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FINAL REPORT

LIQUID OXYGEN TURBOPUMP TECHNOLOGY

by

C. E. Nielson

Rockwell International
Rocketdyne Division

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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NASA-Lewis Research Center
Contract NAS3-21356
Robert E. Connelly, Project Manager

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16. Abstract

A small, high-pressure, LOX turbopump has been designed, fabricated and tested. The pump is a single-stage centrifugal type with power to the pump supplied by a single-stage partial-admission axial-impulse turbine. Design conditions included an operating speed of 7330 rad/s (70,000 rpm), pump discharge pressure of 2977 N/cm^2 (4318 psia), and a pump flowrate of 16.4 Kg/s (36.21 lb/s). The turbopump contains a self-compensating axial thrust balance piston to eliminate axial thrust loads on the bearings during steady-state operation. Testing of the turbopump was achieved using a gaseous hydrogen high-pressure flow to drive the turbine, which generally is propelled by LOX/LH_2 combustion products, at 1041K (1874 R) inlet temperature and at a design pressure ratio of 1.424. Test data obtained with the turbopump are presented which include head-flow-efficiency performance, suction performance, balance piston performance and LOX seal performance. Mechanical performance of the turbopump is also discussed.

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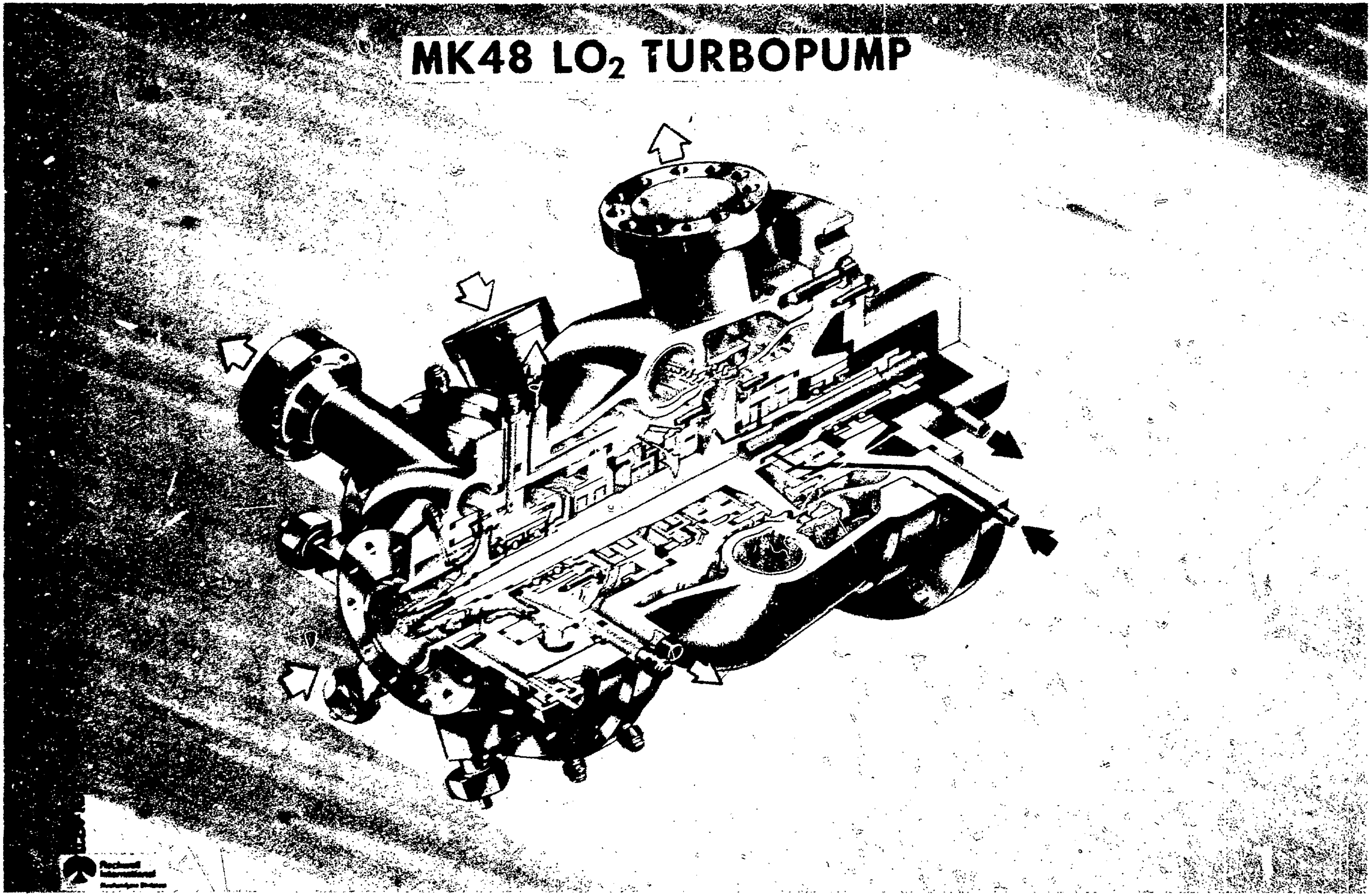
MK48 LO2 TURBOPUMP

FOREWORD

The work presented herein was conducted by the Advanced and Propulsion Engineering and Engineering Test Personnel of Rocketdyne, a division of Rockwell International, under Contract NAS3-21356 from April 1978 to July 1981. Mr. R. Connelly and Mr. D. Scheer, were NASA Project Managers. At Rocketdyne, Mr. H. Diem as Program Manager and Mr. A. Csomor and Mr. C. E. Nielson as Project Engineers were responsible for the technical direction of the program. Special recognition is given to Mr. J. McPherson of the Engineering Development Laboratory for his techncal expertise in rotor-balance, assembly and disassembly of the turbopump; Dr. E. D. Jackson and Mr. F. C. O'Hern of the Rotating Machinery Analysis Department for hydrodynamic analysis and technical expertise provided; and to Mr. J. Pulte of the Chemical and Advanced Component Test Unit providing direction as Test Engineer for the test programs conducted.

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SUMMARY

System studies of reusable vehicles for space manuevering missions require small high-pressure, staged-combustion-cycle engine turbomachinery of the Mark 48-oxidizer turbopump size and type. These turbopumps have relatively low-flow, high-head capability and are physically smaller, which sets them apart from state-of-the-art turbomachinery.

Additional long-life requirements also are placed on the turbopump with operating requirements that encompass 300 starts and 10 hours of operation time-between-overhaul capability.

The Mark 48-O turbopump which was designed, fabricated, and tested under Contract NAS3-17800, uses a floating-ring, controlled-gap, circumferential-type primary LOX seal assembly which may have difficulty in meeting the life and cycle requirements of the turbopump. The feasibility of using a hydrodynamic or hydrostatic, fluid-film type liftoff seal had been demonstrated in previous NASA-Lewis seal tester activity.

The objectives of this program were to modify the Mark 48-O turbopump to accommodate a spiral-grooved, lift-off type primary LOX seal and to conduct tests to evaluate the life characteristics and performance of the seal assembly in comparison to the circumferential floating-ring, controlled-gap seal presently in use on the turbopump. Other objectives were to demonstrate the pump suction performance capability of the turbopump with and without balance piston flow recirculation back to the inlet of the impeller.

The turbopump was assembled for the first test series using the controlled-gap, floating-ring primary LOX seal. A test plan was developed for the baseline tests with this configuration. The objectives were to characterize the seal leakage rates with the controlled-gap seal and slinger configuration. The slinger is a small pumping element adjacent to the primary LOX seal which reduces the pressure at the seal-to-shaft clearance by negative pumping such that vapor will exist at the clearance interface. Creating vaporized fluid at the gap greatly reduces leakage rates. Suction performance tests also were to be conducted during the testing.

The initial configuration was tested during October 1978 at LIMA test stand of Rocketdyne's Advanced Propulsion Test Facility (APTF). Five tests were conducted for a total test time of 174 seconds, and a maximum test speed of 7261 rad/s (69,340 rpm). Special instrumentation was used on the turbopump to measure the data required. On the third test, a successful suction performance test was made at a test speed of 7016 rad/s (67,000 rpm). A 5% pump head loss was achieved at a flowrate of 105% of nominal flow and at that point a suction specific speed of 84210 $(rad/s)(m^3/s)^{1/2}/(J/Kg)^{3/4}$ {24000 $(rpm)(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$} was obtained. On the fifth test of the series, at a speed of 7261 rad/s (69,340 rpm), a pump failure occurred. The failure concluded in a fire which caused major damage to the pump portion of the turbopump. Before the incident, sufficient data were obtained to characterize the primary LOX seal leakage.

A failure investigation followed immediately after the incident and it was concluded that the balance piston axial thrust margin was not sufficient which initiated a failure through the pump bearings or rubbing at the high-pressure balance piston orifice. This was caused in part by a negative impulse reaction occurring in the measured pressure data across the turbine wheel. A review of the data indicated an axial thrust correction should be made and also that it would be beneficial for a rerouting of the balance piston flow to eliminate all of it flowing through the bearings. Also, the addition of a labyrinth seal on the downstream side of the bearings would reduce the slinger-sump pressure to a level below 345 N/cm^2 (500 psia). This limit was considered to be the maximum pressure range for proper operation of the spiral-grooved liftoff seal to be incorporated in the design. The redesign included improved instrumentation capabilities to measure pressure at nine locations in the pump elements. The design was finalized and hardware was procured to replace that damaged by the fire.

Prior to assembly of the turbopump for test with the spiral-grooved liftoff seal, it had been found that technical problems with the spiral-grooved liftoff seal needed to be resolved before it could be incorporated without undue risk in the turbopump. These problems were found through testing of the spiral-grooved liftoff seal in a test rig and the tests indicated the seal could not be considered reliable. As a result, the turbopump was assembled using the original controlled gap seal. The test objectives were to demonstrate the capability of the redesigned balance piston axial thrust control and to complete the suction performance capability tests.

The assembled turbopump was installed in the LIMA test stand. The turbopump was tested for a total of six tests in April 1981 with a total operating time of 749 seconds. Of that time, 146 seconds was at 3141 rad/s (30,000 rpm) and 35 seconds at 7228 rad/s (69,000 rpm). All other time was at speeds below 3141 rad/s (30,000 rpm) or in transient operation. The tests revealed that the balance piston was operating satisfactorily at all speeds and over a wide flow range. Suction performance tests were not accomplished due to a turbine tip seal rubbing problem which resulted in high rotor torque. This could not be resolved without removing the turbopump from the test facility. On the last test near design speed (7330 rad/s, 70,000 rpm) the data indicate a suction performance of only 52631 $(rad/s)(m^3/s)^{1/2}/(J/Kg)^{3/4}$ {15000 $(rpm)(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$} at a flowrate of 103% of design flow. This test was conducted with the balance piston flow being routed overboard and also recirculated back to the impeller eye. This indicates that balance piston recirculation flow effects on suction performance may be considered a potential problem.

The data of the last test series indicate the mechanical operation of the turbopump was satisfactory with only minor mechanical problems that can be readily corrected. The newly incorporated design features function properly and will add to the integrity of the system.

INTRODUCTION

System studies of future DOD and NASA reusable vehicles for space manuevering missions have shown that high-pressure, staged-combustion-cycle engines offer significant benefit in terms of higher vehicle payload capability. These engines, which are in the 10,000- to 25,000-pound-thrust class, require relatively low-flow, high-head turbopumps which are physically smaller and fall outside the design state of the art of rocket turbomachinery. Additionally, and in contrast to past design requirements, the need for low leakage and reuse encompassing 300 starts and 10 hours time-between-overhaul is envisioned. Thus, the designers are confronted with both size and life time uncertainties.

The Mark 48-0 turbopump, which was designed, fabricated, and tested under Contract NAS3-17800, uses a circumferential-type seal assembly which may have difficulty in meeting the life and cycle requirements of the turbopump. The NASA-Lewis Research Center had previously demonstrated the feasibility of hyrodynamic or hydrostatic fluid film-type seals which potentially can achieve the multiple starts and life requirements of the turbopump. This work was accomplished under Contract NAS3-17769, during which two types of fluid film face seals were tested for 11 hours and approximately 3[illegible]0 starts.

The initial objectives of the program were to use the technology gained in the NASA-LeRC seals programs to design a fluid film seal for installation in the Mark 48-0 turbopump and test the configuration under actual turbopump operating conditions. The program plan called for baseline characterization testing of the existing controlled gap seal and slinger configuration to determine baseline seal performance and leakage rates. The parellel objectives were also that of defining pump noncavitating head-flow characteristics and suction performance with the modified impeller inlet. This was begun on the initial test series which was prematurely terminated due to a failure and ensuing fire which caused damage to the pump components of the turbopump.

The spiral groove lift-off seal design for incorporation into the Mark 48-0 turbopump was completed and the seals, as well as other pump components were fabricated. Subsequent testing of the spiral groove lift-off seal in a test rig revealed technical problems with the concept, which need to be resolved by additional component testing before the seal could be considered sufficiently reliable for liquid oxygen turbopump operation.

As a results, the program objectives were redirected to complete the measurement of the pump suction performance and to measure the rotor axial thrust capability. Hardware of the Mark 48-0 turbopump had been redesigned and fabricated to replace those components which were damaged in the test when a pump fire ensued. The objective was to demonstrate with the floating ring seal, the axial thrust control and to define pump suction capability.

DISCUSSION

TURBOPUMP DESCRIPTION AND BACKGROUND

A comprehensive discussion of the MK 48-0 turbopump design requirements, analysis results, and mechanical configuration are presented in Ref. 1 and 2. For convenience, a brief summary of the significant characteristics of the turbopump is included in the following.

Turbopump Requirements

The performance requirements for the Mark 48-0 turbopump are listed in Table 1. The pump is required to deliver 16.4 kg/s (36.21 lb/sec) of liquid oxygen starting with an inlet pressure of 68.9 N/cm^2 (100 psia) provided by the low-pressure pump, to a discharge pressure of 2977 N/cm^2 (4318 psia). The propellant gas for the turbine is a mixture of free hydrogen and steam resulting from the combustion of liquid hydrogen and liquid oxygen. The gas is provided at a temperature of 1041 K (1874 R) and an inlet pressure of 2320 N/cm^2 (3366 psia). The total gas flowrate available is 1.34 kg/s (2.92 lb/sec). The horsepower requirement of the pump is matched by adjusting the pressure ratio across the turbine. Since turbine pressure ratio has a strong influence on the attainable engine combustion pressure in a staged combustion cycle, it is to be maintained at the lowest possible level. As noted in Table 1, the mechanical operating requirements included multiple starts with long-operating durations and potentially long-coast times between operations.

In the area of the pump, the combination of low flowrate and high discharge pressure imposed a difficult impeller fabrication task because of the relatively narrow passages required compared with the outer diameter. The desire for high efficiency, compact packaging, and light weight placed the rotor speed into the 6282 to 9423 rad/s (60,000- to 90,000-rpm) range, pushing bearing DN value to the 1.5 x 10^6 mm rpm limit (Ref. 1). The bearing operation at high DN values in a turbopump installation, as well as the dynamic behavior or the rotor at high speeds, needed to be demonstrated. Because of the high operating speed involved, the bearings would not be able to take an appreciable axial thrust load. This condition dictated that an axial thrust balance device be employed which, in liquid oxygen, would have to be of the nonrubbing type. The operating characteristics of such a device also required evaluation.

In the turbine, the low-pressure ratio (approximately 1.4) and low arc of admission (28%) presented a combination for which no empirical data were available. Performance predictions based on calculations needed to be validated or modified by measured performance data.

From a structural consideration, the requirement for 300 thermal cycles was significant in that it established low-cycle-fatigue criteria and eventually necessitated incorporating a liner in the turbine manifold to limit the maximum thermal gradients in structural walls.

TABLE 1. LIQUID OXYGEN TURBOPUMP NOMINAL DESIGN CONDITION

	Metric Units	English Units
Turbopump		
Capable of operation at pumped-idle conditions (5 to 10 of full thrust)		
Off-design operation	±20% Q/N at full thrust down to 30% Q/N at 20% N	
Number of start-stop cycles	300	
Time between overhaul	10 hours	
Pump		
Type	Centrifugal	
Propellant	Liquid oxygen	
Inlet pressure	68.9 N/cm^2	100 psia
Inlet temperature	90-95.5K	162 to 172 R
Discharge pressure	2977 N/cm^2	4318 psia
Mass flow	16.4 kg/s	36.21 lb/sec
Number of stages	One	
Turbine		
Working fluid	H_2-O_2 combustion products (H_2 x H_2O)	
Inlet temperature	1041	1874 R
Inlet pressure	3220 N/cm^2	3366 psia
Pressure ratio	Minimum necessary to develop pump horsepower requirements.	
Flowrate	1.34 kg/s	2.92 lb/sec
Number of stages	One	
Type	Partial admission	
Service life between overhauls:	*300 Thermal cycles or 10 hours accumulated run time	
Service-free life	*60 Thermal cycles or 2 hours accumulated run time	
Maximum Single Run Duration:	2000 s	
Maximum time between firings during mission:	14 days	
Maximum time between firings during mission:	1 minute	
Maximum storage time in orbit (dry):	52 weeks	

Thermal cycle defined as engine start (to any thrust level) and shutdown

In addition to the performance criteria noted in Table 1 , the contract work statement included certain ground rules (given in Ref. 1) relating primarily to the structural analysis and mechanical design of the turbopump.

Turbopump Description

The original mechanical configuration of the turbopump is illustrated in Fig. 1 , with significant parts identified. The top assembly requirements are established on Rocketdyne drawing number RS009820E, which is included in Appendix A. The design was given the Rocketdyne internal designation of Mark 48-0. This configuration was used in all but the final test series with minor exceptions. In the last test series another configuration was used to improve the instrumentation, and the balance piston fluid routing. This configuration is shown in RS0014079, Appendix A.

Liquid oxygen is introduced to the pump through the axial-flow inlet of 4.214 cm (1.659 inch) diameter and passes through a four-bladed, constant-outer-diameter, tapered-hub inducer which raises the pressure to an intermediate level. From the inducer the liquid proceeds into a centrifugal impeller containing four partial and four full blades. Subsequently, it is diffused in a radial diffuser which incorporates 13 guide vanes. Downstream of the diffuser, liquid oxygen is collected, further diffused in a volute section, and delivered through a single 2.54 cm (1.00 inch) diameter duct.

Hot gas to the turbine is admitted through a scroll-shaped, constant-velocity inlet, lined with a 1.57 mm (0.062 inch) metal liner to maintain the thermal gradients across the structural walls at an acceptable level. The inlet duct diameter is 3.1 cm (1.22 inches). The active arc of the partial-admission nozzle extends over 1.8 rad (103 degrees) or 28.6% of the circumference, and it includes seven flow passages. The gas is fully expanded through the nozzle after which it passes through a single row of unshrouded impulse-type blades (79 blades) of the rotor. The exhaust gas is directed through a row of stationary vanes which guide the gas toward a single radial exit duct of 3.81 cm (1.50 inches) diameter.

The pump shaft and the turbine disk are designed as an integral part. On the outboard end, a stub shaft is used with a stud and nut to extend the rotor. Two pairs of angular-contact, 20-mm ball bearings are used to support the rotor. The pump-end bearings are cooled by recirculating liquid oxygen through them. The outboard shaft seal is pressurized with liquid hydrogen, and the leakage toward the outboard side is used as bearing coolant. A small amount of liquid hydrogen is bypassed around the seal and introduced to the bearing directly as a redundant source of coolant. The bearings in each pair are axially preloaded against each other with Belville springs to prevent ball skidding. The turbine-end bearings are free of other axial loads. The outer-race sleeve of the pump-end bearings is axially retained so that the bearings absorb rotor axial thrust during transient periods when the balance piston does not control the rotor axial position.

Under conditions other than early transient stage during startup or at the end of shutdown, the rotor axial thrust is neutralized by a self-compensating balance piston. The rotating member of the piston is the rear shroud of the impeller.

