PROGRESS REPORT

PR 91570-510-12

For the Period of 1 June 1964, through 30 June 1964

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FACILITY FORM 602

DEVELOPMENT OF A HYDROGEN-OXYGEN SPACE POWER SUPPLY SYSTEM

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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 1 June through 30 June 1964. 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.

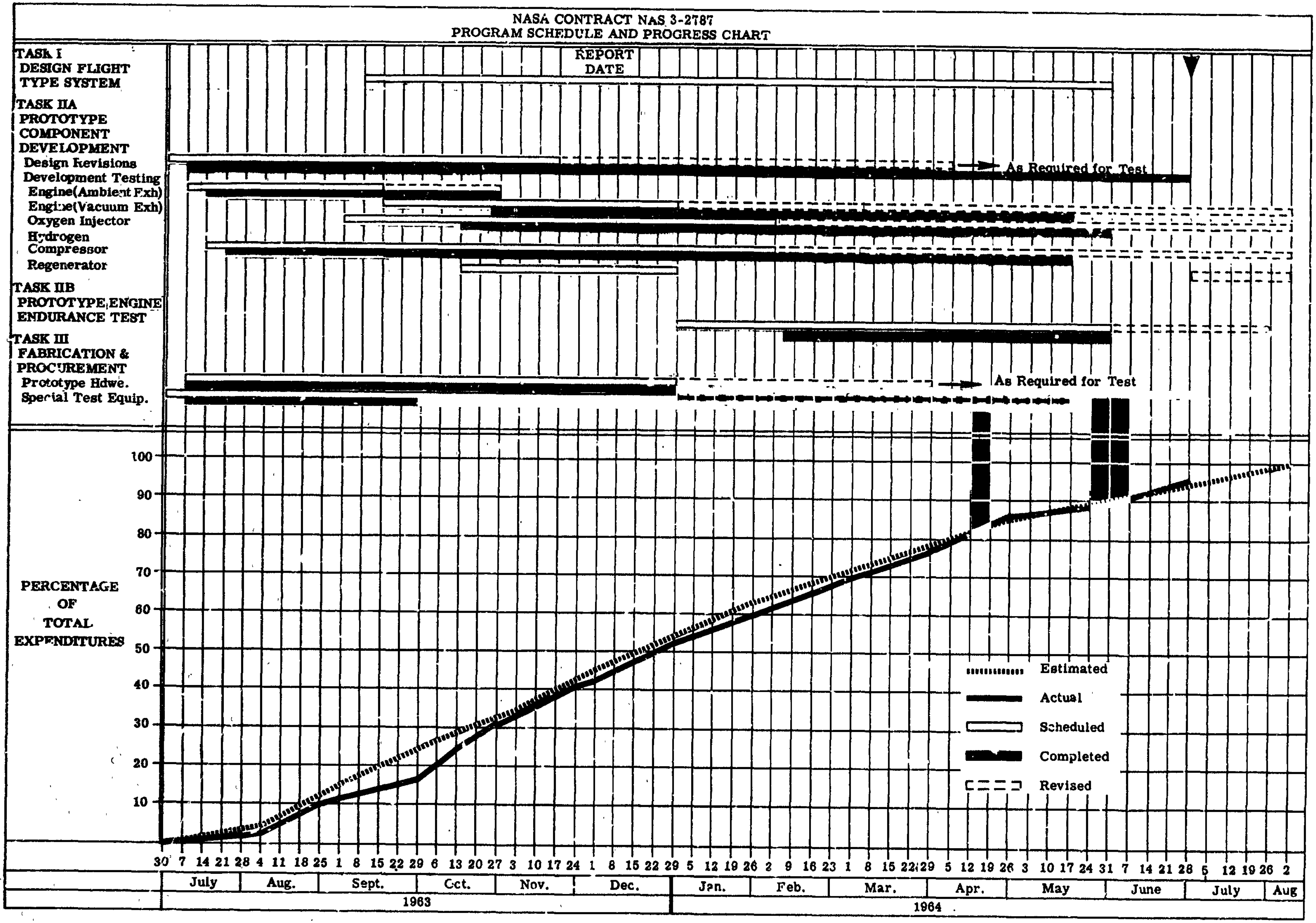
This contract, NAS 3-2787, is a continuation of NASA Contract NAS 3-2550.

PROGRAM SCHEDULE

The program schedule shown in Fig. 1 has been revised to reflect changes in the program plans resulting from a technical review meeting between NASA and Vickers Inc. on January 16 and 17, 1964. Component development and endurance testing will be extended through July, 1964. Flight system design work will continue to be deferred until additional development and endurance testing have been accomplished.

FLIGHT TYPE POWER DESIGN

No work was scheduled during this reporting period on the flight type power system design because of technical direction from the NASA Technical Program Manager.


NASA CONTRACT NAS 3-2787
PROGRAM SCHEDULE AND PROGRESS CHART
TASK I
DESIGN FLIGHT TYPE SYSTEM
TASK IIA
PROTOTYPE COMPONENT DEVELOPMENT
Design Revisions
Development Testing
Engine(Ambient Exh)
Engine(Vacuum Exh)
Oxygen Injector
Hydrogen Compressor
Regenerator
TASK IIB
PROTOTYPE ENGINE ENDURANCE TEST
TASK III
FABRICATION & PROCUREMENT
Prototype Hdwe.
Special Test Equip.
REPORT DATE
As Required for Test
As Required for Test
PERCENTAGE OF TOTAL EXPENDITURES
100
90
80
70
60
50
40
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20
10
Estimated
Actual
Scheduled
Completed
Revised
30 7 14 21 28 4 11 18 25 1 8 15 22 29 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 16 23 1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28 5 12 19 26 2
July
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Fig. 1

PROTOTYPE COMPONENT DEVELOPMENT

Engine

Design and Fabrication

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

1. Two oxygen injector rocker arms and poppets were reworked to provide full hemispherical contact between the two parts with approximately twice the contact area of the original design. The spherical surface of the poppets were of Haynes 6B which was brazed to the L-605 poppet shafts prior to machining. One of the poppets was coated with Pb O by NASA Lewis.

