Engine started and $O_2$ flow increased to full flow. | 1C | 68 Cold 1 Hot | Bushing pressed back into body. |
| 7 | D.S. 33 | $O_2$ Injector Bushing | X611376 | $O_2$ Injector was sticking. Flame plated bushing and shaft seized together. | Engine stopped when $O_2$ flow became erratic. | 1C | 37 Hot | Bushing honed out for an .0008 to .001 clearance and counter-bored to prevent end of shaft from rubbing on bushing. |

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I $H_2$ - $O_2$ ENGINE MODEL EA-1570-515

SHEET NO. 2 of 3

Note: 1. Initial and Date Items you fill in, 2. Rework SK No.'s. can be used as Serial No.'s.

| Failure No. | Data Sheet No. Time & Date of Failure | Part Name | Part No. & Serial No. | Description of Failure (The Part Condition) | Description of Conditions (Active on Part prior to Failure) | Failure Mode No. | Cumulative Time on Part in Minutes | Action Taken |
|---|---|---|---|---|---|---|---|---|
| 8 | 11-1-63 | $O_2$ Injector Retainer | X611378 | The leaf spring had been deformed around end of valve. | Normal inspection of $O_2$ injector. | 1D | 247 Hot | New retainer installed. |
| 9 | 11-13-63 | $O_2$ Valve | X611402 | Some flame plated material came off seat area. | Test stand used for test valve run using cold gas. | 1F | 68 Cold | Valve sent to NASA Lewis for examination. |
| 10 | 11-16-63 | $O_2$ Injector Retainer | X611378 | The leaf spring had been deformed around end of valve. | Normal inspection of $O_2$ injector. | 1D | 232 Hot | New retainer installed. |
| 11 | 11-19-63 | $H_2$ Valve Assembly | X611414 | Seals in $H_2$ valve assembly leaking. | Engine stopped when flames were observed coming from $H_2$ valve assembly. | 2A | 230 Hot | New $H_2$ valve assembly seals installed. One copper seal made. $H_2$ manifold brazed. |
| 12 | 12-7-63 | $O_2$ Injector Valve | X611402 | Some flame plated material came off seat area. | Test stand used for test valve run using cold gas. | 1E | 30 Cold | Valve to be returned to Linde Co. for examination and recommendation. |
| 13 | 11-21-63 | $H_2$ Valve Assembly | X611414 | Seals in $H_2$ valve assembly leaking. | Engine stopped when flames came out of $H_2$ valve assembly. | 2A | 6 Hot | New seals installed. |
| 14 | 11-23-63 | $O_2$ Injector Valve | X611402 | Excessive wear on guide area of valve (flame plated). | Engine stopped when $O_2$ injector could not be controlled. | 1E | 300 Hot | Valve sent to NASA Lewis for metallurgist examination. |

SHEET NO. 3 of 3

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA [illegible]
MARK I $H_2$ - $O_2$ ENGINE MODEL EA 1570 [illegible]

Note: 1. Initial and Date Items you fill in, 2. Rework Sh. No.'s. can be used as Serial No.'s.

| Failure No. | Data Sheet No. Time & Date of Failure | Part Name | Part No. & Serial No. | Description of Failure (The Part Condition) | Description of Conditions (Active on Part prior to Failure) | Failure Mode No. | Cumulative Time on Part in Minutes | Action Taken |
|---|---|---|---|---|---|---|---|---|
| 15 | 12-12-63 | $O_2$ Injector Retainer | X611378 | The leaf spring retainer had been deformed around the end of the valve. | Normal inspection of injector. | 1D | 552 Hot | New retainer installed. |
| 16 | 12-12-63 | $H_2$ Valve Assembly Ring | X610171 | The $H_2$ valve ring had worn through. | Normal disassembly for inspection of $O_2$ injector. | 2C | 819 | New ring installed. |
| 17 | 12-20-63 | $H_2$ Valve Assembly | | $H_2$ valve assembly leakage. | Engine stopped when fire came out of the top seal of the $H_2$ valve assembly. Note: The [illegible] had loosened and may have caused the leak. | 2A | 41 Hot | New seals installed. |

# APPENDIX C

## TEST PLAN FOR JANUARY, 1964

# APPENDIX B

## TEST PLAN FOR JANUARY, 1964

1.0 HIGH ADMISSION TESTS

1.1 Number of Tests 5 - 8

1.2 Description

The engine will be run with a cooled cylinder head, inward opening hydrogen valves, and an oxygen injector configuration capable of high flow rates. The objective will be to determine power, BSPC and heat rejection as a function of hydrogen valve admission and mixture ratio.

1.3 Operating Parameters

Speed: 3000 and 4000 rpm
Hydrogen pressure: 300 psig
Hydrogen temperature: ambient and 500°F
Vacuum exhaust: 100 and 300 mm Hg abs.
Hydrogen valve settings: 20° ATDC - 50° ATDC cutoff, with corresponding oxygen timing

1.4 Estimated Running Time 6 hours

2.0 HEATED INLET TESTS

2.1 Number of Tests 2 - 4

2.2 Description

Hydrogen inlet temperature will be varied in steps to the highest allowable value. Other parameters will be held constant.

2.3 Operating Parameters

Speed: 3000 and 4000 rpm
Hydrogen Pressure: 300 psig
O/F: 1.5:1

Timing will be adjusted to yield 2.0 - 3.0 hp.

2.4 Total Running Time 2 hours

3.0 HALF-HOUR STABILITY TESTS

3.1 Number of Tests 2 - 5

3.2 Description

The engine will be run at a moderate power level at a setting where plenty of performance data is available and run without adjustments or changes for thirty minutes. Data will be taken at five minute intervals. Valve clearances will be checked before and after.

4.0 6 - 8 HOUR ENDURANCE TEST

4.1 Number of Tests 1 - 2

4.2 Description

The engine will be run at moderate power levels for 6 to 8 hours. Data will be recorded every 15 minutes. The engine and injector will be checked for wear before and after this test. Cylinder bore, valve guide clearances, oxygen injector poppet, and seat dimensions, etc. will be recorded before and after.

5.0 ADVANCED HYDROGEN TIMING

5.1 Number of Tests 2 or more

5.2 Description

Hydrogen will be admitted near BDC at a low pressure and temperature and compressed, with the oxygen admitted near TDC. Length and number of tests will be determined by the success of this combustion technique.

5.3 Operating Parameters

1. $H_2$ - 40° ABDC - 60° ABDC - Approximately 50 psi

2. $O_2$ Midpoint at TDC - 500 - 1000 psi cooled cylinder head

5.4 Estimated Running Time 3 hours

In addition to and concurrent with these tests, piston rings of various configurations will be evaluated and exhaust samples will be taken and chemically analyzed. It is assumed that the No. 1 engine with its present cylinder bore will be used all month.