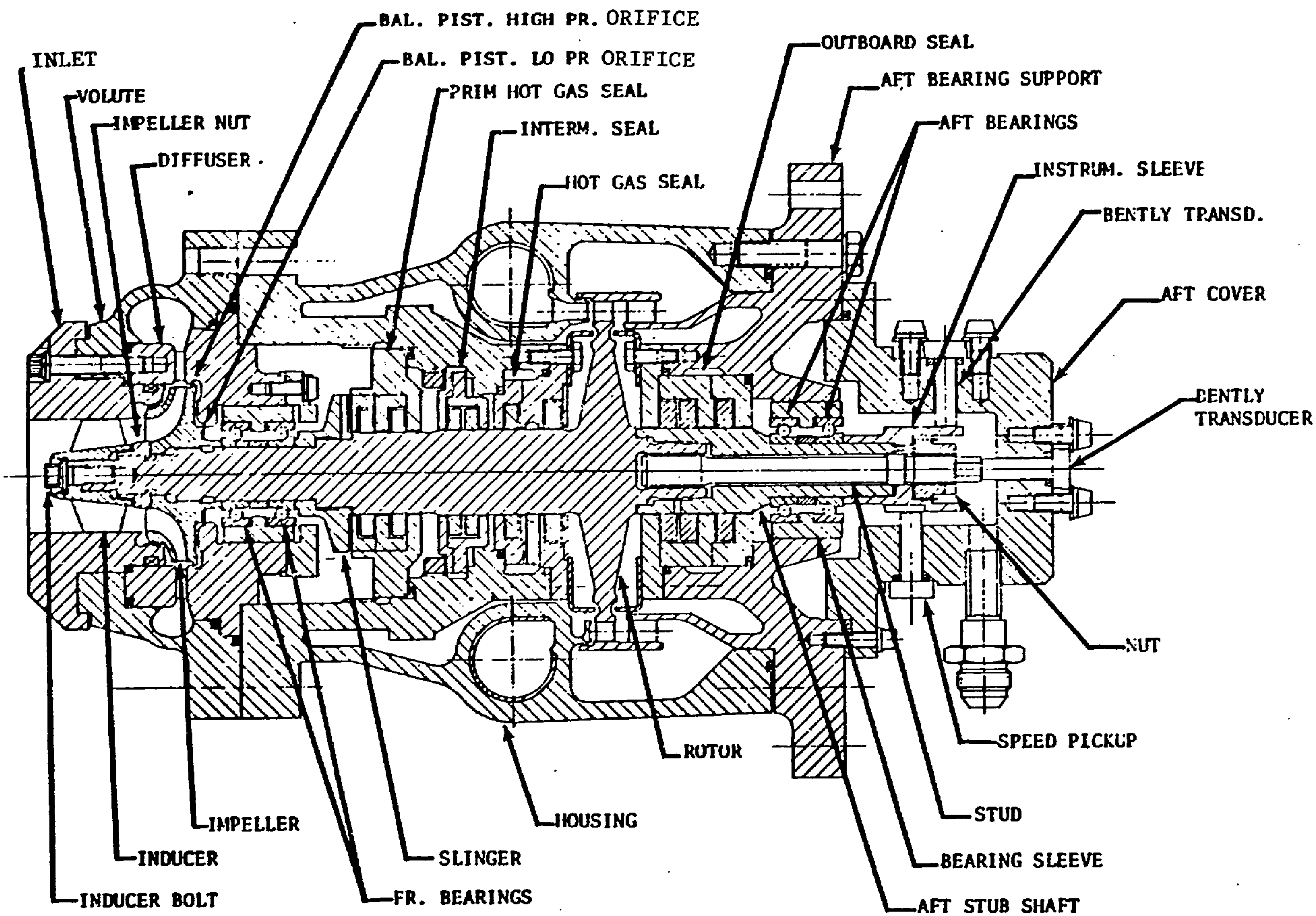


Figure 1. Mark 48-0 Turbopump

To operate the piston, high-pressure liquid oxygen from the impeller discharge passes through a high-pressure orifice located at the outer diameter of the impeller into the balance cavity. From the cavity, the liquid passes through a low-pressure orifice near the impeller hub into the sump. From there the liquid oxygen is returned to the eye of the impeller through internal axial passages either in the diffuser vanes or around the volute and radial holes in the diffuser and inlet. Thrust-compensating effect is achieved by virtue of the fact that the high- and low-pressure orifice openings vary with the axial position of the rotor, and the pressure force on the rear shroud of the impeller varies correspondingly; e.g., an unbalanced load toward the pump inlet causes a reduction in the high-pressure orifice gap and an increase in the low-pressure orifice gap. This, in turn, causes a reduction in the pressure force of the impeller rear shroud, introducing a compensating load change.

Because of the danger of explosion when rubbing in liquid oxygen, the balance piston orifices were designed as noncontacting type, formed by the axial proximity of close clearance, 0.038-mm (0.0015-inch) average, diametral, cylindrical surfaces.

To preclude mixing liquid oxygen from the pump with the combustion products from the turbine, the two regions are separated by three dynamic seals. All three seals are of the controlled-gap type, with two seal rings in each. The controlled-gap concept was selected for this application primarily because it has low-drag torque, a must for idle-mode starts. This concept also minimizes power absorption during steady-state operation, and permits very long service life. Pump fluid is contained by the primary LOX seal. The oxygen which flows past this seal is drained overboard from the cavity formed by the primary and intermediate seals. A slinger containing pumping ribs was included upstream of the primary LOX seal to reduce the pressure at the seal gap to a level that will vaporize the fluid. The objective was to reduce the mass flowrate through the seal with this technique.

On the turbine side, because of the high pressure involved, sealing and drainage was accomplished in two steps. An overboard drain was included downstream of the first ring, which reduces the pressure between the two rings to 79 N/cm^2 (115 psia). The small amount of turbine gas which leaks past the second ring is drained overboard with a drain cavity pressure of approximately 15 N/cm^2 (20 psia).

To provide separation of the pump and turbine fluids, an intermediate seal was incorporated between the two drain areas with a GHe purge which maintains the cavity between the two rings at a minimum of 35 N/cm^2 (50 psia).

Test History

Turbine. Calibration of the Mark 48-0 turbine, to establish its aerothermodynamic performance, was accomplished with ambient-temperature GN_2 as the propellant. The rotor speeds were maintained in the range of 523 to 1185 rad/s (5000 to 18,000 rpm) to simulate the operational wheel tip speed/gas spouting velicity ratios (U/C_0).

The testing was performed at Wyle Laboratory, El Segundo, California, during February 4 through 9 1976. A total of 11 tests were made, with GN_2 working fluid, at velocity ratio (U/C_0, total to static) ranging from 0.115 to 0.606, and turbine speeds from 523 to 1885 rad/s (5000 to 18,000 rpm). A plot of turbine efficiency is shown in Fig. 2. The efficiency was calculated with Lebow torquemeter torque and isentropic available energy (total-to-static) across the turbine. At a design velocity ratio of 0.343, the turbine total-to-static measured efficiency was 51% compared with a predicted value of 59.8%. Calculations show that with the measured performance the pressure ratio of the turbine would have to be increased from the design value of 1.424 to 1.54 to generate the required power level.

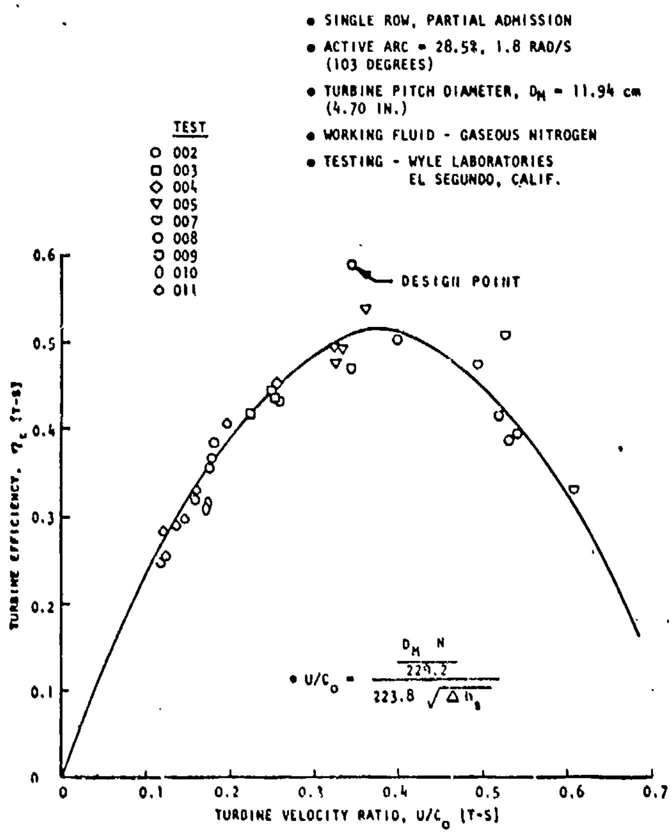


Figure 2. Mark 48-0 Turbine Performance

The combination of low-pressure ratio (1.42) and low arc of admission (28.5% of circumference) placed this turbine in an operating region in which turbine technology had not been develeped. Potential improvement in the performance may be realized by increasing the number of active nozzle passages and reducing the throat width to obtain the required total throat area. Depending on the engine installation, improvements in the exhaust manifolding may be possible to minimize the pressure losses charged to the turbine.

Turbopump Testing. A total of five test series have been run on the Mark 48-0 turbopump. Initial testing of Mark 48-0 turbopump P/N RS009820E, S/N 01-0, began in the Lima test stand of the Rocketdyne Propulsion Research Area (PRA) on 9 July 1976 and was concluded on 11 August 1976. A total of 18 turbopump tests for an accumulated duration of 266.8 seconds was accomplished on the turbopump assembly. The test effort was divided into two main categories: Performance mapping, using GH_2 as turbine drive media, with LN_2 and LOX as the pumped fluid; and integrity testing, using combustion products from a LOX/LH_2 gas generator as the turbine drive gas media, with LOX as the pumped fluid. Gas generator injector P/N RS005024-131, S/N 2, a coaxial five-element design, was used during the hot-fire testing. A brief description of the tests performed during the initial series is presented in Table 2.

The second test series was run during July 1977 on turbopump S/N 01-1; five tests were conducted. These are described in Table 3. This series accumulated a total time of 158 seconds on the turbopump. The testing encompassed noncavitating head-flow characterization of the pump. Critical NPSH was partially determined. The initial test series had indicated the impeller inlet area needed to be increased to improve performance and this was done prior to test series No. 2. Also, the balance piston and bearing coolant flow was routed overboard so it could be measured and controlled. These tests were run utilizing a gaseous hydrogen (GH_2) drive gas to power the turbine. During test 005 at 7006 rad/s (66,900 rpm), a pump fire occurred and damaged the pump hardware extensively. The origin of the problem was established as the primary LOX seal nut backing out of its installed position and blocking the exit passage of the balance piston and bearing coolant fluid. Design changes were made to a second set of components and the primary seal nut locking feature was improved. Other modifications were completed to protect the pump-end bearing from the high pressure drop from all the balance piston flow passing through it and to reduce the high axial load caused by it. These modifications were to drill eight bypass holes of 2.18mm (0.086 inch) diameter through the bearing cartridge. This was to reduce the amount of the balance piston flow directly through the bearing and thereby decrease the pressure drop across the bearings extending their life and reducing the balance piston sump pressure. This improved the balance piston axial thrust range on the low sump pressure end. These modifications and test results are described in detail, in Ref. 2.

A third test series was conducted in May of 1978 on turbopump S/N 02-0B after the above-mentioned modifications were completed. In that test series, four tests were run with an accumulated time of 236 seconds. In these tests the head-flow characteristics were obtained at low speed 3142 rad/sec (30,000 rpm). A short time was obtained at 7330 rad/sec (70,000 rpm). A summary of these tests is given in Table 4. Posttest inspection after test 006 revealed high rotor torque caused by the turbine tip seal rubbing. The turbopump was removed from the test stand for disassembly and inspection.

TABLE 2. MARK 48-0 TURBOPUMP TESTING

(P/N RS009820, S/N 01-0)

Test No.	Test Date	Test Duration, Seconds	Accumulated		Remarks
			Starts	Duration, Seconds	
016-011	7-9-76	30	1	30	Initial test using LN_2 as pumped fluid. Turbine drive media--GH_2. 30,800 rpm achieved satisfactorily.
016-012	7-13-76	9	2	39	Pumped fluid: LN_2, turbine drive media: GH_2 targeted rpm: 60,000. Premature cutoff by turbine radial accelerometer vibration safety cutoff system (VSC) exceeded 10 g rms. RPM attained: 45,979.
016-013	7-13-76	5	3	44	Pumped fluid: LN_2, turbine drive media: GH_2 satisfactory rotordynamic test. Maximum turbopump rpm: 61,965.
016-014	7-16-76	70	4	114	Pumped fluid: LOX, turbine drive media: GH_2 planned H-Q at 30,000 and 60,000 rpm. H-Q obtained at 30,000 rpm. Turbine radial accelerometer VSC cutoff at 15 g rms at 52,500 rpm.
016-015	7-16-76	30	5	144	Pumped fluid: LOX, turbine drive media: GH_2 planned objective: H-Q mapping at 60,000 rpm. Some H-Q data obtained at 60,850 rpm, but test prematurely cut off by observer due to a fire in a facility system.
016-016	7-16-76	12	6	156	Pumped fluid: LOX, turbine drive media: GH_2 planned objective: H-Q at 60,000 rpm. Premature cutoff by turbine radial accelerometer VSC system at 52,000 rpm.
016-017	7-16-76	37	7	193	Pumped fluid: LOX. turbine drive media: GH_2 planned objective: H-Q at 60,000 and 70,000 rpm. Achieved satisfactory H-Q data at 60,000 rpm. Attempted to increase turbopump speed to 70,000 rpm, but was prematurely cut off by turbine radial accelerometer VSC system at a speed of 64,000 rpm. This test concluded series I testing. The turbopump and facility system were modified for hot-fire testing with the gas generator system.

TABLE 2. (Continued)

Test No.	Test Date	Test Duration, Seconds	Accumulated Starts	Accumulated Duration, Seconds	Remarks
016-018	8-3-76	0	8	193	Gas generator ignition not achieved. Cutoff by ignition detect system. Posttest analysis showed problem to be associated with exciter system. Exciter changed prior to next test. Scheduled 60,000 rpm.
016-019	8-3-76	2.81	9	195.81	Objective: 60,000 rpm. Satisfactory test. A turbopump rpm of 57,629 was achieved with a turbine inlet total pressure of 1837 psia at 1761 R (Note: turbine discharge orificing resulted in a turbine pressure ratio of 1.85.) Gas generator c* efficiency: 98.9%
016-020	8-3-76	0.58	10	196.39	Objective: 60,000 rpm. Test prematurely terminated by turbine inlet overtemp. Maximum rpm achieved 58,378. Analysis revealed the fuel injection pressure lower than actual controller set pressure. Result: Higher GG mixture ratio with cutoff at 1960 R. Turbine inlet temperature controller readjusted using site data.
016-021	8-3-76	16.58	11	212.97	Objective: 60,000 rpm for test stand duration. Objective partially achieved. Maximum rpm achieved was 62,800, but the test was terminated prematurely by turbine inlet overtemp. Review of data shows main fuel valve position operating in high-flow gain region, only 2-1/2% open. For next test, the LH_2 tank pressure will be reduced to force MFV further open. Gas generator c* efficiency; 99.3%
016-022	8-9-76	0	12	212.97	Objective: 70,000 rpm for test stand duration (~50 seconds) Test prematurely terminated by turbine radial accelerometer VSC system. Test terminated during fuel-lead stage at 56,000 rpm and 15 g rms.
016-023	8-9-76	0.62	13	213.59	Objective: 70,000 rpm for test stand duration (~50 seconds) Test prematurely terminated by turbine radial VSC system at 20 g rms. Maximum rpm achieved was 68,725.

TABLE 2. (Concluded)

Test No.	Test Date	Test Duration, Seconds	Accumulated Starts	Accumulated Duration, Seconds	Remarks
016-024	8-9-76	1.2	14	214.79	Objective: 70,000 rpm for test stand duration (~50 seconds) Test prematurely terminated by turbine radial accelerometer at 20 g rms. Maximum turbopump rpm: 69,157.
016-025	8-9-76	2.39	15	217.18	Objective: 70,000 rpm for test stand duration (~50 seconds) Test prematurely terminated by turbine inlet overtemp. Fuel injection pressure again below controller set pressure resulting in high GG mixture ratio and overtemp. Maximum rpm: 68,199.
016-026	8-11-76	5.82	16	223.0	Objective: 70,000 rpm for test stand duration (~50 seconds) Test prematurely terminated by observer due to a fire in a facility system. Maximum rpm achieved: 74,191.
016-027	8-11-76	3.01	17	226.01	Objective: 70,000 rpm for test stand duration (~50 seconds) Test prematurely terminated by turbine inlet overtemp. Data analysis showed the fuel injection pressure controller to be lower than required by 69 N/cm^2 (100 psi). A site data correction was made for the next test. Maximum rpm achieved: 62,867.
016-028	8-11-76	40.79	18	266.8	Objective: H-Q excursion at 70,000 rpm, and test stand duration (~50 seconds) All objectives except duration were achieved. Manual control of turbopump discharge throttle valve achieved H-Q excursions. Maximum rpm achieved was 68,685. The test was automatically terminated when the intermediate seal purge supply level decreased below 150 psig (redline). The gas generator c* efficiency during the test averaged 99.7%.

TABLE 3. MARK 48-0 TURBOPUMP TEST SERIES NO. 2 SUMMARY
(TURBOPUMP S/N 01-1)

TEST NO.	TEST DATE	TEST DURATION, SECONDS	ACCUMULATED		REMARKS
			STARTS	DURATION, SECONDS	
016-001	7-21-77	7	1	7	ACHIEVED SPEED OF 14,200 RPM. CUT OFF BY FAILED RADIAL ACCELEROMETER. BALANCE PISTON FLOW ROUTED OVERBOARD.
016-002	7-21-77	71	2	78	OBTAINED HEAD-FLOW DATA AT 29,300 RPM.
016-003	7-21-77	18	3	96	OBTAINED DATA AT 28,300 RPM. TEST CUT BY PUMP DISCHARGE PRESSURE REDLINE 3447 N/CM2 (5000 PSIG) AT 69,000 RPM.
016-004	7-21-77	33	4	129	OBTAINED HEAD-FLOW DATA AND BALANCE PISTON SHIFT AT 69,000 RPM. BALANCE PISTON FLOW ROUTED OVERBOARD.
016-005	7-26-77	32	5	161	SPEEDS TO 66,900 RPM. PUMP FIRE DAMAGED PUMP HARDWARE.

TABLE 4. MARK 48-0 TURBOPUMP TEST SERIES NO. 3 SUMMARY
TURBOPUMP S/N 02-0

TEST NO.	TEST DATE	TEST DURATION, SECONDS	ACCUMULATED		REMARKS
			STARTS	DURATION, SECONDS	
016-003	5-19-78	31	1	31	TEST OBJECTIVE HEAD-FOW AT 30,000 RMP MAXIMUM SPEED 29,500 RPM. VIBRATION CUT ERRONEOUSLY - INSTRUMENTATION PROBLEM. BALANCE PISTON FLOW OVERBOARD.
016-004	5-23-78	124	2	155	OBTAINED HEAD-FOW MAPAT 30,000 RPM. FACILITY DURATION CUTOFF - LOW LH_2 PRESSURE.
016-005	5-25-78		3	193	PLANNED HEAD-FLOW TEST AT 70,000 RPM. TURBINE PRESSURE RAMP SLOWED DOWN IN SECOND CRITICAL SPEED RANGE - VIBRATION CUTOFF AT 55,000 RPM - PUMP RADIAL ACCELEROMETER.
016-006	5-31-78	43	4	236	PLANNED HEAD-FOW TEST AT 70,000 RPM EIGHT (8) SECONDS AT 66,000 RPM, OTHER AT 30,000 RPM. TEST CUT FOR HIGH PUMP BEARING COOLANT TEMPERATURE. HIGH ROTOR TORQUE ON POSTTEST INSPECTION.

Mechanical Performance. Testing of the LOX turbopump in test series No. 1 encompassed 18 starts, with a total accumulated time of 267 seconds. The three initial tests were conducted with LN_2 as the pump fluid; in subsequent tests, LOX was used. The first seven tests were performed using ambient-temperature GH_2 to drive the turbine; in the remainder of the tests, the combustion product of LH_2 and LOX at approximately design temperature was the turbine drive gas. The longest test durations conducted were 70 seconds with ambient GH_2 drive and 41 seconds with hot-gas drive. The operation covered a rotor speed range of 0 to 7768 rad/s (74,191 rpm), a maximum pump discharge pressure of 3175 N/cm^2 (4606 psia), and a maximum turbine inlet temperature of 1133 K (2040 R).