2. New oxygen injector poppets are being fabricated to the redesigned configuration shown in Figs. 2 and 3. This design provides approximately three times the contact area of the original design and eliminates the slot in the rocker arm. Both Haynes 6B and L605 parts are being fabricated.

3. A redesigned retainer for the cylinder head insert was fabricated (see Fig. 4). The objective of this design was to increase the reliability of the retainer and reduce the possibility of leakage through the cylinder head insert "K" seal.

4. A new combustion chamber shape (Fig. 8 type) is being machined into a cylinder head insert blank (see Fig. 5).

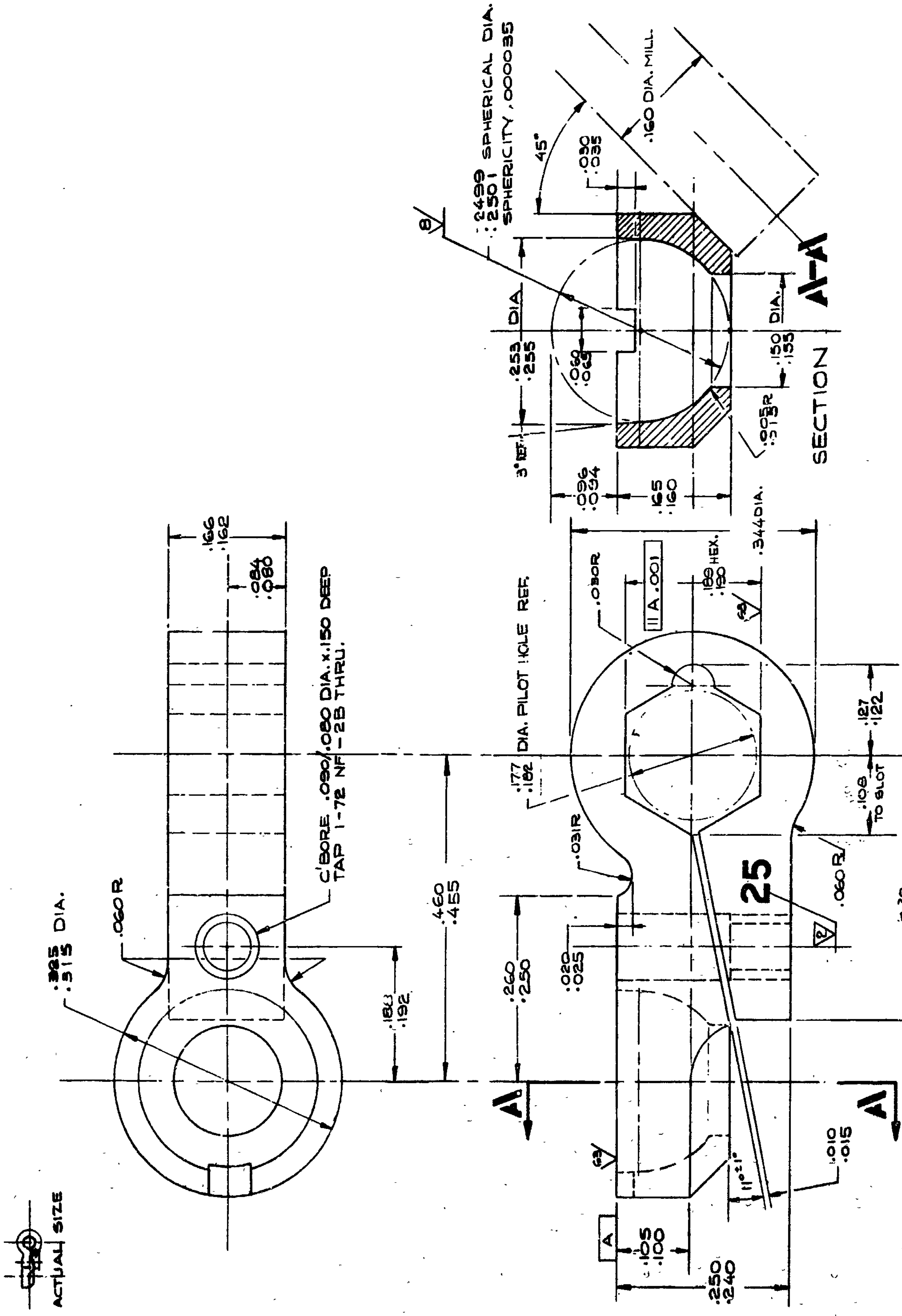

Fig. 2 - O_2 Injector Rocker Arm

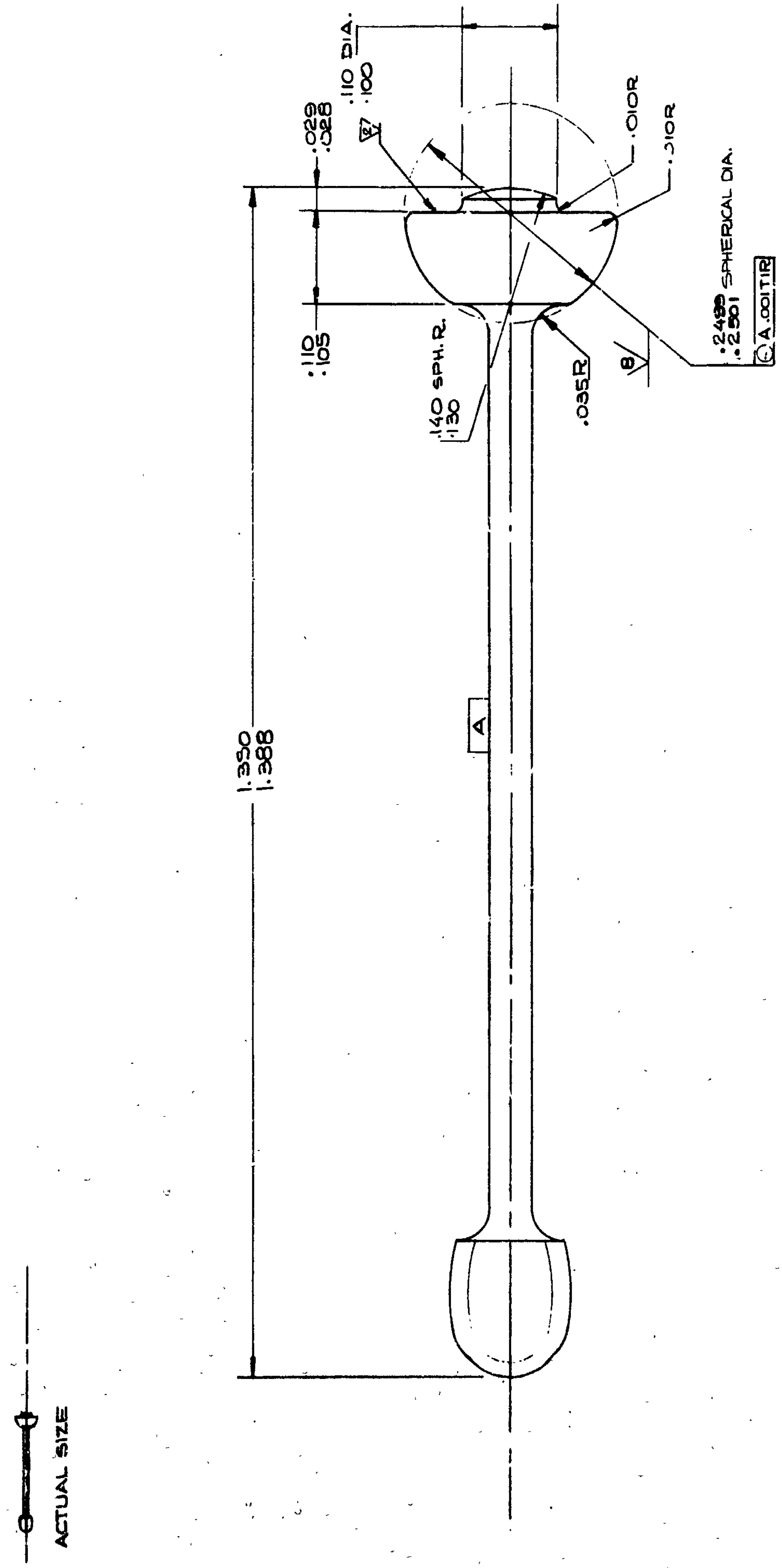

Fig. 3 - O_2 Injector Poppet Valve