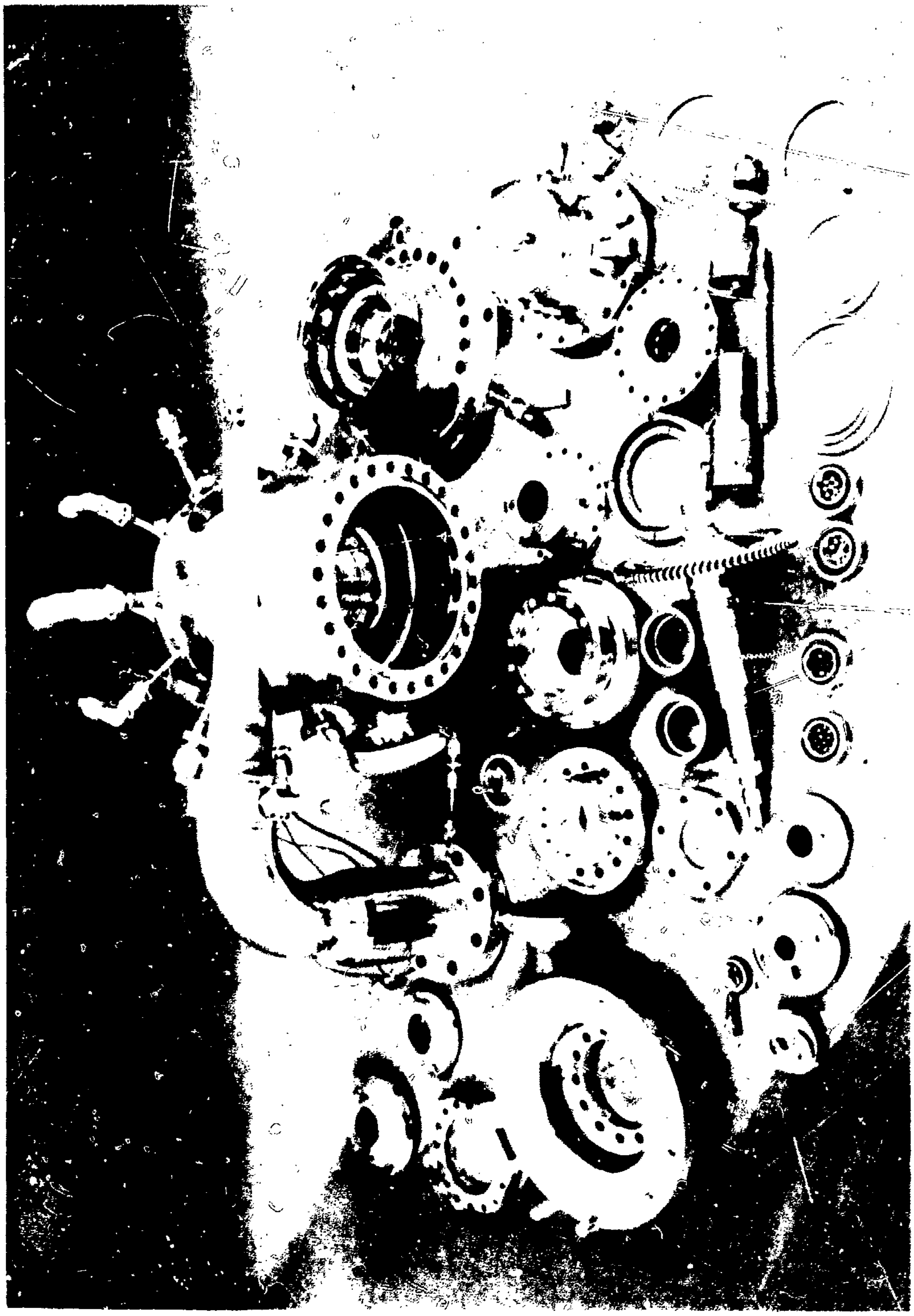
Several tests were terminated by the vibration sensor device monitoring the output of the accelerometers attached to the turbopump housing. This was caused by a combination of several factors. Normally on a new turbopump, several tests are required to establish its vibration signature and thus set the cutoff point at the appropriate levels. It appears that with the Mark 48-O turbopump, this level is in the 20 to 25 g rms range in conjunction with a 2 KHz low-pass filter.

Some of the early runs were terminated because the cutoff redline was set too low. In addition, the manual GH_2 feed control system employed on the first seven runs frequently resulted in slow transition through critical speed zones, with attendant buildup in vibration levels.

Bently proximeter data and accelerometer data obtained from high-frequency tapes showed increased synchronous activity at 4115, 5026, and 5528 rad/s (39,300, 48,000, and 52,800 rpm). These compared favorably with the analytically predicted critical speeds of 4723 and 5482 rad/s (45,108 and 52,363 rpm, respectively). No evidence of subsynchronous vibration was present in the data.

The measured seal drain pressures, temperatures, and flowrates were, in general, in good agreement with predicted values, indicating proper functioning of the shaft seals. During chilldown of the pump on the LN_2 tests, it was noted that the secondary hot-gas drian line frosted over. This could occur as a result of heat transfer through conduction, but possibly also as a result of the pump fluid from the primary LOX seal drain cavity leaking across the intermediate seal. To prevent a potentially hazardous condition, the purge pressure level in the intermediate seal was raised to 138 N/cm^2 (200 psig). No problem was experienced at this pressure level with mixing of incompatible fluids. It is quite possible that the originally planned purge pressure of 41 N/cm^2 (60 psig) would be adequate. This could be established on future tests by sampling and analyzing the drain fluids during chilldown.

The turbopump was disassembled after the first test series to permit visual inspection of the components. Figure 3 shows the condition of the more significant parts. The condition of most of the components was excellent; only two discrepancies were apparent: The pump-end bearings showed evidence of overheating, and the chrome plating on the rotor under the primary hot-gas seal ring had flaked off.



1XY55-8/31/76-C1A*

Figure 3. Mark 48-0 Components After Testing

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After test series No. 2, in which a fire damaged the pump-end hardware, evaluation on disassembly revealed the failure occurred due to the primary seal retaining nut backing out and restricted the balance piston overboard flow.

The damage to the hardware included the pump inlet, inducer, impeller, diffuser, and pump end bearings, with some burning evident in the balance piston return cavity. All the hardware aft of and including the primary LOX seal was in satisfactory condition with the exception of the turbine wheel where it had rubbed on the pump side hot gas shielding and its retaining bolts. Analysis of the axial thrust control range prior to the blockage of the balance piston drain indicated adequate margin.

The mechanical performance evaluation on test series No. 3 hardware revealed a continuing problems regarding the chrome plating on the primary hot-gas turbine seal. Chrome plating applied to the rotor shaft flaked off directly under the seal. This possibly contributed to the high torque observed after the last test. The cause of the flaking was thought to be due to the sharp corner of the shaft relief where the chrome plating terminated. This resulted in inadequate adherence and eventually led to chipping and flaking. For the next build, plating was extended over the corner to relieve the problem. The condition of both pump and turbine bearings were excellent after test series No. 3. Posttest analysis indicated adequate cooling and low-coolant pressure differential across the pump and bearing. The nominal and maximum axial and radial loads were acceptable, indicating the bearings were functioning properly.

The performance of all four shaft dynamic seals was excellent in all tests. Pressure levels in the drain systems were maintained at sufficiently low levels to preclude intermixing of the pump and turbine propellants. The primary LOX seal in particular has been proven a very reliable, rugged concept. In conjunction with the slinger, its measured leakage rate at design speed was approximately 0.068 kg/s (0.15 lb/sec).

Pump Hydrodynamic Performance. Figure 4 is a plot of the pump overall head rise as a function of flow, where both data and the predicted head are scaled to a speed of 7329 rad/s (70,000 rpm). For test series No. 1, the scaling was accomplished using the affinity laws which have been thoroughly substantiated as applicable for LOX and LN_2. The data consist of 66 data points from 15 tests, with test speeds varying from 1628 to 7768 rad/s (15,550 to 74,190 rpm), and with pumped fluids of both LOX and LN_2, primarily the former. The symbols used for the data points distinguish the different operating speed ranges tested. There was no indication that the results were dependent on the pumped fluid medium.

The low-speed data show fairly good agreement with the predicted head rise, but may be indicating a slightly steeper H-Q slope than predicted. However, as speed increases, the test data deviate more from the predicted curve, falling short of the curve at the higher flowrates. This type of deviation is typical of that experienced when cavitation is limiting the performance. To investigate this deviation, the ratio of the test head rise divided by the predicted head rise was calculated and plotted as a function of suction specific speed (N_{ss}) in Fig. 5. The initial plot tended to indicate a great deal of data scatter without clear trend. However, when different symbols were used to represent the different inlet

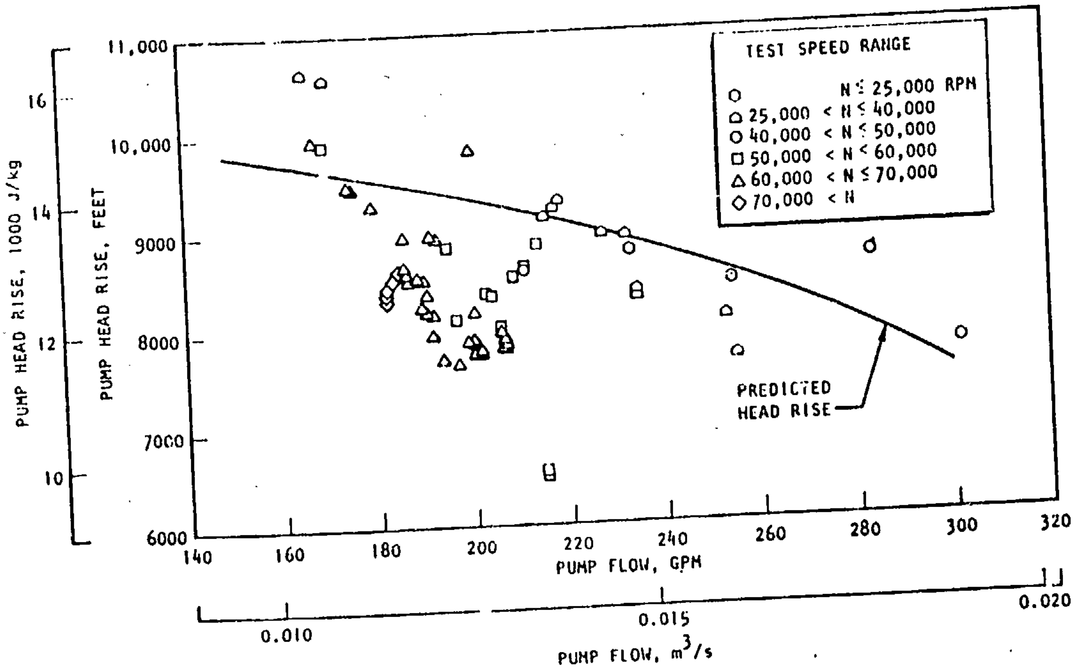

Figure 4. MK 48 LOX Pump Data and Predicted Head Rise Scaled to 70,000 rpm

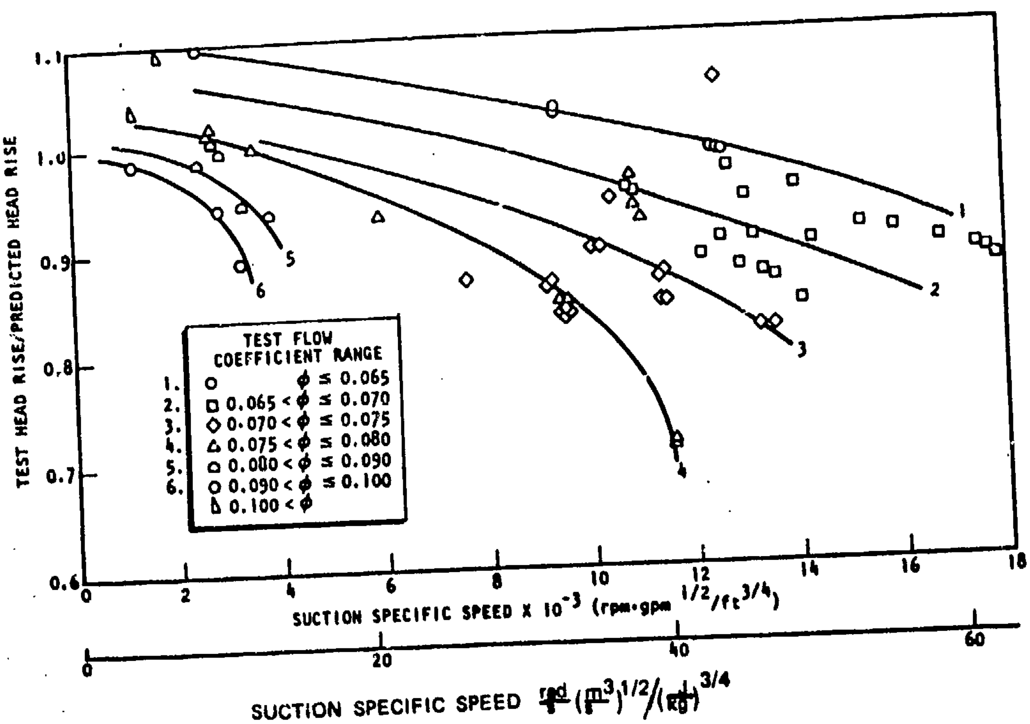

Figure 5. Relative Head Rise as a Function of N_{ss}

flow coefficients (ϕ_{in}) tested, the data showed a clear trend. For all coefficients, there is a tendency of the head ratio to drop as N_{ss} increases. However, as flow coefficient increases, this dropoff occurs at successively lower values of N_{ss}. This trend again is strongly indicative of cavitation limitations, with the amount of cavitation increasing either with increasing N_{ss} or with increasing flow coefficient at a constant value of N_{ss}.

The cavitation appears to occur at much lower values of N_{ss} than would be expected from the design, considering it does have an inducer designed for good suction performance. This would indicate the more likely possibility that the impeller was cavitating rather than the inducer. This could be caused by:

1. A failure of the inducer to produce its design head rise, which is required to keep the impeller out of cavitation
2. An inadequate impeller design from a cavitation standpoint
3. Too much hot cryogenic being pumped into the impeller eye from the balance piston/bearing area

An independent computer analysis of the inducer to verify the head rise capability indicated the inducer head output to meet or exceed the originally predicted values. Analysis of the impeller inlet to determine the cause of the poor suction performance indicated that the through-flow area near the leading edge was restricted and could cause the poor suction performance. As a result the impeller eye diameter was increased from 4.19 to 4.44 cm (1.650 to 1.750 inches) and the impeller leading edge was cut back 0.52 radians (30 degrees) of wrap. Further analysis of the balance piston return flow effects on impeller inlet performance indicated the decreased impeller eye blockage would be beneficial to suction performance. Analysis revealed that balance piston fluid returned to the impeller eye did not vaporize, and modification to remove the impeller inlet blockage was necessary to improve suction performance.

Additional suction performance data were revealed on test series No. 2 test 005 when operation up to a suction specific speed of 85263 (rad/s $(m^3/s)^{1/2}/(J/Kg)^{3/4}$ 24,300 rpm $(gpm)^{1/2}/(ft\ lbf/lb)^{3/4}$ was analyzed for a flow coefficient of 0.094 with no evidence of cavitation. The combined head-flow performance data of the 1977 tests and the 1978 tests are given in Fig. 6. A second order curve fit of all the data is also given, The data presented are at test speeds from 3141 to 7330 rad/s (30,000 to 70,000 rpm), scaled to 7330 rad/sec (70,000 rpm). These data show the slope to be greater than predicted but very close to predicted head at the design flow. The test data cover a flow range of 58% to 112% of design flow.

The isentropic efficiency data for test series 2 and 3 are given in Fig. 7. The data scatter is caused by the low accuracy of the temperature rise measurement at the low operating speeds of 3142 rad/s (30,000 rpm). In general, most of the data lies slightly below the original prediction.

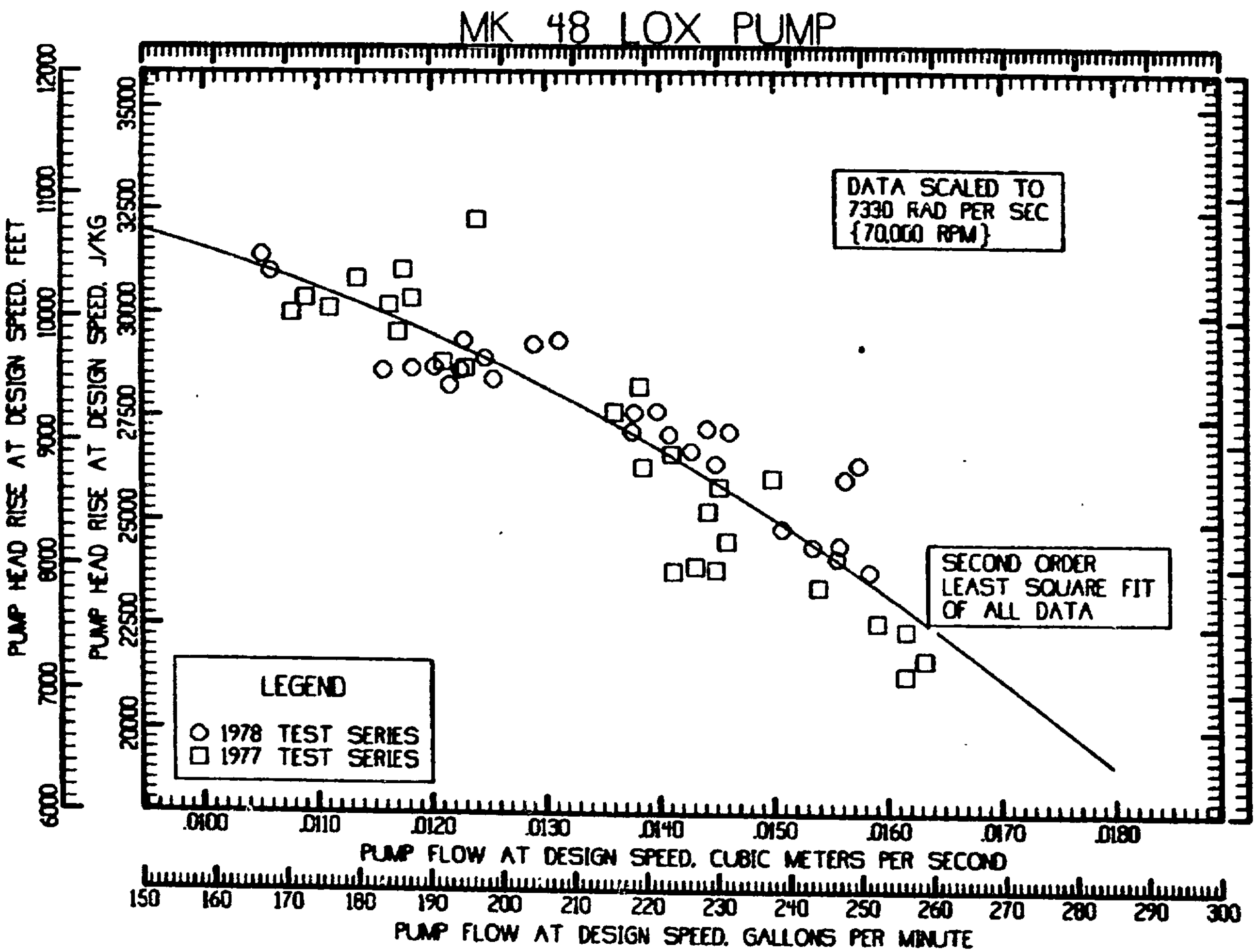

Figure 6. Pump Head-Flow Curve Based on Composite Data From 1977 and 1978 Tests

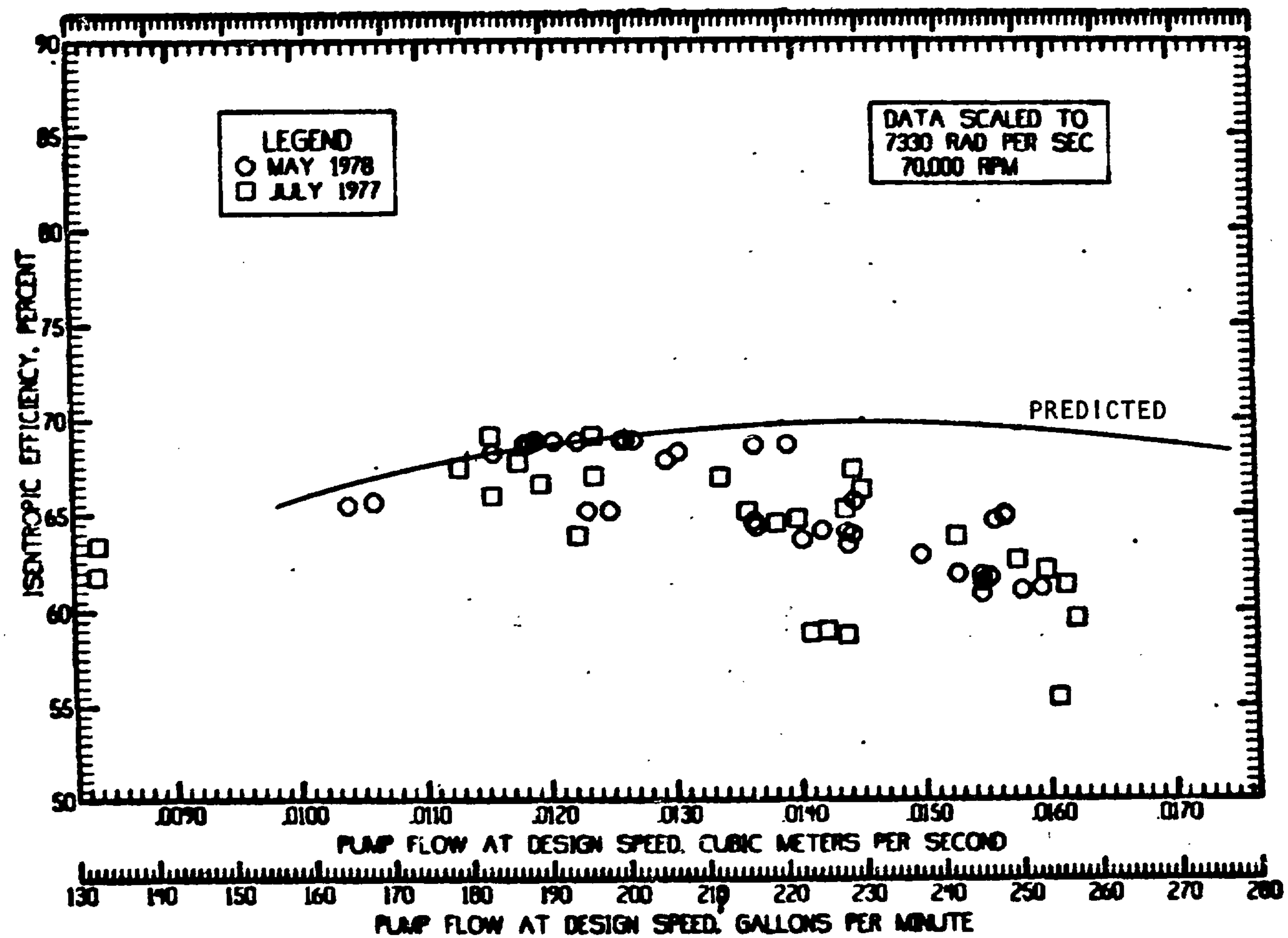

Figure 7. Mark 48-0 Pump Efficiency, Test Series 2 and 3

Axial Thrust Control. Data from test series No. 1 showed the balance piston to be operating in a satisfactory manner, particularly on those tests where part of the flow was bled overboard and the return cavity pressure was, thereby, reduced. To improve the thrust margin in an internal recirculation mode, it was recommended the size of the return flow passages be enlarged.

After test series No. 2 in 1977, the measured static pressure distribution on the components was used to develop a thrust model. The axial thrust computer program model was used to predict the axial thrust balance piston performance of the test series No. 3, test 006. The complete results are presented in detail in Ref. 2 . The results indicated the balance piston flow agreed well with the measured overboard drain values. The predicted sump pressures also showed good accuracy with the measured data. The data indicated the range of thrust of the balance piston was adequate. The ideal balance piston operating point would be in the midpoint of the thrust range for an ideal configuration. The analysis indicates that at the low speed of 3142/rad/s (30,000 rpm) the balance piston operated at a position where the axial thrust was only 16% of the thrust range. At the higher design speed of 7330 rad/s (70,000 rpm), the margin increased to 26 to 32% of the thrust range. The total axial balance piston travel, δ, is 0.25 mm (0.010 inch). The balance piston travels from the balance piston high pressure orifice full closed at $x = o$ to the low pressure orifice full closed at $x = \delta$. For each position of the balance piston, there is a corresponding unique value of the balance cavity pressure and balance piston axial thrust. From the computer program thrust model, it was predicted that the balance piston position at the above presented axial thrust percentage range was at $x/\delta = 0.47$ at the low speed and at x/δ between 0.280 to 0.330 at the high speed operating points. An improvement in operating the pump closer to midrange of thrust and position could be achieved by a reduction in the balance piston sump pressure. This reduction reduces the balance cavity pressure at $x/\delta = o$ and increases the axial thrust range of the system. The operating condition found on test series No. 3 was an acceptable operating condition with sufficient margin for safe operation.

Bearing Coolant Flow. After the initial test series of the turbopump, examination of the pump-end bearings showed evidence of overheating. The first three tests of the series were in LN_2 operation. The total accumulated time on the tests with LN_2 was 44 seconds, with a maximum rotor speed of 6492 rad/s (62,000 rpm). These bearings had similar appearance to other bearings damaged in LN_2 operation. Total test time in LN_2 was held to a minimum because of concern for bearing damage. There was also evidence from the LOX tests that the bearing flow could be substantially less than desired and that coolant temperatures were higher than expected due to the higher back pressure at the balance piston sump caused by high downstream resistance. It was desirable to obtain bearing coolant flow temperatures of approximately 110 K (200 R). Data from initial tests of series No. 1 indicated temperatures up to 160 K (290 R) at speeds of 6282 rad/s (60,000 rpm). Temperatures were greatly improved when the balance piston downstream resistance was reduced by opening an instrumentation line and allowing some of the balance piston return flow to dump overboard. The results were that the coolant temperatures were reduced to a maximum of 130 K (235 R) at 7330 rad/s (70,000 rpm). This confirmed that an increased coolant rate would effectively reduce the bearing coolant temperature to acceptable levels.

During the 1977 test series No. 2, a direct measurement of the pressure drop was not available but calculations from the available instrumentation and the calculations of the slinger pressure gradient indicated a pressure drop across the bearings at 258 N/cm^2 (375 psi). The loads caused by the high pressure drop would shorten the bearing life considerably so it was decided to lower the resistance by drilling eight bypass holes of 2.18 mm (0.086 inch) diameter through the bearing cartridge. This was to reduce the pressure drop to apporixmately 62 N/cm^2 (90 psi) as this would improve bearing life considerably. Since all of the balance piston flow initially passed through the bearings, the reduction in downstream resistance would also improve the balance piston margin and range. Subsequent data from two pressure taps located upstream and downstream respectively, of the pump end bearings indicated pressure drop across the bearings of between 4 and 7 psi. These values are thought to be erroneous on the low side.

Seal Performance. In all of the first three test series, the same seal packages were used. These seals performed satisfactorily with two minor exceptions. During initial testing it was determined that an increased intermediate seal purge pressure level should be applied. This pressure was required to prevent frosting of the secondary hot-gas drain line, which indicated some pump fluid may be getting past the primary seal drain cavity and causing the childown of the secondary hot-gas drain. All tests have been conducted with purge supply pressures above 104 N/cm^2 (150 psi) with no hazardous condition developed. It is expected that this pressure could be reduced further with no problem. The second problem is mechanical: the chrome flaking under the primary hot-gas seal ring. This was originally thought to have been due to inadequate plating but could also be due to a heating condition caused by tight clearance and lack of seal flow. This condition was found in subsequent tests which will be documented in test series No. 5 results.

ANALYSIS AND DESIGN MODIFICATIONS

The major objective of the program was to utilize previously gained fluid film seal technology to design a fluid film seal for installation in the Mark 48-O turbopump, and to test the configuration under actual turbopump conditions. The NASA-Lewis Research Center had previously demonstrated the feasibility of using hydrodynamic or hydrostatic fluid film-type seals. These seals were considered to have the potential to achieve the multiple starts and life requirements of small turbopumps of this type. The first requirement was to obtain baseline pump and seal performance data with the existing primary LOX seal. Previous testing on the Mark 48-O turbopump had been curtailed due to high torque on posttest inspection. The turbopump had been disassembled and the cause was traced to rubbing of the turbine tip. The turbine tip of the turbopump is unshrouded and operates at a relatively small diametral clearance in a housing which has a copper plated mating surface. The rubbing had been slight but caused the copper surface to restrict the smooth turning of the rotor. This was corrected by grinding the surface back to the required diameter and finish. It was also found that the chrome plating on the shaft had deteriorated under the primary hot-gas seal and this had also contributed to the rotor torque. This was thought to be due to the chrome plating extending only to the edge of a relief in the shaft and to inadequate adherence. To correct this situation the chrome plating was removed and replated. The plating was extended past the relief and the replating was done with tighter controls on the processes.

Another change to the turbopump from the original design was the increase in inducer tip diametial clearance to 0.41 mm (0.016 inch) from the value of 0.28 mm (0.011 inch) from the previous build. This was to reduce the level of rubbing of the inducer on the silver plated inlet tunnel found in previous builds.

Hydrodynamic Analysis

It was desirable to reduce the temperature rise of the balance piston and bearing coolant flow because the fluid is returned to the impeller eye. A lower temperature of the recirculated fluid would improve the suction performance. The greatest contributor to the heating of the fluid was found to be caused by the slinger. This heating can be reduced by reducing the slinger diameter. The height of the slinger must be sufficient to cause vaporization of the fluid before reaching the primary LOX seal radius. Liquid at the seal will increase the leakage rate which is undesirable.

The balance piston flow temperature rise as a function of slinger height is shown in Fig. 8 . The decreasing slope of the temperature rise as the radius is increased is due to changes in fluid properties with temperature change. The effect of slinger height on the net slinger axial thrust is shown in Fig. 9 . Figure 10 and 11 show the effects of slinger height on vaporization of the fluid and, therefore, sealing performance of the slinger. Figure 10 shows the radius at which the vapor pressure is reached as a function of slinger tip radius. It can be seen that for a slinger tip radius of approximately 24.8 mm (0.975 inch), vaporization occurs just at the seal radius. Slinger height below this radius will result in liquid at the seal with potential increase in seal leakage. Figure 11 shows the pressure expected at the seal as a function of the slinger height. The discontinuity in the curve is at the slinger height at which the predicted vapor pressure is reached at the seal radius.

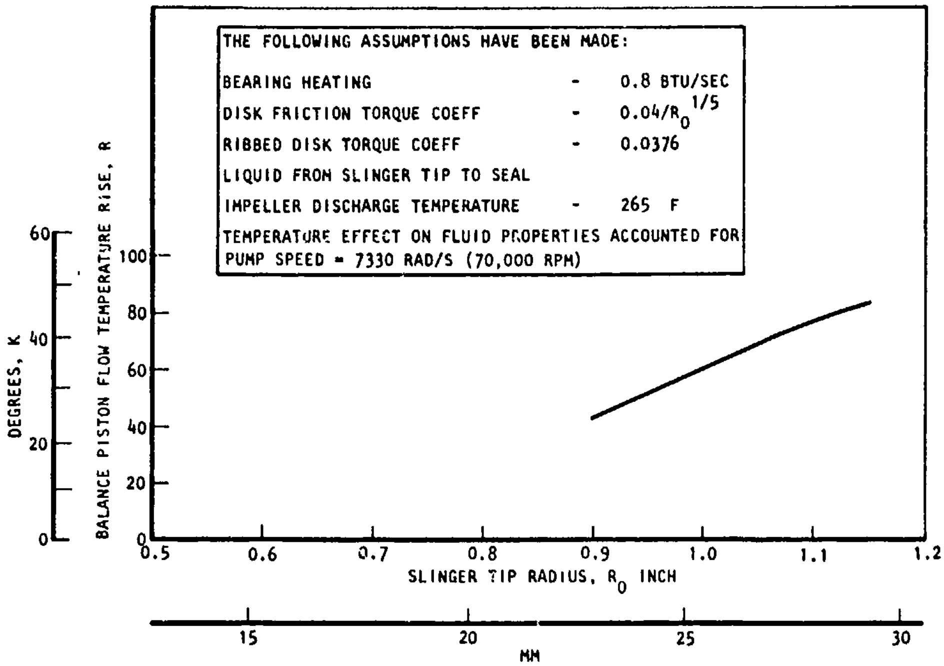

Figure 8 . Mark 48 Oxidizer Expected Balance Piston Temperature Rise as a Function of Slinger Height

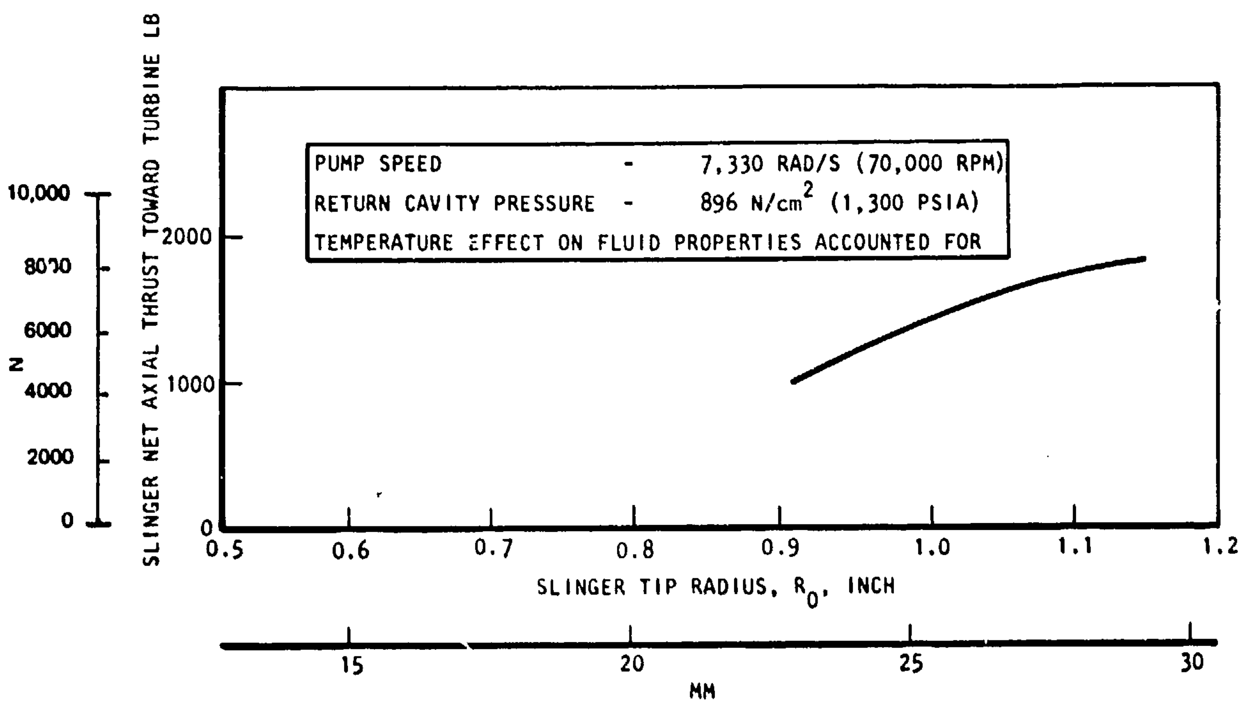

Figure 9. Mark 48 Oxidizer Expected Net Slinger Thrust as a Function of Slinger Height

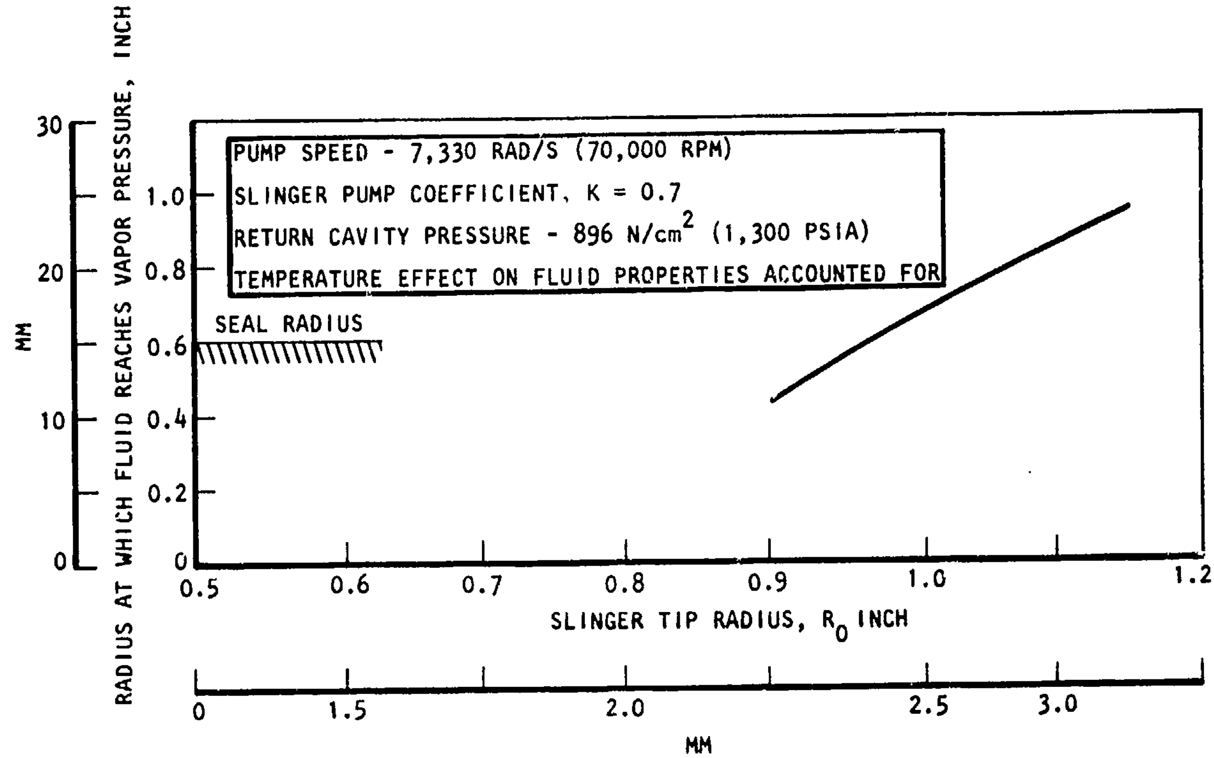

Figure 10. Mark 48 Oxidizer Expected Radius of Vapor Interface on Back of Slinger as a Function of Slinger Height

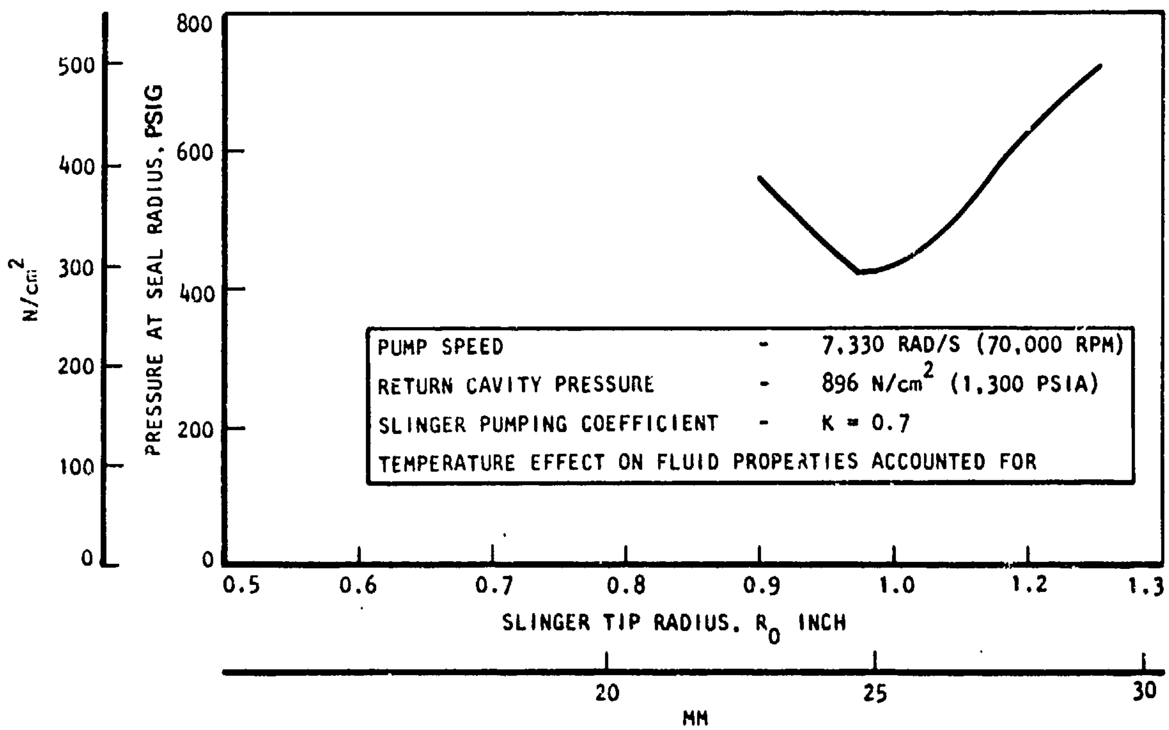

Figure 11. Expected Seal Pressure as a Function of Slinger Height Assuming Vaporization of Pumped Fluid When Pressure Reaches Vapor Pressure

It was recommended that the slinger height not be reduced below 25.4 mm (1.00 inch) in order to maintain vapor at the seal radius, and this was the radius slinger height selected.

Axial Thrust Analysis

Analysis of the axial thrust from data taken in test series No. 3, May 1978, indicated no changes need be made to the turbopump design. The analysis of the axial thrust was reported in Ref. 2 and indicated the thrust range of the balance piston was adequate and the thrust operating point had 16% thrust margin at 3142 rad/s (30,000 rpm) and between 26 to 32% thrust margin at 7330 rad/s (70,000 rpm). Reduction in the slinger diameter by 2.54 mm (0.100 inch) would, however, reduce axial thrust of the rotor assembly approximately 5% of the net thrust range. This would cause the margins quoted above to decrease by 5 points. No changes to the axial thrust balance piston were made for these tests except the tests were to be run with the balance piston flow dumped overboard and the balance piston flow return holes were plugged by inserting pins in the return holes. This was so balance piston flow could be controlled and measured.