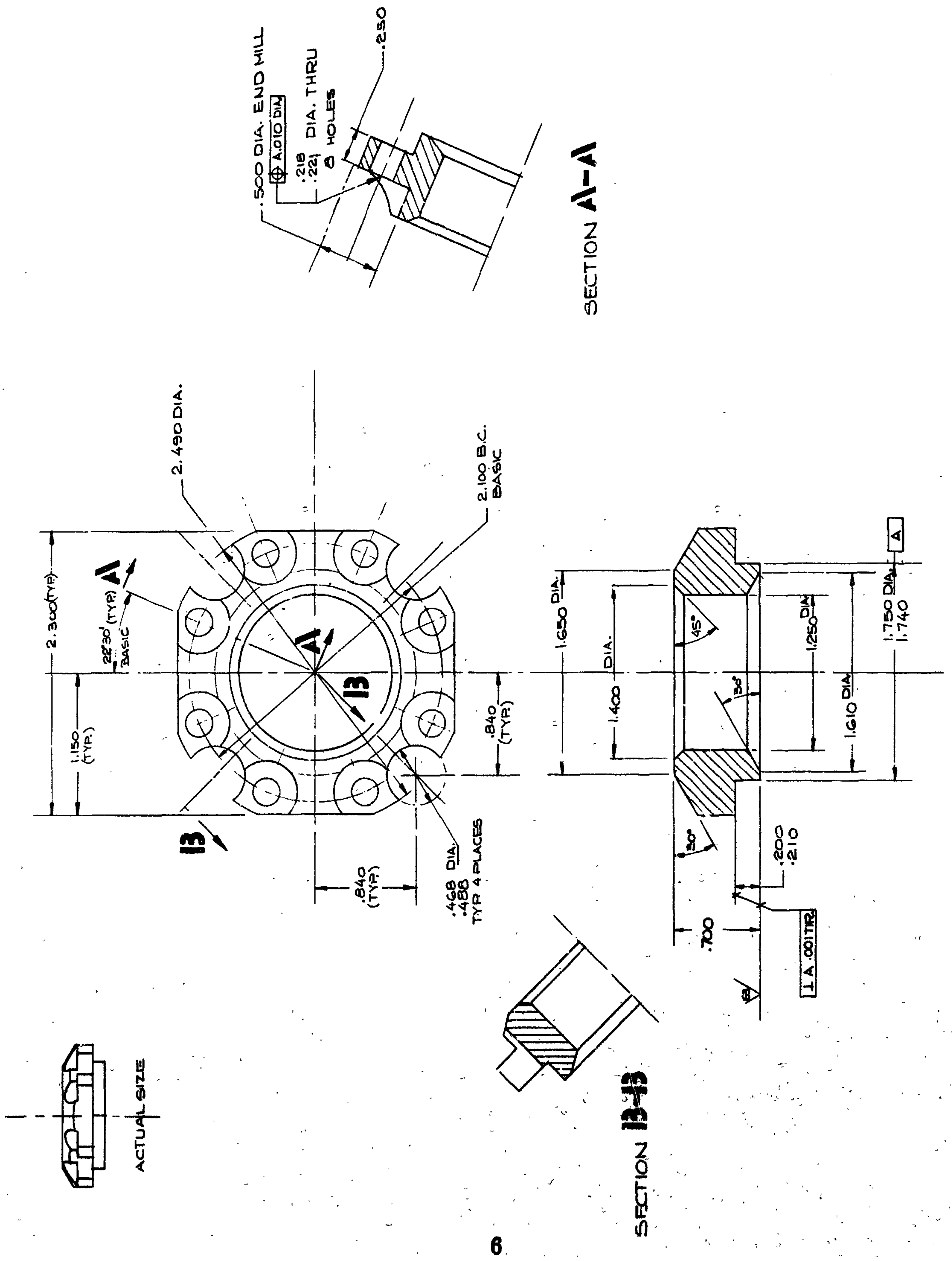

Fig. 4 - Combustion Chamber Retainer

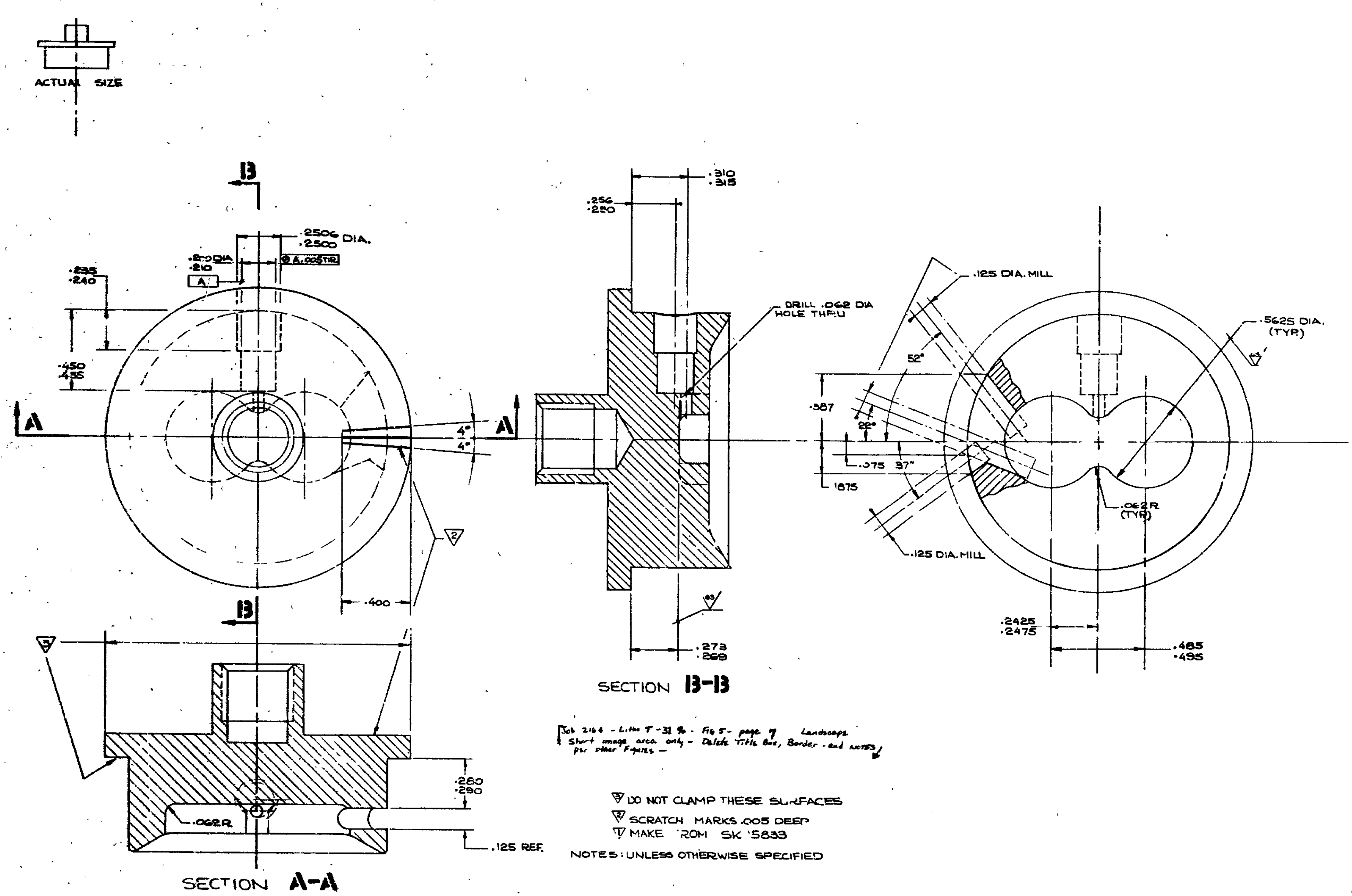

Fig. 5 - "Figure 8" Type Combustion Head

5. A cylinder head insert, provided by NASA Lewis, was machined for catalyst. This combustion chamber contained a protrusion which resembled the peak of a sombrero, and was designated the "Mexican Hat" configuration.