Spiral Groove Lift-Off Seal Analysis

The spiral groove lift-off seal for incorporation into the turbopump was analyzed as to its specific operating characteristics, environmental requirements and compatibility with the turbopump design. The objective of the analysis was to use the technology gained in previous NASA research on hydrodynamic or hydrostatic fluid film-type seals. This technology would assist in a seal design which could be incorporated into the turbopump to replace the pump primary floating ring type seal. Two lift-off seals tested under NASA Contract NAS3-17769 for 11 hours and approximately 360 starts had demonstrated the feasibility of using this type of seal to achieve multiple start and long life requirements on the turbopump (Ref. 3). The major concern was that the conventional floating ring seal may have difficulty in meeting the life and cycle requirements of this type of turbopump. The installation of this seal is given in the upper half segment of Fig. 12. The configuration of the floating ring seal is shown below the centerline in the same figure.

The pressure level in the cavity upstream of the seal is approximately 938 N/cm^2 (1360 psia). Since current lift-off seal technology is limited to pressure differentials of less than 345 N/cm (500 psi), it was necessary to reduce the cavity pressure to that level to minimize operating risk. To accomplish this, a two-step labyrinth was added as a throttling device, immediately downstream of the bearings.

A hydrodynamic model of the balance piston fluid flow loop was generated to define the pressures and temperatures at significant points. The analysis performed with the model indicated that the pressure upstream of the seal can be maintained below the 345 N/cm (500 psi) level, which is compatible with existing lift-off seal technology. It also revealed that incorporating the labyrinth between the bearings and the seal cavity will not result in inadequate coolant flow through the bearings, and that the balance piston maintains a satisfactory thrust control.

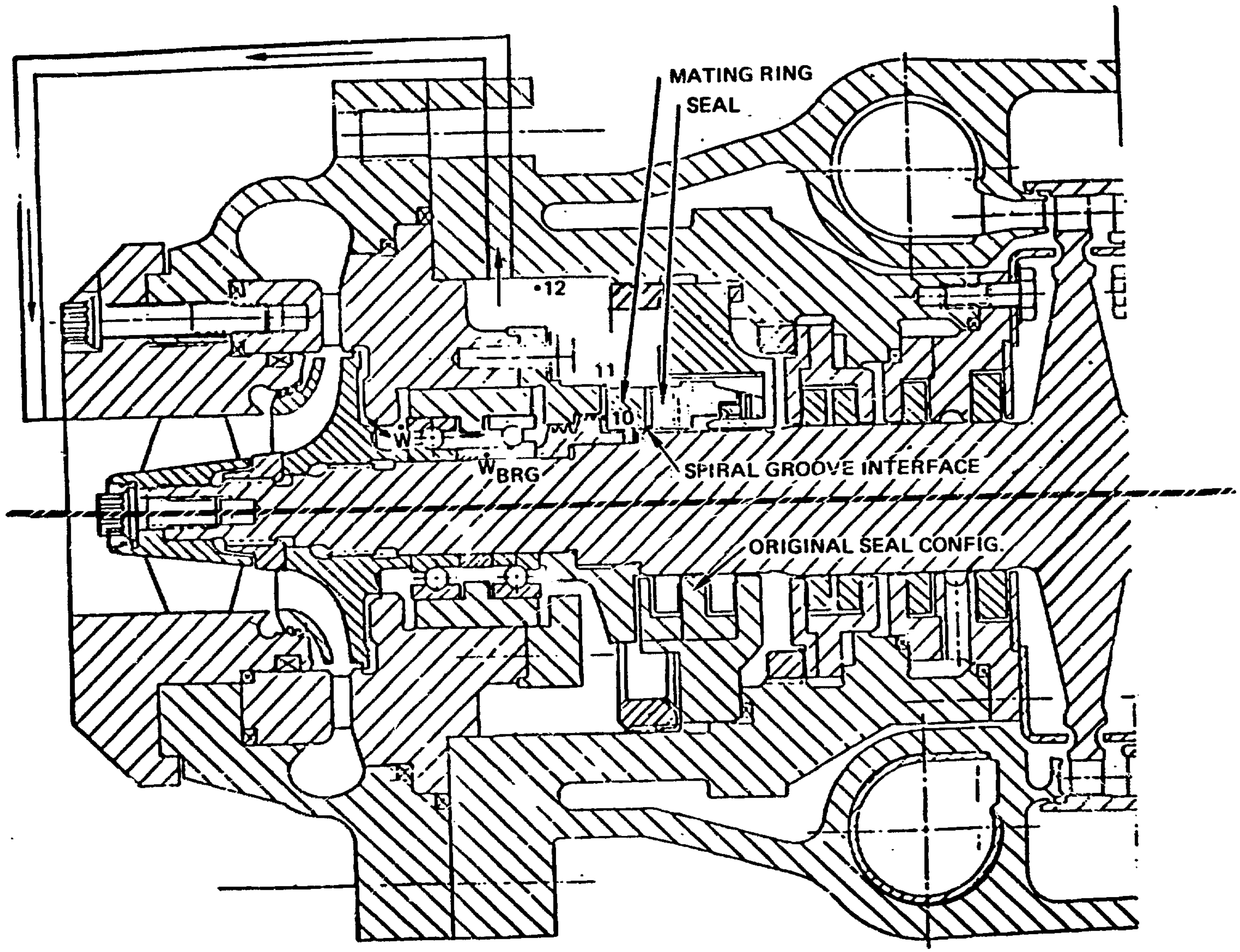

Figure 12. Lift Off/Floating Ring Seal Installations

A finite element stress analysis was performed, using the results of the hydrodynamic and thermal analysis, to establish the mating ring and seal ring operating deflections. The design goal was to maintain the sealing interface gap between the mating ring and seal ring from parallel to 50 microinches in convergence. A divergent gap across the seal face results in unstable seal operation. The mating ring deflection was controlled by adjusting the corner chamfer to vary the centrifugal loading.

The Monel K-500 mating ring and the P-692 graphite seal ring were analyzed as two separate axisymmetric models. The temperature gradients, surface pressure distributions, and boundary conditions of the models are shown in Fig. 13 and 14. The mating ring is rotated at the shaft speed of 7330 rad/s (70,000 rpm). Axial deflections along the spiral groove surface were obtained for three mating ring designs and one seal ring design. The three mating ring designs evaluated were a 1.91 mm (0.075 inch) and 1.27 mm (0.050 inch) chamfer at the opposite OD corner and a no-chamfer design.

The results indicate that sealing surface deflections of the Monel mating ring can be readily controlled by the corner chamfer. The relative axial deflection of the OD with respect to the ID is reduced from 955 to 383 micromillimeters (37.6 to 15.1 microinches) in the convergent direction by changing the corner chamfer from 1.91 to 1.27 mm (0.075 to 0.050 inch).

It reverses to 130 micromillimeters (5.1 microinches) in the divergent direction without a corner chamfer.

The carbon seal ring surface deflection is 508 micromillimeters (20 microinches) in the convergent direction. The total surface deflection between the mating ring with 1.27 mm (0.050 inch) chamfer and seal ring is 889 micromillimeters (35 microinches). The results of the finite element deflection analysis are given in Fig. 15.

Both the Monel K-500 mating ring and the P-692 graphite seal ring designs are structurally adequate. The factor of safety on yield is 2.2 and the factor of safety on ultimate is 3.2 for the mating ring. The factor of safety on ultimate is greater than 10 for the seal ring.

The effective stress levels in the three mating ring designs were about the same. The maximum effective stress was 32,128 N/cm^2 (46,600 psi). The yield strength of Monel K-500 used in the mating ring is 71.000 N/cm^2 (104,000 psi) and the ultimate strength is 105,000 N/cm^2 (152,000 psi) at 260 K (-200 F). Stresses and deflections of the graphite seal ring result from the external surface pressures and spring reaction. The maximum effective stress is 896 N/cm^2 (1300 psi). The ultimate compressive strength of Carbon P-692 is 25,165 N/cm^2 (36,500 psi) at -260 K (-200 F). Integration of the spiral groove lift-off seal assembly into the turbopump was completed and is shown in Fig. 12 and Drawing 9R0012300 of Appendix A.

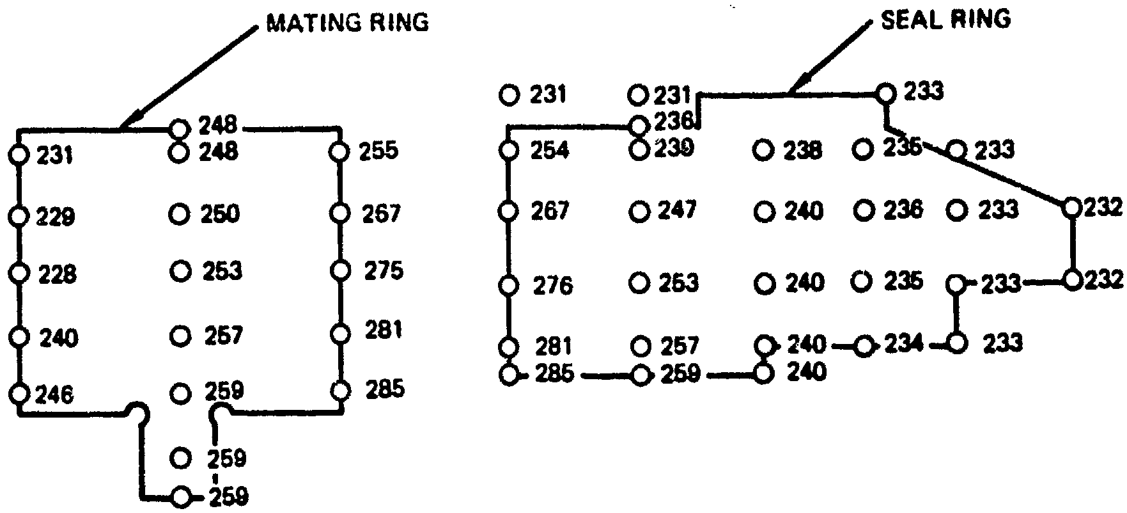

Figure 13. Mark 48-0 Spiral Groove LOX Seal Temperature Gradients (R, Used in Finite Element Models)

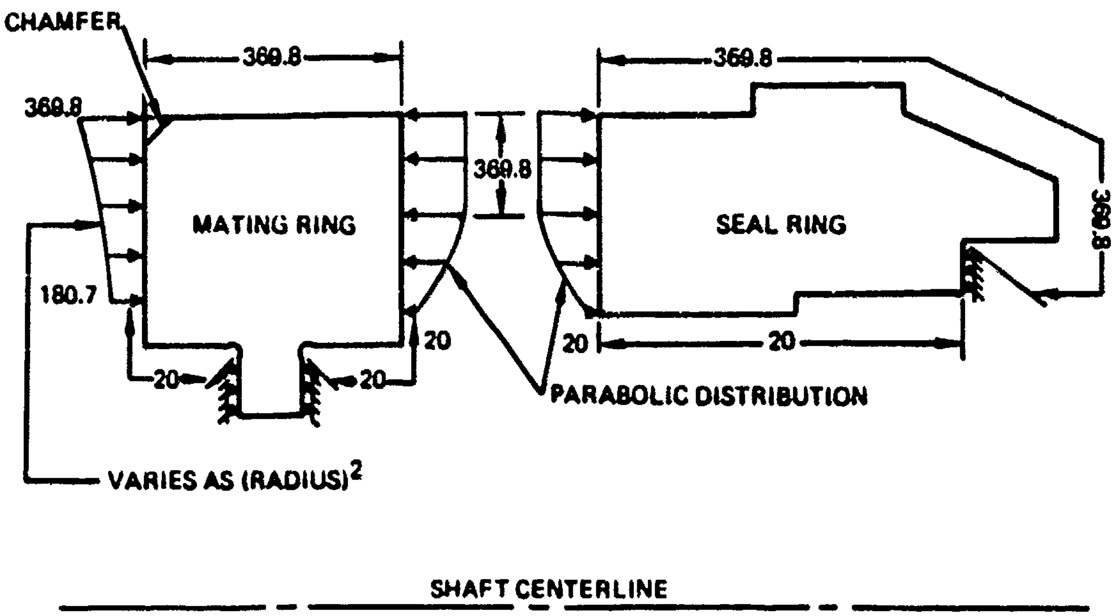

Figure 14. Mark 48-0 Spiral Groove LOX Seal Pressure Distribution (Psia Used in Finite Element Models)

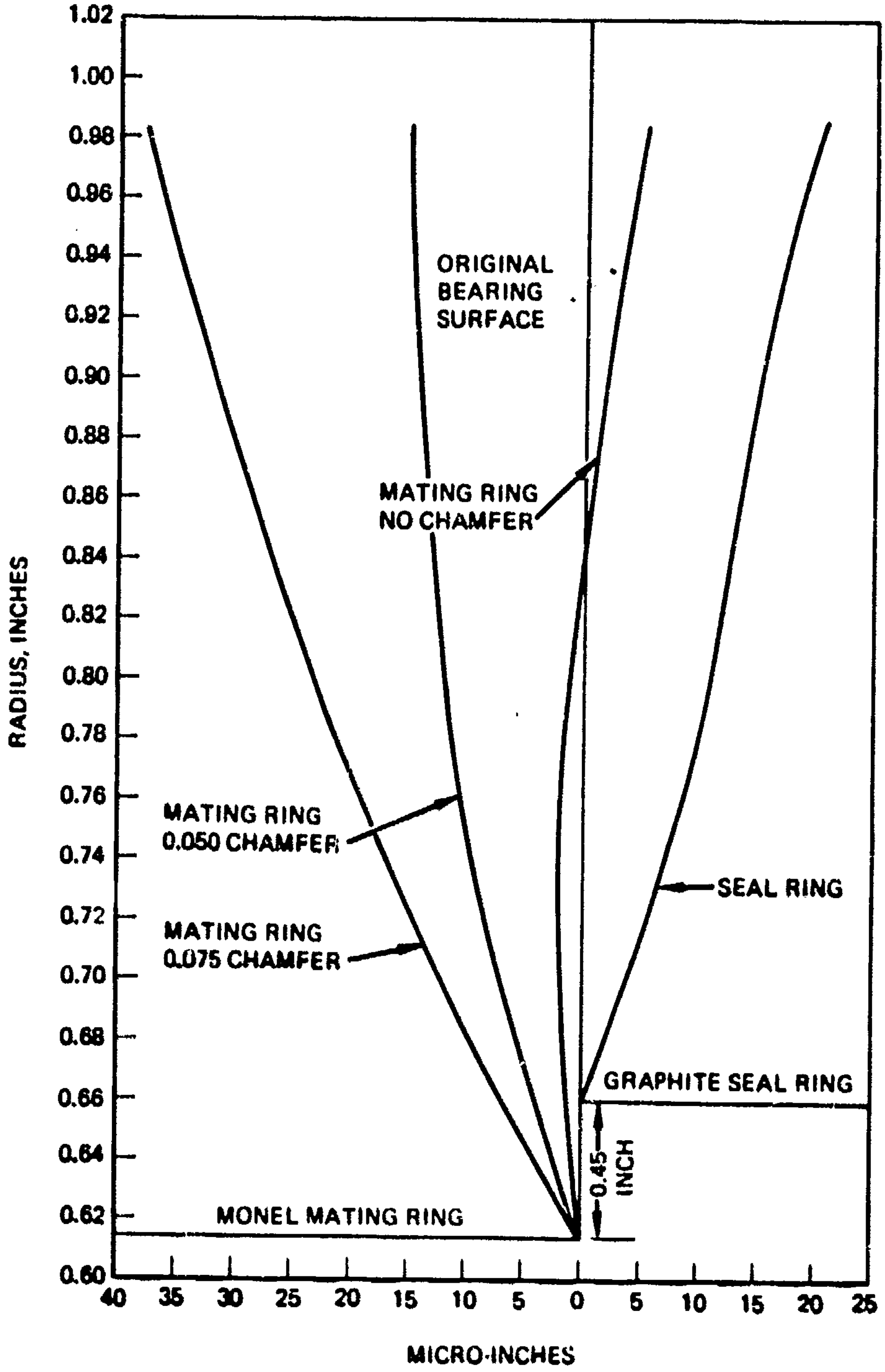

Figure 15. Monel Mating Ring and Graphite Seal Ring Deflection of Sealing Surface Radius vs Relative Microinches

TURBOPUMP S/N 02-1 ASSEMBLY AND TEST

The specific objectives planned for the test program of turbopump S/N 02-1 were twofold. The first objective was to obtain baseline primary LOX seal performance data in preparation for test comparison and analysis of the spiral groove lift-off seal to be incorporated in the next turbopump tests. The second was to determine the critical NPSH of the turbopump with the balance piston fluid directed overboard and with the balance piston fluid recirculated back to the impeller inlet. Prior to this time only a partial indication of suction performance had been achieved. On the first test series the data indicated very low suction performance. This initiated the enlargement of the impeller eye and the suction performance in test series No. 2 was measured at a noncavitating operation of up to 85263 [(rad/s) $(m^3/s)^{1/2}$ $(J/Kg)^{3/4}$] {24,300 [RPM $(gpm)^{1/2}$ $(Ft\text{-}lbf/lbm)^{3/4}$} at a flow coefficient of 0.094 or 110% of nominal flow. The cavitation limit was never achieved during those tests. The scope of the program was expected to be completed in three full duration tests.

Turbopump Assembly and Installation

The Mark 48-0 turbopump S/N 02-1 modifications were completed and the turbopump was assembled in August and September of 1978. The assembly configuration is that given in Fig. 16. Changes from the original configuration are summarized in Table 5. The few changes made to the turbopump and their rationale have been discussed previously. Dynamic balancing of the rotor assembly was accomplished on the Gisholt balancing machine with a capability of accurately detecting 6 x 10^{-4} mm (25 microinch) radial motion. For the Mark 48-0 rotor mass of 2.84 Kg (6.25 lb), this translates into a machine accuracy limit of 98N (22 lb) at the design speed of 7330 rad/s (70,000 rpm). The rotor was supported in the balance cradle by two pairs of turbopump bearings, each pair axially preloaded in the bearing cartridge exactly as in the turbopump assembly.

Balancing was initiated using the main rotor and the rear stub shaft assembly, and wax corrections were made in the plane of the turbine wheel and the stub shaft.

Subsequently, the slinger, impeller, inducer, and instrumentation sleeves were added, making wax corrections in the plane of each component before the next part was added. After the wax corrections were completed, several repeatability checks were made in which the rotor was disassembled and reassembled, and the change in residual imbalance was established, and the runouts at several stations were measured. Satisfactory repeatability was obtained. The permanent balance of the rotor was then accomplished by grinding material in designated areas of the component parts.

The assembly of turbopump S/N 02-1 was accomplished in similar fashion to previous turbopump builds, in accordance with the procedure described in Ref. 1. The front and rear bearing inner race thicknesses were selected to provide a minimum bearing preload of 245 N (55 lb), and to obtain a total bearing travel within each cartridge of approximately 0.23 mm (0.009 inch). Measurements were made during assembly of the turbopump to establish critical clearances and fits. Critical clearances in the pump area are given in Fig. 17.

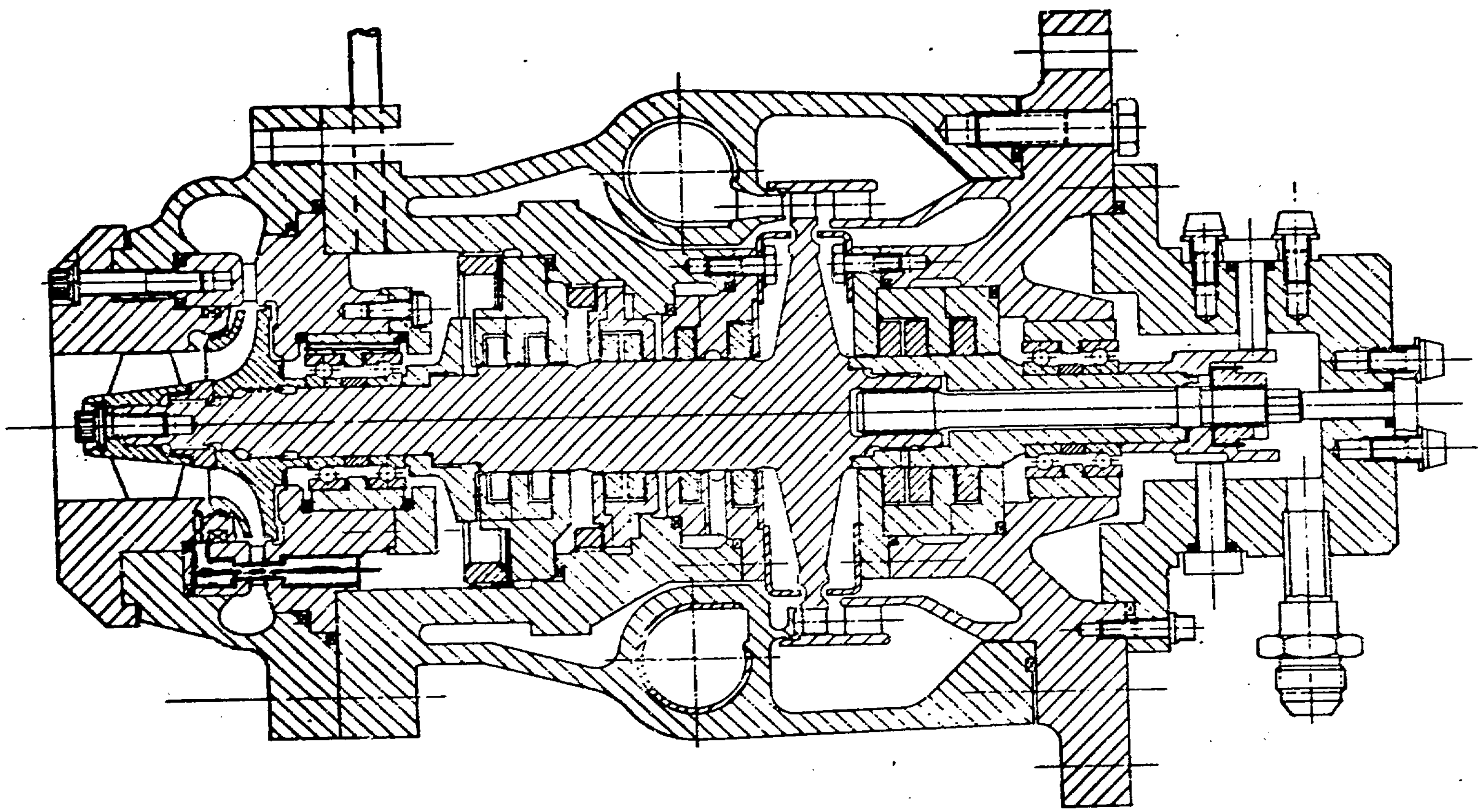

Figure 16. Mark 48-0 Turbopump S/N 02-1 Configuration

TABLE 5. MARK 48-0 CONFIGURATION SUMMARY

CHANGES TO ORIGINAL DESIGN	01-1 (1977)	02-0 (MAY 1978)	02-1 (SEPT 1978)
IMPELLER INLET AREA ENLARGED	X	X	X
IMPELLER DISCHARGE-TO-INLET/BALANCE PISTON RETURN CAVITY LEAK PATH ELIMINATED	X	X	X
BALANCE PISTON INTERNAL RECIRCULATION PLUGGED	X	X	X
BALANCE PISTON OVERBOARD BLEED PORT ADDED	X	X	X
BALANCE PISTON EXTERNAL RECIRCULATION RETURN ADDED TO INLET HOUSING	X	X	X
SLINGER CLEARANCE REDUCED TO 0.035 INCH	X	X	X
INDUCER DISCHARGE PRESSURE PORT ADDED	X	X	X
IMPELLER FRONT SHROUD PRESSURE PORT ADDED	X		
REDESIGNED PRIMARY SEAL NUT		X	X
REDESIGNED PRIMARY SEAL NUT LOCK		X	X
BYPASS HOLES AROUND BEARINGS		X	X
SPRING ADDED TO FORWARD CARTRIDGE		X	X
BALANCE PISTON OVERBOARD BLEED PORT ENLARGED		X	X
MODIFIED SHAFT PLATING DESIGN		X	X
INDUCER TIP CLEAR INCREASED (0.016 INCH)			X
REDUCED SLINGER DIAMETER			X
			X

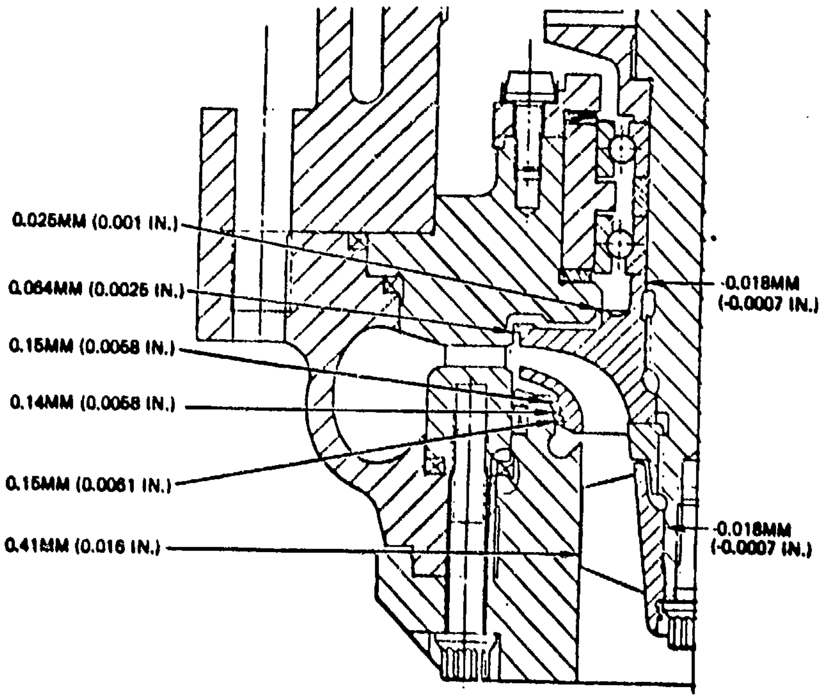

Figure 17. S/N 02-1 Diametral Clearances and Fits

After the turbopump was assembled, a push-pull test was performed on the rotor to establish the external loads which the bearings support as a function of rotor position with respect to the balance piston orifice positions. The movement of the balance piston can be refered to the symbols h_1 and h_2 which define the balance piston high and low-pressure axial clearances, respectively as shown in Fig. 18. The results of the push-pull test which characterizes the load-travel response of the rotor within the spring loaded bearing package is given in Fig. 19. As indicated by the curve, the bearing stops were positioned so that the balance piston orifices axial clearances would overlap (i.e., h_1 and h_2 would be negative) by 0.102 mm (0.0040 inch) and 0.076 mm (0.0030 inch) respectively before a sizable load of 2002N (450 lb) would be imposed on the bearings.

After the turbopump assembly, a series of leak checks were performed to ensure the sealing requirements of the turbopump were achieved. The turbopump was installed into the Advanced Propulsion Test Facility (APTF) in the LIMA test stand. The necessary connecting ducting was fitted to the turbopump. A schematic of the major ducting in the test facility is given in Fig. 20. The balance piston overboard flow system included a single discharge line from the turbine housing flange draining from downstream of the bearings and out of the slinger-primary LOX seal cavity. This flow was to be dumped overboard or fed back to pump inlet after being measured using a pressure differential across an orifice in the exit line.

Test Series No. 4 (October 1978)

The purpose of the test series was to define the baseline performance of the primary LOX seal for later comparison to the spiral groove lift-off seal test data to be generated in the next turbopump build and test series. In addition, suction performance tests were planned to define the suction performance of the turbopump with and without recirculation of the balance piston flow. The test plan called for three tests to accomplish the objectives. These planned tests and the operating requirements are given in Table 6. Turbopump instrumentation was similar to previous turbopumps tested. A detailed instrumentation list is given in Table 7 and specific turbopump instrumentation is illustrated in Fig. 21.

TABLE 6. MARK 48-0 TEST PLAN, S/N 02-1 PERFORMANCE (75 SECONDS; TURBINE PROPELLANT GH_2)

TEST NO/DAY	OBJECTIVE	N, RPM	CONDITIONS	
			BALANCE PISTON FLOW	OPERATION
1/1	CHECKOUT AND SUCTION PERFORMANCE WITHOUT RECIRCULATION		100% O/B	NPSH AT Q/N NOMINAL
2/2	SUCTION PERFORMANCE WITH RECIRCULATION	70K	100% RECIRCULATION	NPSH AT Q/N NOMINAL
3/3	SUCTION PERFORMANCE WITH	70K	100% RECIRCULATION	NPSH AT 70%, 130% Q/N NOMINAL

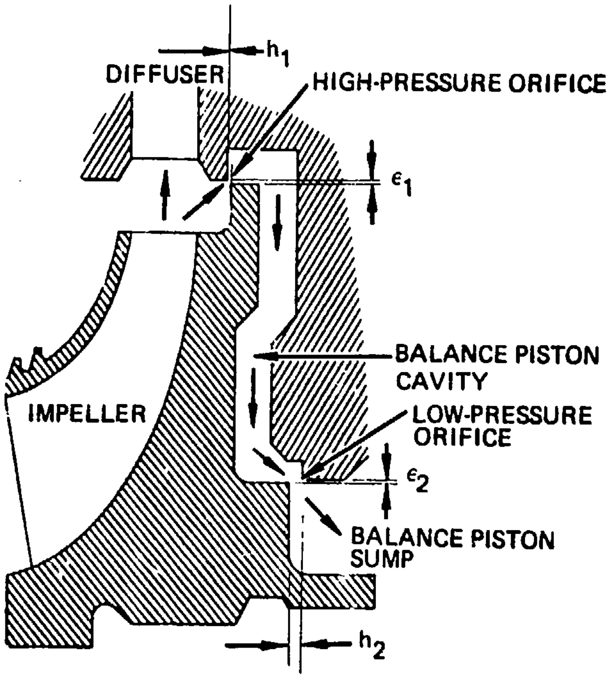

Figure 18. Mark 48-0 Turbopump Balance Piston

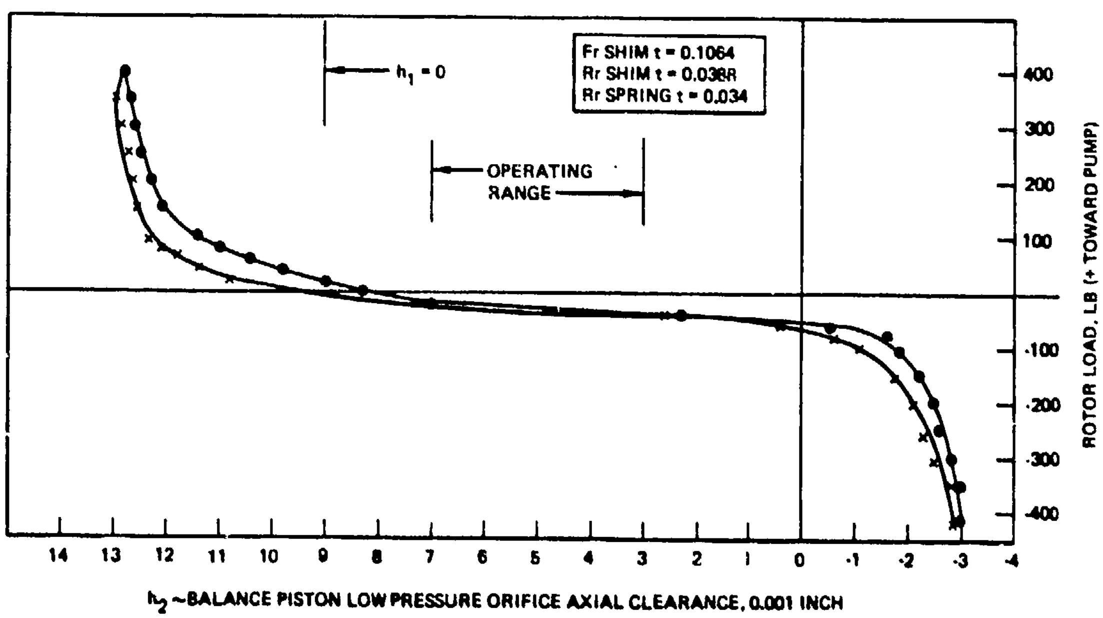

Figure 19. Mark 48-0 Turbopump Rotor Load Travel Characteristics (S/N 02-1)

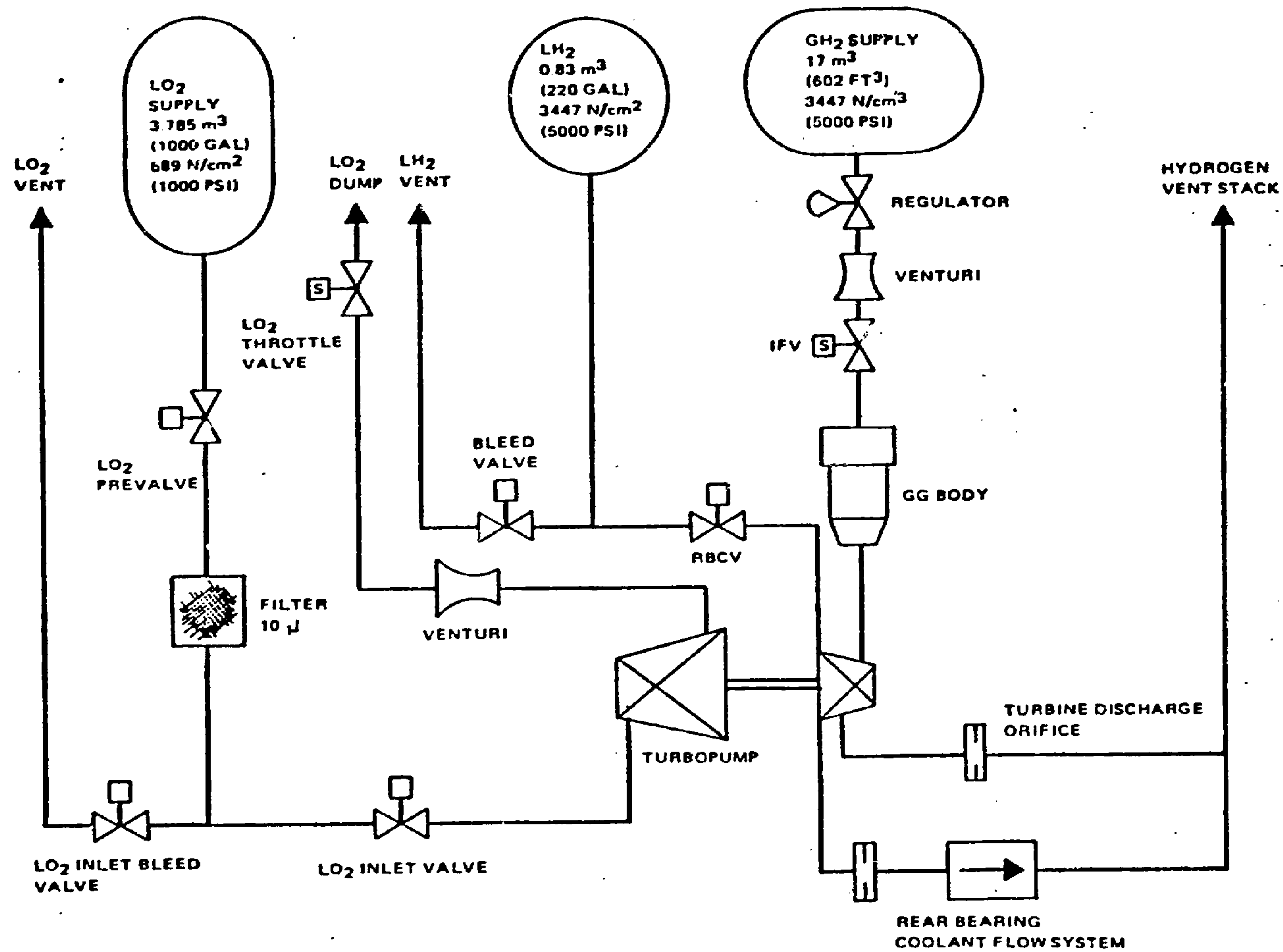

Figure 20. LIMA Stand Schematic for Mark 48-0 Testing (GH_2 Drive)

TABLE 7. INSTRUMENTATION LIST (GASEOUS HYDROGEN TURBINE DRIVE)

SYSTEM	PARAMETER	ID	PID	RANGE	REDLINE	BECKMAN	DIGR	OSC	FM TAPE	LOCATION	COMMENTS
GH_2	REGULAR U/S PRESSURE	PGHR	062	5000 PSIG		X	X			FACILITY LINE	
	VENTURI U/S PRESSURE	PGHV	071	5000 PSIG		X	X				VENTURI S/N 9731 P/N VP031200-SGR
	VENTURI U/S TEMPERATURE	TGHV	047	0 TO 200 F		X					THERMOCOUPLE
	VENTURI ΔP	PGHD	061	500 PSID		X	X				
	GN_2 SPIN VALVE U/S PRESSURE	PSV1	082	5000 PSIG		X					
	GN_2 SPIN VALVE D/S PRESSURE	PSV2	074	5000 PSIG		X					
	GN_2 SPIN VALVE POSITION	GHSV	055	TRACE		X		X			METER DISPLAY FOR DIGR REQUIREMENT
TURBOPUMP LOX OUTLET CONTROL	THROTTLE VALVE POSITION	TVP	057	TRACE		X		X			METER DISPLAY FOR DIGR REQUIREMENT
	THROTTLE VALVE OUTLET PRESSURE	PDTP	100	5000 PSIG		X					
GENERAL	LH_2 HIGH PRESSURE, TANK PRESSURE	PHT	087	5000 PSIG		X	X				
	FACILITY DUCT PRESSURE	PFX	069	500 PSIG		X					
	FACILITY DUCT TEMPERATURE	TFX	029	0 TO 2000 F		X				FACILITY LINE	THERMOCOUPLE
	AXIAL PROXIMITY INDICATOR	BAP	TAPE	TAPE FM	X			X	X		
	RADIAL PROXIMITY INDICATOR NO. 1	BAP	TAPE	TAPE FM	X			X	X		
	RADIAL PROXIMITY INDICATOR NO. 2	BTP	TAPE	TAPE FM				X	X		90 DEGREES FROM NO. 1
	PUMP AXIAL ACCELERATION	PAA	TAPE	TAPE FM	X			X	X		
	PUMP RADIAL ACCELERATION	PRA	TAPE	TAPE FM	X			X	X		
	TURBINE RADIAL ACCELERATION	TRA	TAPE	TAPE FM	X			X	X		
	PUMP SPEED	RPM	111	100,000 RPM	X	X	X	X	X		
	HELIUM SUPPLY PRESSURE	PHUS	104	0 TO 500 PSIG		X					
LOX PUMP	LOW PRESSURE, TANK PRESSURE	PØXT	068	500 PSIG		X	X			FACILITY LINE	
	INLET PRESSURE	PØIN	098	200 PSIG	X	X	X	X			PIEZOMETER RING
	INLET TEMPERATURE	TØIN	043	-259 TO -300 F	X	X	X			FACILITY LINE	RTB
	INDUCER DISCHARGE PRESSURE	PIND		2000 PSIG		X					
	IMPELLER DISCHARGE PRESSURE	PIDP	067	5000 PSIG		X	X				
	DIFFUSER DISCHARGE PRESSURE	PDDP	084	5000 PSIG		X					
	PUMP DISCHARGE PRESSURE	PDP	089	5000 PSIG	X	X	X	X		FACILITY LINE	PIEZOMETER RING X-Y PLOTTER
	PUMP DISCHARGE TEMPERATURE	PDT	045	-100 TO -300 F		X					RTB
	BALANCE PISTON CAVITY PRESSURE 1	P10	096	5000 PSIG	X	X	X				
	BALANCE PISTON CAVITY PRESSURE 2	P11		5000 PSIG		X					
	BALANCE PISTON SUMP PRESSURE	P12	086	5000 PSIG		X	X				
	BALANCE PISTON RETURN FLOW PRESSURE	P13	094	5000 PSIG		X					
	BALANCE PISTON RETURN FLOW TEMPERATURE	PBT	036	-250 TO -300 F	X	X	X				PUMP BEARING RIB SUPPLIED
	DSCH VENTURI U/S PRESSURE	PUVP	088	5000 PSIG		X					VENTURI S/N 8877 P/N V321059-SGR
	DSCH VENTURI U/S TEMPERATURE	TUVP	046	-250 TO -300 F		X					RTB
	DSCH VENTURI ΔP	PVDP	063	350 PSID		X	X				X-Y PLOTTER

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 7. (Continued)