6. The cast iron cylinder and cast iron cylinder and jacket assembly drawings were changed to make fabrication more compatible with the braze assembly method. One new cylinder is being fabricated.

7. Two new cylinder and jacket assemblies were brazed, one with a cast iron cylinder and one with a T-15 tool steel cylinder.

Assembly

The No. 2 cylinder assembly which ran the 100 hour endurance test last month was vapor-blasted and installed with new piston rings on the fourth buildup of Engine No. II after the 24 hours endurance run of 2 June. The hydrogen valve assembly was removed, cleaned and reassembled with a new Elgiloy outer valve spring after an additional 6 hours running on this same buildup. A failure of the inner hydrogen valve spring (Elgiloy type), was encountered after additional endurance running which necessitated the removal and teardown of this engine buildup (see Fig. 6).

The disassembly and inspection of the fifth buildup of Engine No. I which ran the 100 hour endurance test of last month indicated no abnormal wear of component parts except the hydrogen valve spider leg was worn through to the safety pin hole.

The sixth buildup of Engine No. I incorporated the following changes:

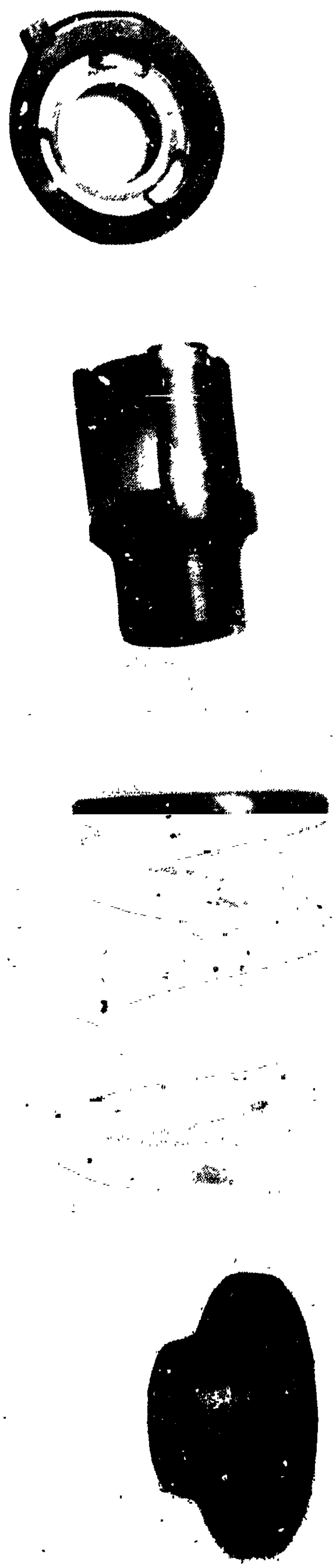

Fig. 5 - Broken Valve Spring

1. A reworked piston ring housing for three piece compression rings.

2. A new Elgiloy outer hydrogen valve spring and a hardened spider and follower assembly.

3. The No. 2 cylinder assembly was vapor honed. New piston sealing rings were installed.

After the 31 hour endurance run on June 24-25 the Elgiloy outer valve spring broke and the following corrective actions were taken.

1. A new non-heat shield type hydrogen valve assembly was reworked to get more lubrication to the guide area and installed to the head.

2. A used outer valve spring (music wire) was substituted.

Performance Testing

The majority of the performance tests this month have been pre-endurance checkout and calibration runs; and investigation of new cylinder head and catalyst configurations.

Some representative performance data are shown in Tables I and II. Propellant consumption has attained a new low of 1.60 lb/hp hr at 4000 rpm and 1.70 lb/hp hr at 3000 rpm. This performance level has been repeated in several runs, including endurance tests. Performance in endurance tests does not deteriorate until some malfunction (such as inadequate oxygen flow due to lost lift in the injector) occurs. There is, however, a tendency for misfiring at low exhaust back pressure after the first six or eight hours.

TABLE I

PERFORMANCE TEST DATA - JUNE, 1964

Entry	Time, Date	Hour	* O_2 Injector Config.	Speed, rpm	Power, hp	O/F	BSPC, lb/hp-hr	BMEP, psi	Cylinder Head
1	6-1	6:23pm	1	3500	2.02	1.10	2.06	84	Mushroom, 9% cl. vol.
2	6-1	6:35pm	1	3000	1.87	1.13	2.19	91	Mushroom, 9% cl. vol.
3	6-1	6:48pm	1	4000	2.51	1.00	1.98	92	Mushroom, 9% cl. vol.
4	6-10	5:55pm	2	3000	2.29	1.11	1.87	111	Mushroom, 9% cl. vol.
5	6-10	6:00	2	2500	1.94	1.55	2.24	113	Mushroom, 9% cl. vol.
6	6-10	6:14	2	3500	2.78	1.12	1.75	116	Mushroom, 9% cl. vol.
7	6-10	6:24	2	4000	3.12	1.07	1.70	114	Mushroom, 9% cl. vol.
8	6-10	6:32	2	3000	2.41	1.14	1.82	117	Mushroom, 9% cl. vol.
9	6-15	4:38	2	3500	3.25	1.51	1.64	135	Mexican Hat, 8.5% cl.
10	6-15	4:45	2	4000	3.54	1.37	1.60	129	Mexican Hat, 8.5% cl.
11	6-15	4:55	2	3000	2.83	1.66	1.69	135	Mexican Hat, 8.5% cl.
12	6-15	5:03	2	4000	3.48	1.49	1.66	125	Mexican Hat, 8.5% cl.
13	6-15	8:10	2	3000	2.48	1.34	1.75	121	Mushroom, 9% cl.
14	6-15	8:20	2	3500	2.84	1.20	1.76	119	Mushroom, 9% cl.
15	6-15	8:30	2	4000	3.37	1.21	1.62	122	Mushroom, 9% cl.
16	6-15	8:35	2	4000	3.34	1.18	1.62	122	Mushroom, 9% cl.
17	6-24	8:30	3	3000	2.60	1.28	1.78	127	Mushroom, 9% cl.
18	6-24	8:38	3	4000	3.33	1.10	1.68	122	Mushroom, 9% cl.
19	6-29	5:27	3	4000	3.81	1.47	1.63	138	Figure 8, 9.7% cl.
20	6-29	5:33	3	3000	2.70	1.81	1.82	129	Figure 8, 9.7% cl.

* Numbers refer to entires in Table II

TABLE II

OXYGEN INJECTOR CONFIGURATIONS

1. Poppet and seat of Haynes 25, calcium fluoride plated. Orifice 0.032 inch diameter, straight with conical expansion.

2. Same as (1), with orifice enlarged to 0.045 inch.

3. Welded poppet with Haynes 25 nose and stem, and Haynes 6B rocker bearing end. A leaf spring used between the poppet and retainer. Poppet nose coated with lead oxide.

Compressor

No work was done on the compressor development effort during this report period.

PROTOTYPE ENGINE ENDURANCE TESTS

A total of 156.5 hours endurance testing was accumulated this month. These endurance tests are described below. Results are shown in Table III.

June 2 - 3

Engine No. II ran on the endurance test stand for 24.6 hours. The following operating conditions and performance levels were observed during the first several hours.

Cylinder head temperature	1470 - 1500°F
Hydrogen inlet temperature	500°F
Speed	3000 rpm
Power	2.2 - 2.4 hp
BSPC	2.0 - 2.2 lb/hp-hr
O/F	1.06 - 1.16
Exhaust back pressure	200 mm Hg

The oxygen inlet pressure was gradually raised from the initial setting of 700 psig to 850 psig during the run to maintain the same oxygen mass flow (as determined by cylinder head temperature). After 17 hours it was also necessary to raise engine speed to keep the oxygen flow high enough to sustain combustion.

The test was stopped because of a fire caused by a hydrogen leak at a tube fitting downstream from the hydrogen heater.

TABLE III

HYDROGEN - OXYGEN ENGINE

ENDURANCE TEST SUMMARY

Date	Hrs. per Test	Accum Hrs	Engine Buildup	hp	SPC lbs/hp-hr	Objective Achieved	Remarks
	**	**					Cooled head.* No
2/5/64	8.1	8.1	1-4	2.2-2.5	2.1-2.3	yes	changes between runs
2/6/64	6.1	14.2	1-4	2.2-2.7	2.0-2.2	yes	inspection only
2/24/64	12.2	26.4	1-4	2.3-2.7	1.9-2.3	yes	Cooled head*
2/28/64	9.4	35.8	1-4	2.2-2.6	1.7-2.0	no	Uncooled head.* Test aborted due to external O_2 leak
5/19-23	100.1	135.9	1-5	0.9-2.1	1.8-3.1	yes	Adjusted O_2 Injector at 51.2 hrs to compensate for wear
6/2 - 3	24.6	160.5	2-4	*** 2.2-2.4	*** 2.0-2.2	no	***Data not complete Test aborted due to fire caused by H_2 leak from external fitting
6/11-12	32.0	192.5	2-4	2.4-2.6	1.6-1.9	no	Test stopped due to H_2 valve sticking
6/15-18	65.5	258.0	2-4	*** 2.4-2.7	*** 1.6-1.9	no	***Data not complete test aborted due to broken H_2 valve spring
6/24-25	34.4	292.4	1-6	*** 2.5-2.7	*** 1.7-2.0	no	***Data not complete Test aborted due to broken H_2 valve spring

* All tests were with uncooled head except as noted.

** Test time includes pre-endurance checkout time provided no wearing or moving parts are replaced.

After the engine cooled to ambient temperature, leaks were observed in the "K" seal in the head insert and in the oxygen injector nose seal. The rocker-to-valve clearance in the O_2 injector rocker arm assembly was 0.0185 inch (the original clearance was 0.0003 inch). All coating was worn from wear surfaces at both ends of the poppet valve.

Oxygen injector valve lift decreased from 0.0132 inch to 0.008 inch during the run.

After the run, cracks were found on the cylinder head gasket seating surface of the cylinder and in the top braze joint between the cylinder and the cooling jacket. The cracking is attributed to a malfunction of the cylinder cooling system which caused momentary overheating of the cylinder.

This engine featured the following components;

Mushroom cylinder head with 9% clearance volume, housing platinum wire; 0.032 inch diameter straight 0_2 injector orifice; brazed cylinder assembly; steel cylinder-to-head seal; hard-faced hydrogen valve followers; calcium fluoride plated poppet nose and guide area; and unplated rocker end.

June 11 - 12

Engine No. II ran 32.0 hours including 2.5 hours of pre-endurance check-out and performance testing.

Oxygen injector nose temperature	1000°F
Cylinder head temperature	1300 - 1500°F
Hydrogen inlet temperature	500°F
Speed	3000 rpm
Power	2.38 - 2.64 hp
BSPC	1.65 - 1.80 lb/hp-hr

O/F	1.00 - 1.30
Exhaust back pressure	185 mm Hg

The test was stopped after approximately 6 hours to replace a defective oil line (external to the engine). The engine was restarted without adjustment or replacement of parts.

The test was terminated due to irregular engine operation and combustion roughness. The oxygen injector lift decreased from 0.0138 inch to 0.010 inch due to wear. Oxygen injector valve lash increased from 0.004 inch to 0.008 inch.