SYSTEM	PARAMETER	ID	PID	RANGE	REDLINE	BECKMAN	DIGR	OSC	FM TAPE	LOCATION	COMMENTS
TURBINE	INLET STATIC PRESSURE	PTIS	065	5000 PSIG		X	X	X			
	INLET TOTAL PRESSURE	PTIT	080	5000 PSIG		X					KIEL PROBE SUPPLIED
	INLET TEMPERATURE NO. 1	CT-1	024	0 TO 2000 F		X					WALL + 0.150"
	INLET TEMPERATURE NO. 2	CT-2	025	0 TO 2000 F		X	X				CORE TEMPERATURE
	NOZZLE D/S PRESSURE	PND	077	5000 PSIG		X					
	TURBINE WHEEL EXHAUST PRESSURE	PWD		5000 SPIG		X					
	EXHAUST TOTAL PRESSURE	PTDT	079	5000 PSIG		X					
	EXHAUST STATIC PRESSURE	PTDS	070	5000 PSIG		X					
	EXHAUST TEMPERATURE	TTD	023	-100 TO +2000 F		X					THERMOCOUPLE
SEALS AND BEARINGS	PRIMARY LOX SEAL DRAIN LINE PRESSURE	P14	081	100 PSIG	X	X	X				
	PRIMARY LOX SEAL DRAIN LINE TEMPERATURE	LSDT	011	-300 TO +100 F		X	X				THERMOCOUPLE
	LOX SEAL DRAIN ORIFICE U/S PRESSURE	LSØP		100 PSIG		X					
	PRIMARY HOT GAS SEAL DRAIN ORIFICE U/S PRESSURE	P15	102	100 PSIG		X					
	PRIMARY HOT GAS SEAL DRAIN ORIFICE U/S TEMPERATURE	HGPT	028	0 TO 2000 F		X					THERMOCOUPLE
	SECONDARY HOT GAS SEAL DRAIN LINE PRESSURE	P16	091	500 PSIG	X	X					
	SECONDARY HOT GAS SEAL DRAIN LINE TEMPERATURE	HGST	026	0 TO 2000 F		X					THERMOCOUPLE
	SECONDARY HOT GAS SEAL DRAIN ORIFICE U/S PRESSURE	P17	097	100 PSIG		X					
	SECONDARY HOT GAS SEAL DRAIN ORIFICE U/S TEMPERATURE	HGØT	027	0 TO 2000 F		X					THERMOCOUPLE
	INTERMEDIATE SEAL ORIFICE U/S PRESSURE	P18	092	500 PSIG	X	X	X				
	INTERMEDIATE SEAL PURGE ORIFICE U/S TEMPERATURE	SPT	012	-100 TO +100 F		X					THERMOCOUPLE
	REAR BEARING COOLANT SUPPLY PRESSURE	P19	095	5000 PSIG	X	X					
	REAR BEARING COOLANT SUPPLY TEMEPRATURE	TBC	035	-450 TO -250 F		X					RTB
	REAR BEARING COOLANT DRAIN PRESSURE	P20	103	1000 PSIG	X	X	X				500 PSIG
	LOX SEAL ORIFICE U/S TEMPERATURE	LSØT		-300 TO +100 F		X					THERMOCOUPLE

TABLE 7. (Concluded)

SYSTEM	PARAMETER	ID	PID	RANGE	REDLINE	BECKMAN	DIGR	OSC	FM TAPE	LOCATION	COMMENTS
SEALS AND BEARINGS (CONTINUED)	REAR BEARING COOLANT DRAIN TEMPERATURE	TBCD	014	-450 TO -250 F	X	X	X				THERMOCOUPLE
	REAR BEARING COOLANT ORIFICE PRESSURE	P21	093	350 PSIG		X	X				
	REAR BEARING COOLANT ORIFICE TEMPERATURE	TBCO	015	-100 TO +100 F		X	X				THERMOCOUPLE
	REAR BEARING COOLANT ORIFICE D/S PRESSURE	P22		0 TO 350 PSIG		X					
SPECIAL	BALANCE PISTON RECIRCULATING PRESSURE	PBPR		5000		X	X				
	BALANCE PISTON OVBD PRESSURE	PBPO		5000		X	X				
	BALANCE PISTON RECIRCULATION TEMPERATURE	TBPR		-300 TO ±100 F		X	X				THERMOCOUPLE
	BALANCE PISTON OVBD TEMPERATURE	TBPO		-300 TO ±100 F		X	X				THERMOCOUPLE
	BALANCE PISTON OVBD PRESSURE	DPBPO		0 TO 50 PSIG		X					
	BALANCE PISTON RECIRCULATION	DPBPR		0 TO 50 PSIG		X					
	INTERMEDIATE SEAL PURGE ORIFICE D/S PRESSURE										

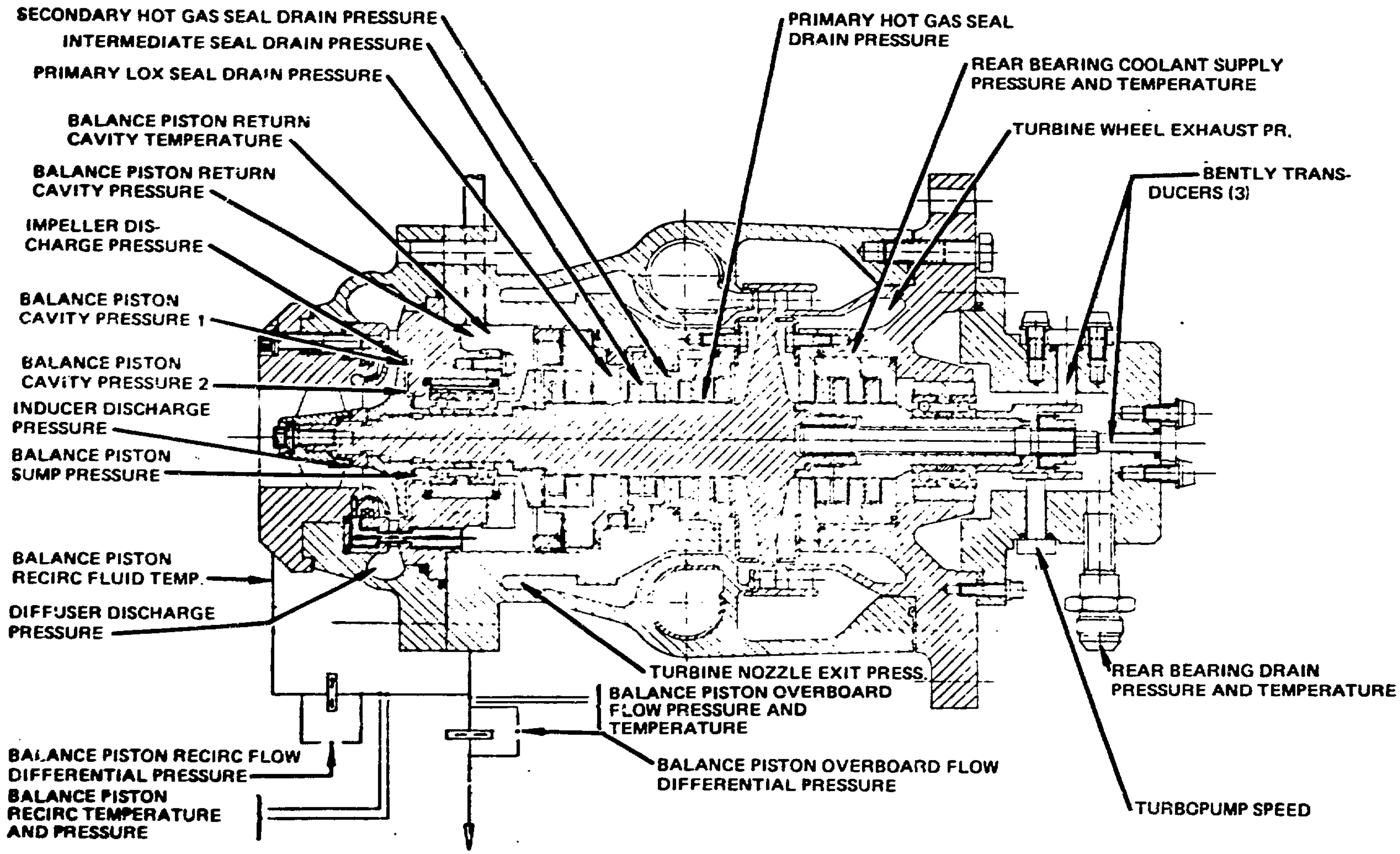

Figure 21. Mark 48-0 Turbopump Instrumentation

Facility instrumentation was similar to that previously used. The instrumentation capability of the test cell is given in Table 8 and was sufficient to record all the data required. As a safety precaution on all tests a set of redlines were provided which required the turbopump to operate within specified limits of speed, pressures, temperatures, and accelerometer levels. The redline parameters defined for the tests are given in Table 9. The redline limits, when exceeded, would cause the test to be terminated either by an automatic cutoff monitor or by an observer watching an instrument.

The balance piston overboard flow was measured by an orifice differential pressure and reference temperature as shown in Fig. 21. The flow could then be dumped overboard or recirculated back into the pump inlet behind the inducer at the impeller eye. Proximeter transducers measured axial and radial motion of the rotating shaft, and speed was also measured from an instrumentation cap at the aft end of the turbine bearings. The turbine bearings are cooled by liquid hydrogen supplied from an external source and the proximeters and speed probes are subjected to the LH_2 environment.

In order to measure the leakage on the primary LOX seal, the LOX seal drain line was run through a heat exchanger to insure a mixture of gaseous oxygen (GOX) and helium prior to passing through an orifice. A schematic of the intermediate seal purge, primary LOX seal cavity, and secondary hot gas seal cavity flow paths is given in Fig. 22. The pressure and temperature are measured upstream of the orifice with the downstream pressure being atmospheric. The flow is a measure of combined oxygen and helium but the helium purge flow was of such a low magnitude its effect can be neglected.

The tests on the turbopump were conducted in early October 1978. A total of five tests were made with a total duration of 174 seconds of operation. A summary of the test series is given in Table 10. The first test planned was that of checkout of the system at 524, 3142, and 7330 rad/s (5,000, 30,000 and 70,000 rpm) with a suction performance test to follow at a nominal flowrate and the balance piston flow not being recirculated back to the pump inlet. The first two test attempts failed to achieve the desired goals. Test 016-007 had problems with regulation of the GH_2 turbine supply pressure, which controls speed. The test was cut by an erroneous bearing coolant temperature reading caused by faulty instrumentation. The maximum speed achieved in the test was 1048 rad/s (10,000 rpm). The second test was terminated after a maximum speed of 838 rad/s (8,000 rpm) due to the GH_2 turbine supply pressure regulator malfunction.

Third test (016-009) of the series was a satisfactory test with a maximum speed of 7016 rad/s (67,000 rpm). A 5% pump head loss was accomplished in the suction performance portion of the test. The test was terminated when the facility minimum supply pressure limit on GH_2 drive gas pressure was encountered, which occurs when the turbine gaseous hydrogen throttle valve is fully open and the pressure supply does not allow the turbine to maintain speed. The fourth test (015-010) was scheduled to be a high-speed suction performance test at 7330 rad/s (70,000 rpm) with the balance piston flow recirculated back to the pump inlet. The test duration was 28 seconds and was terminated because of low pressure differential across the balance piston flow measuring orifice. This indicated the balance piston flow was lower than desired for proper balance piston operation.

TABLE 8. MARK 48-0 TURBOPUMP, GH_2 DRIVE TEST INSTRUMENTATION

RECORDER	NUMBER OF CHANNELS
DIGITAL DATA ACQUISITION SYSTEM	64
CEC OSCILLOGRAPH	12
DIRECT INKING RECORDERS	27
HIGH FREQUENCY TAPE RECORDER	7
DIGITAL EVENT RECORDER	120
OSCILLOSCOPE (BENTLY AND ACCELS)	4 (MINIMUM)
MILLIKIN CAMERAS	2
TELEVISION (B&W WITH REPLAY CAPABILITY)	2

TABLE 9. MARK 48-0 TURBOPUMP LO_2 TURBOPUMP REDLINES, AMBIENT HYDROGEN TURBINE DRIVE

CUTOFF MONITOR	REDLINE IDENTIFICATION	REDLINE LIMIT
OBSERVER	LOX INLET TEMPERATURE	176 R MAXIMUM
AUTOMATIC/OBSERVER	LOX PUMP INLET PRESSURE	92 PSIA MINIMUM
AUTOMATIC	TURBOPUMP SPEED	77,000 RPM MAXIMUM
OBSERVER	BALANCE PISTON RETURN FLOW TEMPERATURE	ΔT = 10 R MAXIMUM AFTER STABILIZATION
OBSERVER	REAR BEARING DRAIN TEMPERATURE	ΔT = 10 R MAXIMUM AFTER STABILIZATION
OBSERVER	BALANCE PISTON CAVITY PRESSURE	SPECIFIC RANGE EACH TEST
AUTOMATIC	LOX PUMP DISCHARGE PRESSURE	5000 PSIG MAXIMUM AND ΔP = 10%
AUTOMATIC/OBSERVER	PRIMARY LOX SEAL DRAIN LINE PRESSURE	30 PSIG MAXIMUM
AUTOMATIC	TURBINE SECONDARY SEAL DRAIN LINE PRESSURE	30 PSIG MAXIMUM
AUTOMATIC	INTERMEDIATE SEAL PURGE (HELIUM) PRESSURE	150 PSIG MINIMUM
AUTOMATIC	TURBOPUMP RADIAL ACCELEROMETER*, **	15 G RMS
OBSERVER	BALANCE PISTON RECIRCULATION FLOW ORIFICE DELTA PRESSURE	TBD
OBSERVER	BALANCE PISTON SUMP PRESSURE	FUNCTION OF TEST SPEED

*2 KHz LOW PASS FILTER
**VIBRATION SAFETY CUTOFF DEVICE

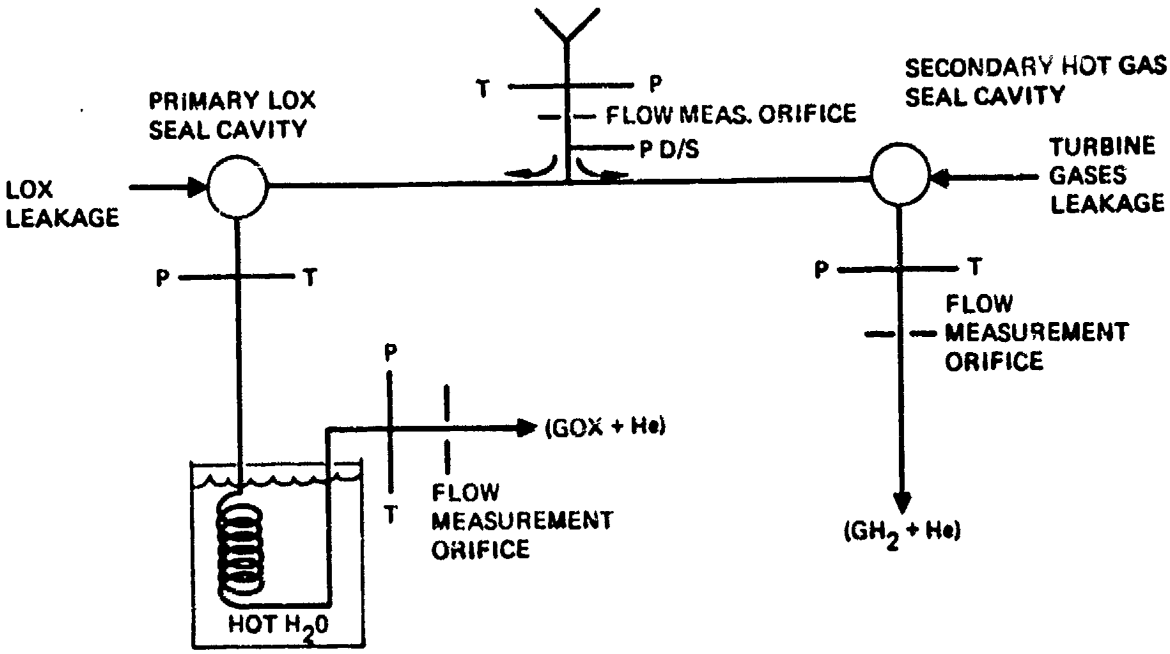

Figure 22. Primary LOX Seal Flow Measurement and Helium Seal Purge System

TABLE 10. MARK 48-0 TURBOPUMP TEST SERIES NO. 4 SUMMARY, TURBOPUMP S/N 02-1

TEST NUMBER	TEST DATE	TEST DURATION SECONDS	ACCUMULATED		REMARKS
			STARTS	DURATION SECONDS	
016-007	10-4-78	48	1	48	PLANNED NPSH TEST AT 7330 RAD/S (70,000 RPM). PROBLEMS WITH TURBINE GH_2 SUPPLY REGULATOR. CUT TEST. BEARING COOLANT TEMPERATURE. HIGH MAXIMUM TEST SPEED 1048 RAD/S (10,000 RPM).
016-008	10-4-78	35	2	83	MAXIMUM TEST SPEED 838 RAD/S (8,000 RPM). TURBINE GH_2 PRESSURE REGULATOR MALFUNCTION.
016-009	10-5-78	56	3	139	SATISFACTORY NPSH TEST TO 7016 RAD/S (67,000 RPM; WITH BALANCE PISTON FLOW OVERBOARD. 5% HEAD DROP ON CAVITATION TEST.
016-010	10-6-78	28	4	167	PLANNED NPSH TEST AT 7330 RAD/S (70,000 RPM) WITH BALANCE PISTON FLOW RECIRCULATED IN PUMP. REACHED SPEED OF 3141 RAD/S (30,000 RPM). CUT OFF FOR INSUFFICIENT BALANCE PISTON RECIRCULATING FLOW.
016-012	10-10-78	7	5	174	PLANNED NPSH TEST AT 7330 RAD/S (70,000 RPM) WITH BALANCE PISTON FLOW RECIRCULATED IN PUMP REACHED SPEED OF 7251 RAD/S (69,240 RPM) - STABILIZED. SUDDEN SHIFT IN PARAMETERS AND 2 SECONDS LATER PUMP DISCHARGE PRESSURE DROPS INITIATING TEST CUT; FIRE ENSUED. DAMAGING PUMP.

The maximum speed achieved was 3142 rad/s (30,000 rpm). After examination of the data, the flow orifice diameter for the balance piston was increased from 0.221 to 0.260 inch and the balance piston recirculation line size was increased from 12.7 to 25.4 mm (0.50 to 1.00 inch) to reduce the line resistance and increase balance piston flow. The primary LOX seal drain orifice size was also reduced after test 016-010 from 22.2 to 12.5 mm (0.875 to 0.500 inch) diameter to improve accuracy of the seal leakage flow measurement.

The next attempt to test was test 016-011 but was cut on startup due to the balance piston recirculation flow temperature indicating insufficient chill in the balance cavity sump area. No speed was achieved.

Test 016-012 was a planned suction performance test at 7261 rad/s (70,000 rpm) with the balance piston flow recirculated to pump inlet. In the test, the pump speed was increased to approximately 3142 rad/s (69,340 rpm) over a period of approximately 7 seconds. At this point the oxidizer pump sustained a failure which included a fire which caused major damage to the pump.

Incident Investigation, Test 012

The turbopump failure and attendant fire instigated an immediate investigation of the incident. The data and hardware from the test was reviewed in a failure mode analysis including the following:

Data Review
Hardware Condition
Hydrodynamic Performance
Balance Piston Analysis
Thermal Analysis
Vibration Analysis
Bearing Condition Evaluation

Data Review. A review of the data from test 016-012 incidated the pump exhibited normal behavior through the 3141 rad/s (30,000 rpm) operation and through the first 5 seconds of high speed operation near 7225 rad/s (69,000 rpm). The speed trace of the data is given in Fig. 23. At that point, a sudden shift occured in most turbopump parameters. Approximately 2 seconds later, pump discharge pressure dropped suddenly initiating a test termination. A review of the major parameters is illustrated in Fig. 24. The figure shows the shift in parameters at approximately 43.3 seconds. The shift indicates a decrease in pump speed combined with an increase in pump discharge pressure, impeller front shroud pressure, and balance piston cavity pressure along with flowrate measured in pump discharge line. The pressures that decreased were the balance piston sump pressure, all pressures in the balance piston return flow loop, with a decrease in flow in the balance piston line. These data indicate increased pressure in the pump zone and decreased pressure in the balance piston sump zone, which is indicative of impeller balance piston movement aft toward the turbine thus closing the low pressure orifice h_2 of Fig. 18 or forward closing the high pressure orifice h_1. The initial drop in balance piston cavity pressure would indicate first movement was forward.