Post test inspection indicated that the irregular engine operation was due to hydrogen valve sticking.

The injector used a 0.045 inch diameter straight orifice and a calcium fluoride plated poppet.

June 15 - 18

Engine No. II ran 65.5 hours including 3.5 hours of pre-endurance check-out and performance testing.

Cylinder head temperature	1425°F
Oxygen injector nose temperature	1035°F
Speed	3000 rpm
Power	2.56 hp
BSPC	1.70 lb/hp-hr
O/F	1.33
Exhaust back pressure	174 mm Hg

The oxygen injector lift was initially set at 0.0133 inch cold. The engine was stopped after 6.8 hours and checked. There was no detectable leakage past the rings or valve stems, and injector lift after 1 hour cooldown was 0.0132 inch. The engine was then restarted.

After the test oxygen injector valve lift was 0.0074 inch. This corresponds to an overall wear rate of less than 0.0001 inch per hour. There was no seal or gasket leakage after the test.

This was the longest continuous run to date without adjustment. Oxygen inlet pressure was held to a maximum of 1000 psig. The test stopped when insufficient oxygen was admitted to sustain combustion, even at this inlet pressure. After 24 hours the crankcase pressure rose from a normal 0 - 4 psig to + 8 psig. The crankcase was vented and thereafter blew an appreciable volume of hydrogen and oil mist. The post test teardown revealed a broken valve spring on the inner hydrogen valve, which permitted excessive hydrogen flow down the valve stems.

June 24 - 25

Engine No. I ran 34.4 hours including 2.5 hours of pre-endurance check-out and performance testing. Combustion was not as smooth as in previous buildups and the engine frequently misfired and shut itself off after 27 hours. The run was terminated when the engine could not be restarted. Teardown revealed a broken valve spring in the outer hydrogen valve. The oxygen injector lost .003 inches lift due to wear. A typical data point is given below.

Cylinder head temperature	1390°F
Injector nose temperature	980°F
Hydrogen inlet temperature	500°F
Speed	3000 rpm
Power	2.5 hp
BSPC	1.75 lb/hp-hr
O/F	1.28
Exhaust back pressure	257 mm Hg

All endurance runs this month used the 9% mushroom cylinder head and the following timing:

H_2 10° BTDC - 35° ATDC
O_2 15° ATDC - 55° ATDC

This criteria ensured a power level of at least 2.3 hp at 3000 rpm. It was originally planned to use a cylinder head temperature of 1600°F but oxygen injector nose temperature was felt to be a more meaningful limitation due to the nose seal leakage problem. A nose temperature limit of 1000°F and exhaust back pressure of less than 300 mm Hg were used. It was usually possible to run on a pressure of less than 200 mm Hg.

RELIABILITY AND QUALITY ASSURANCE

General

There were no reliability milestones scheduled during the month of June. The functions of Reliability and Quality Assurance for the remainder of the program are routine monitoring and reporting activities.

Two meetings were held during June between the NASA Western Operations Office Reliability and Quality monitor and Vickers, Incorporated Reliability personnel. Areas of discussion and inspection are described below.

Instrumentation Control

The calibration control procedure submitted in the February Progress Report is presently being implemented and is approximately 90% complete.

Failure Reporting and Analysis

Monitoring of all failures of the H_2-O_2 engine continued as described by the Vickers failure reporting plan in the November Progress Report, Appendix A.

Three new modes of failure have been recorded and are coded as follows:

Cylinder Braze Assembly Failure	(2I)
Hydrogen Valve Spring Breakage (inner)	(2J)
Hydrogen Valve Spring Breakage (outer)	2K)

The spring breakage is due to fatigue caused by overstressed valve springs. Corrective action involves redesign to permit the use of larger springs.

APPENDIX A

FAILURE REPORT AND SUMMARY SHEETS

ENGINE FAILURE MODES

1. Oxygen injector

   A. Broken flex pivot
   B. Static seal leak
   C. Bushing to shaft seizure
   D. Leaf spring retainer deformed
   E. Flame plated valve worn
   F. Rocker shaft Brinelled
   G. Rocker shaft galled
   H. O_2 injector rocker arm and poppet wear
   I. Leaf spring broke

2. Engine

   A. H_2 valve assembly leakage
   B. Catalyst plug gasket leak
   C. H_2 valve retainer ring broke
   D. Piston dome retaining screw broke
   E. Piston seized in cylinder
   F. Top cylinder-to-cooling jacket "O" ring failure
   G. Copper, head-to-cylinder gasket
   H. Haskel "K" seal leakage
   I. Top-of cylinder cracked
   J. Broken H_2 valve spring (inner)
   K. Broken H_2 valve spring (outer)

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

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 Hours	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	1.17 Cold 0.7 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	4.3 Cold 1.25 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 ΔP gauge showed increased 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	1.47 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	2.36 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	1.13 Cold 1 Min 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	6.15 Hot	Bushing honed out for an 0.0008 to 0.001 clearance and counterbored to prevent end of shaft from rubbing on bushing.
8	11-1-63	O_2 Injector Retainer	X611378	Leaf spring had been deformed around end of valve.	Normal inspection of O_2 injector.	1D	4.12 Hot	New retainer installed.

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

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 Hours	Action Taken
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.	1E	1.13 Cold	Valve sent to NASA Lewis for examination.
10	11-16-63	O_2 Injector Retainer	X611378	Leaf spring had been deformed around end of valve.	Normal inspection of O_2 injector.	1D	3.87 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	3.83 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	0.50 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	0.10 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	5.0 Hot	Valve sent to NASA Lewis for metallurgist examination.
15	12-12-63	O_2 Injector Retainer	X611378	Leaf spring retainer deformed around end of valve.	Normal inspection of injector.	1D	9.3 Hot	New retainer installed.
16	12-12-63	H_2 Valve Assembly Ring	X610171	H_2 valve ring worn through.	Normal disassembly for inspection of O_2 injector.	2C	13.65	New ring installed.
17	12-20-63	H_2 Valve Assembly		H_2 valve assembly leakage.	Engine stopped when fire came out of top seal of H_2 valve assembly. Note: The 3 screws had loosened and may have caused the leak.	2A	0.68 Hot	New seals installed.

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

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 Hours	Action Taken
18	1-17-64	Piston Dome Retaining Screw	X611408	Piston dome retaining screw failed in tension allowing piston dome to jam between piston and cylinder head, thus causing the engine to stop abrubtly.	Engine had been run hot for 43 minutes when a strange noise started followed by an abrupt stop of the engine.	2D	9.0 Cold 6.28 Hot	Use new piston design now being fabricated. Interim Corrective Action: 1. Reduce installing torque from 80in-lb to 50in-lb. 2. Design rework to reduce or eliminate leakage and to increase screw diameter.
19	2-6-64	O_2 injector rocker shaft	X610099	Rocker shaft was Brinelled by needle bearings.	Engine had been run for 14 hours endurance run.	1F	37.6	Evaluate oilite bushing bearing.
20	3-12-64	O_2 injector rocker shaft	X610099	Rocker shaft was galled by lower iron oilite bearings.	Engine did not run steady and O_2 injector lift had dropped.	1G	0.68 Hot 0.42 Cold	Shaft polished and hardened. Alternate bearing materials and shaft finishes to be evaluated.
21	3-30-64	Piston Assembly	X612030	Piston seized to cylinder due to local thermal expansion of piston top nearest O_2 inlet port.	Head insert deflecting O_2 axially down cylinder onto piston.	2E	1 Min Hot 6.9 Cold	Increase piston-to-cylinder clearance and reposition head insert.
22	3-31-64	Piston Assembly	X612030	Piston rings and top of piston scored cylinder and started to seize in cylinder.	Piston to cylinder and ring gap clearance still insufficient.	2E	3 Min Hot 7.0 Cold	Further increase piston-to-cylinder clearance and increase ring g[illegible].
23	4-10-64	O Ring	X612049	"O" Ring leaked Dowt[illegible]m at top of cylinder.	Cylinder wall temperature was higher than expected.	2F	2.1 Hot	New "O" Rings installed. Viton "A" 'O'-Rings Ordered

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2767
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

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 Hours	Action Taken
24	4-13-64	O Ring	X612049	2F		2F	0.7 Hot	New "O" Rings installed. Viton "A" 'O'-Rings ordered
25	4-14-64	O Ring	X612049	2F		2F	0.37 Hot	SK 15822 Viton O Rings installed.
26	4-16-64	Head Seal	X612207	Head seal leaked during run	Flame came out from under head.	2G	0.37 Hot	New seal installed
27	4-21-64	O Ring	SK 15822	2F		2F	1.54 Hot 1.92 Cold	New O Ring installed
28	4-22-64	O Ring	SK 15822	2F		2F	0.93 Hot	New O Ring installed
29	4-27-64	O Ring	SK 15832	2F		2F	2.38 Hot	New O Ring installed
30	4-28-64	O Ring	SK 15822	2F		2F	0.32 Hot	New O Ring installed
31	4-28-64	Head Seal	X612207	2G	Flame came out from under head	2G	0.32 Hot	New seal installed
32	5-1-64	Head Seal	X612207	2G		2G	1.60 Hot	New seal installed
33	5-1-64	Haskel Seal	X609921	Haskel "K" seal leaked	Leaked after run	2H	2.55 Hot	New seal installed
34	5-5-64	Head Seal	X612207	2G		2G	3.58 Cold 0.97 Hot	New seal installed
35	5-5-64	Haskel Seal	X609921	2H		2H	3.58 Cold 0.97 Hot	New seal installed
36	5-12-64	Head Seal	X612207	2G		2G	2.22 Cold 5 Min Hot	New seal installed

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

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 Hours	Action Taken
37	5-12-64	Haskel Seal	X609921	2H		2H	2.22 Cold 5 Min Hot	New seal installed
38	5-13-64	Head Seal	X612207	2G		2G	0.7 Hot	New stainless seal installed
39	5-23-64	Haskel Seal	X609921	2H		2H	1.68 Hr. 49 Min Hot	Design study
40	5-23-64	O_2 Rocker Arm O_2 Poppet Valve	X612212 SK154154	Seating surfaces worn Poppet seat worn concave	Valve lift reduced after run	1H	1h38m cold 105h8m hot	Design study
41	5-27-64	Haskel Seal	X609921	2H		2H	1hr3m	New seal installed
42	6-2-64	Haskel Seal	X609921	2H		2H	1.2 Hr.	New seal installed
43	6-5-64	Cylinder Assy.	SK15858	Top of cylinder cracked		2I	27 Hr.	New cylinder assy. installed
44	6-11-64	Haskel Seal	X609921	2H		2H	1.75Hr.	New seal installed
45	6-18-64	H_2 Valve Spring	SK15449	H_2 Valve spring found to be broken	H_2 flow erratic	2J	91.0Hr.	New spring installed
46	6-28-64	H_2 Valve Spring	SK15450	H_2 Valve spring found to be broken	H_2 flow erratic	2K	110.5H	New spring installed
47	6-29-64	O_2 Leaf Spring		O_2 spring broke	O_2 flow excessive	1I	39.4	Spring eliminated from design