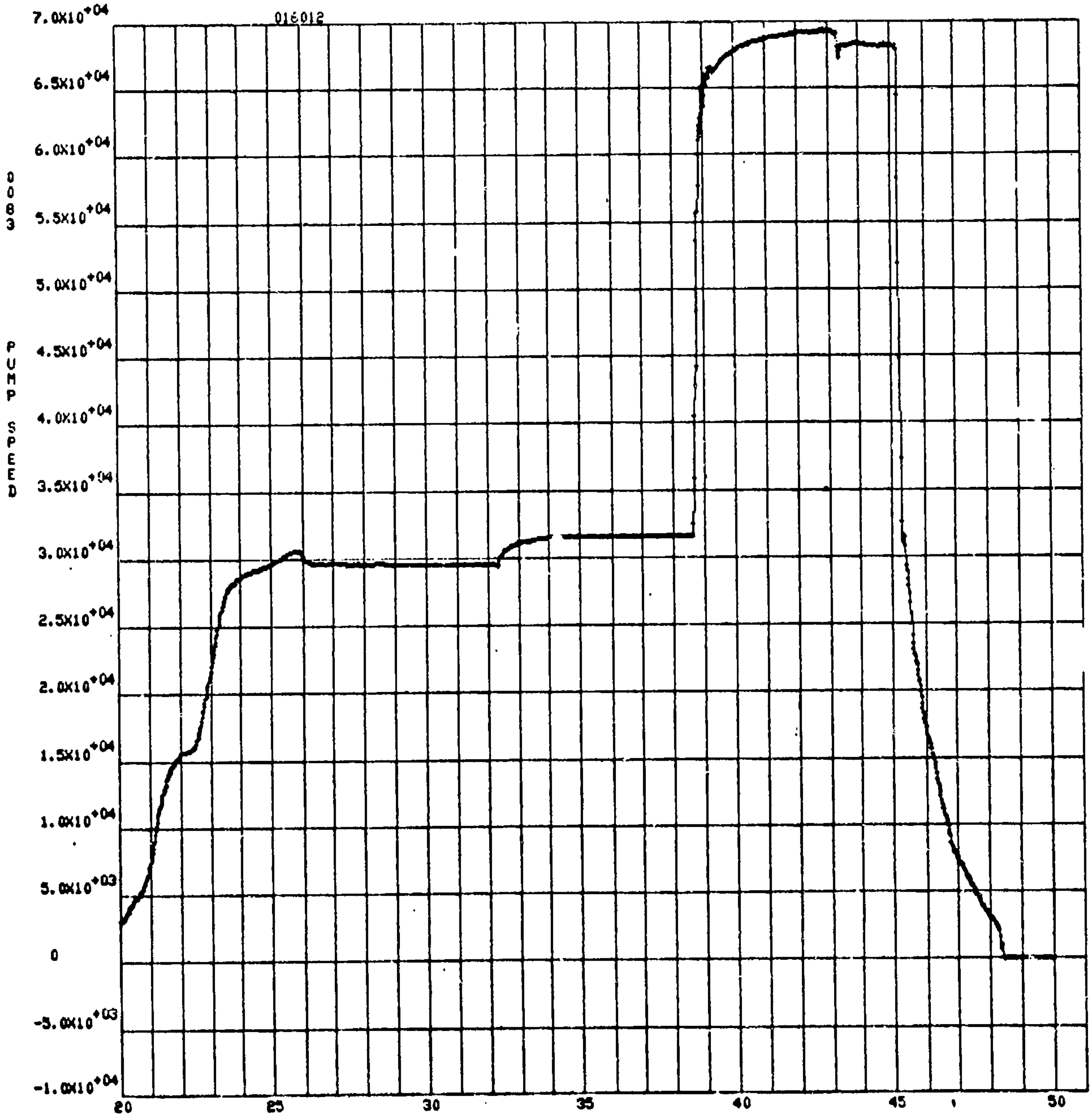

Figure 23. Mark 48-0 Test 012 Speed Trace (S/N 02-1, 1978)

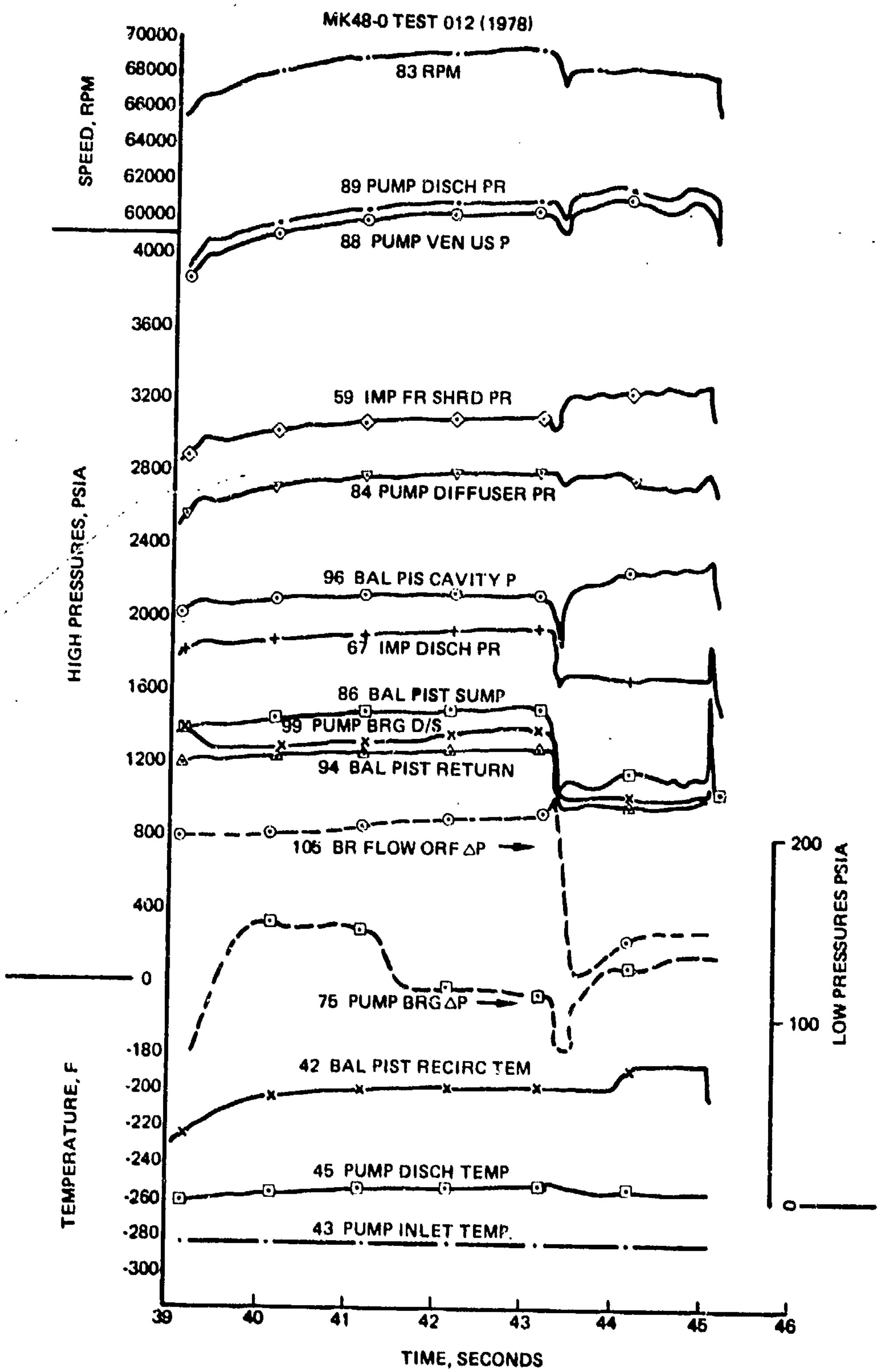

Figure 24. Turbopump Test 012 Data Correlation With Time

Hardware Analysis. The pump hardware was extensively damaged. The burn pattern was mainly limited to forward and included the impeller as shown in Fig. 25. Some minor burning was located in the return cavity but the slinger and primary LOX seal and seal retaining nut were in relatively good condition, indicating they were not the cause. The heaviest burning was concentrated at the inducer, impeller front shroud and impeller tip. Both impeller and inducer were burned to the hubs and large sections of the inlet, diffuser and volute were consumed. A major portion of the damage is shown in Fig. 26. The bearing closest to the impeller was intact but frozen with slag, and the inner race was cracked. The No. 2 bearing had failed with the cage fractured, the balls were creased, and approximately one-quarter of the cage was located in bearing No. 1. No fire was evident in the bearing but the inner race was also cracked. All evidence pointed the fact that the rotor had shifted toward the pump end, including the turbine wheel which had a deep rub on the upstream (pump) side with no rubbing on the downstream side.

Data Analysis. A review of the pump and turbine hydrodynamic performance indicated that the turbine power was constant and normal and the pump head-flow performance was normal. The pump data prior to the shift were compared with the previous test series No. 2 and 3. The head-flow performance is presented in Fig. 27. There is no apparent change in performance indicated. The same is true for the isentropic efficiency given in Fig. 28 when compared with test series No. 3 data. A comparison of the head-flow performance before and after the shift is given in Fig. 29. It indicates there was a change in performance where the flow increased approximately 2% and the head increased 4.5%. This small shift would be caused by the reduction in net recirculation with an attendant decrease in the flow through the impeller, which would also increase the head rise. Thus, the pump performance is seen to be normal throughout the test including after the apparent rotor shift.

Balance Piston Analysis. The analysis of the balance piston performance was done using an analytical model refined by comparing the available measured pressure values to the predicted values. The production of the balance piston force range was then made for three values of sump pressure. This was compared to the summation of axial forces calculated by pressure data on the other component parts of the turbopump rotor assembly. The results are illustrated in Fig. 30. These data indicate that the balance piston operating point required for thrust margin was not centered in the balance piston force range but was marginal. Reduction in sump pressures to 690 N/cm^2 (1000 psi) indicates the margin would be improved but only slightly. The analysis also revealed that the measured recirculation flow was higher than predicted by the model, indicating a larger total gap from high to low pressure orifice or a possible bypass flow around the balance piston. Also, the measured balance piston cavity pressure could not be matched by the analytical program. This indicated that the measurement was either faulty or the pump was operating with a negative high pressure orifice clearance.

Thermal Analysis. The thermal analysis investigation based on the available temperature measurements inducated that the recirculation fluid was always in the liquid state. Furthermore, no increase in energy level of the recirculated fluid was apparent during the apparent rotor shift. These results show also that no heat addition occurred in the bearings indicating that no bearing failure was in progress.

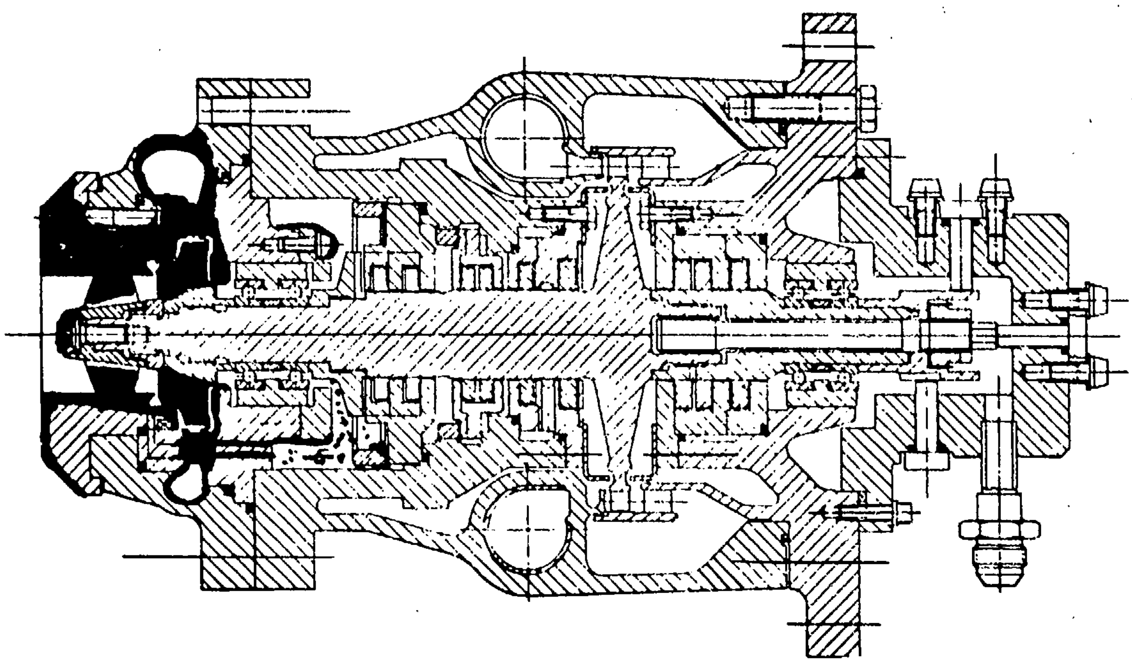

Figure 25. Mark 48-0 Turbopump S/N 02-1 Burn Pattern

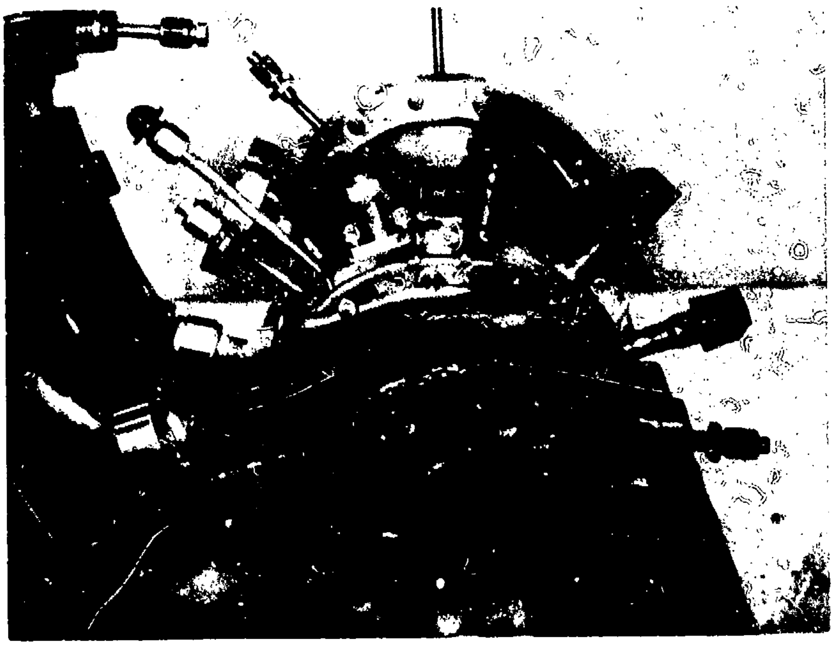

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Figure 26. Pump Hardware Damage

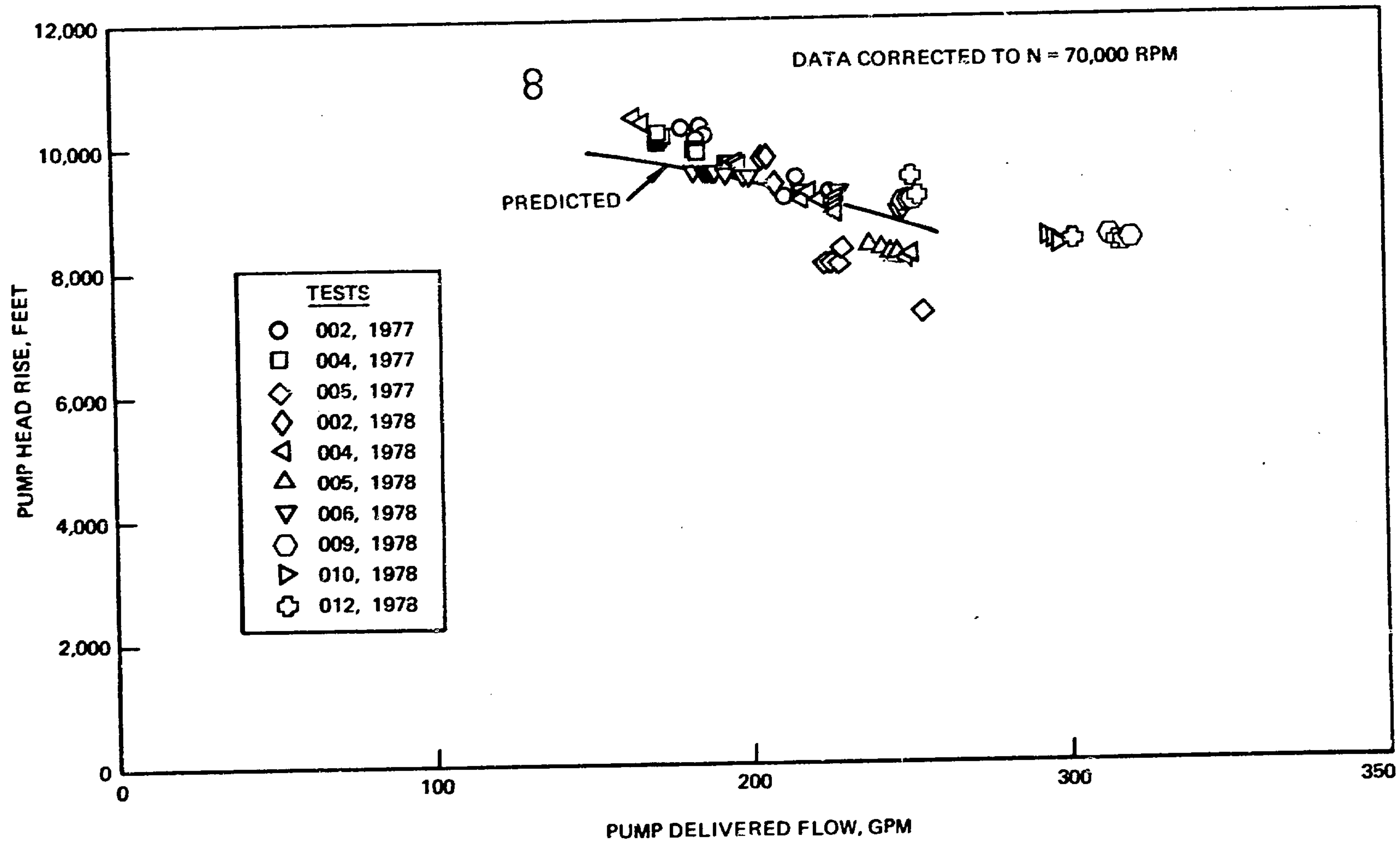

Figure 27. Mark 48-0 Pump Performance, 1977 and 1978 Test Series

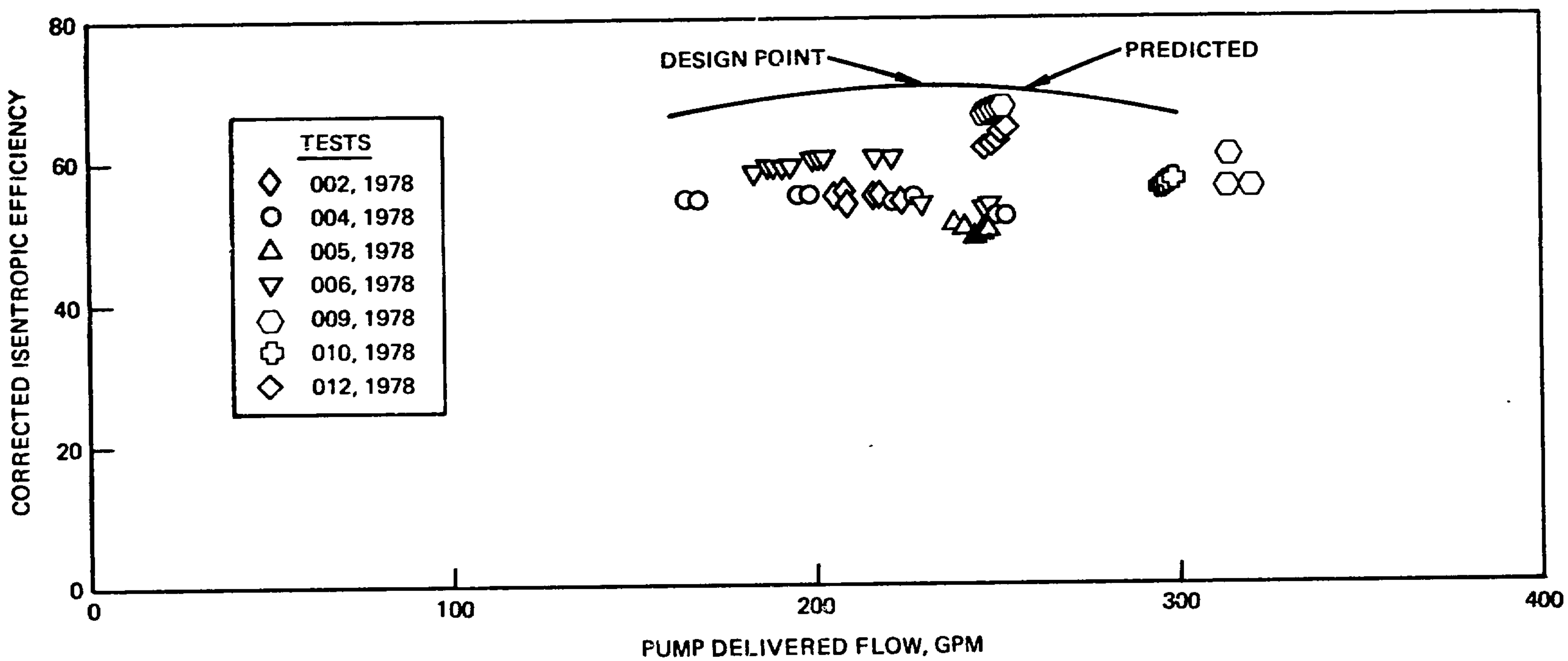

Figure 28. Mark 48-0 Pump Performance, 1977 and 1978 Test Series

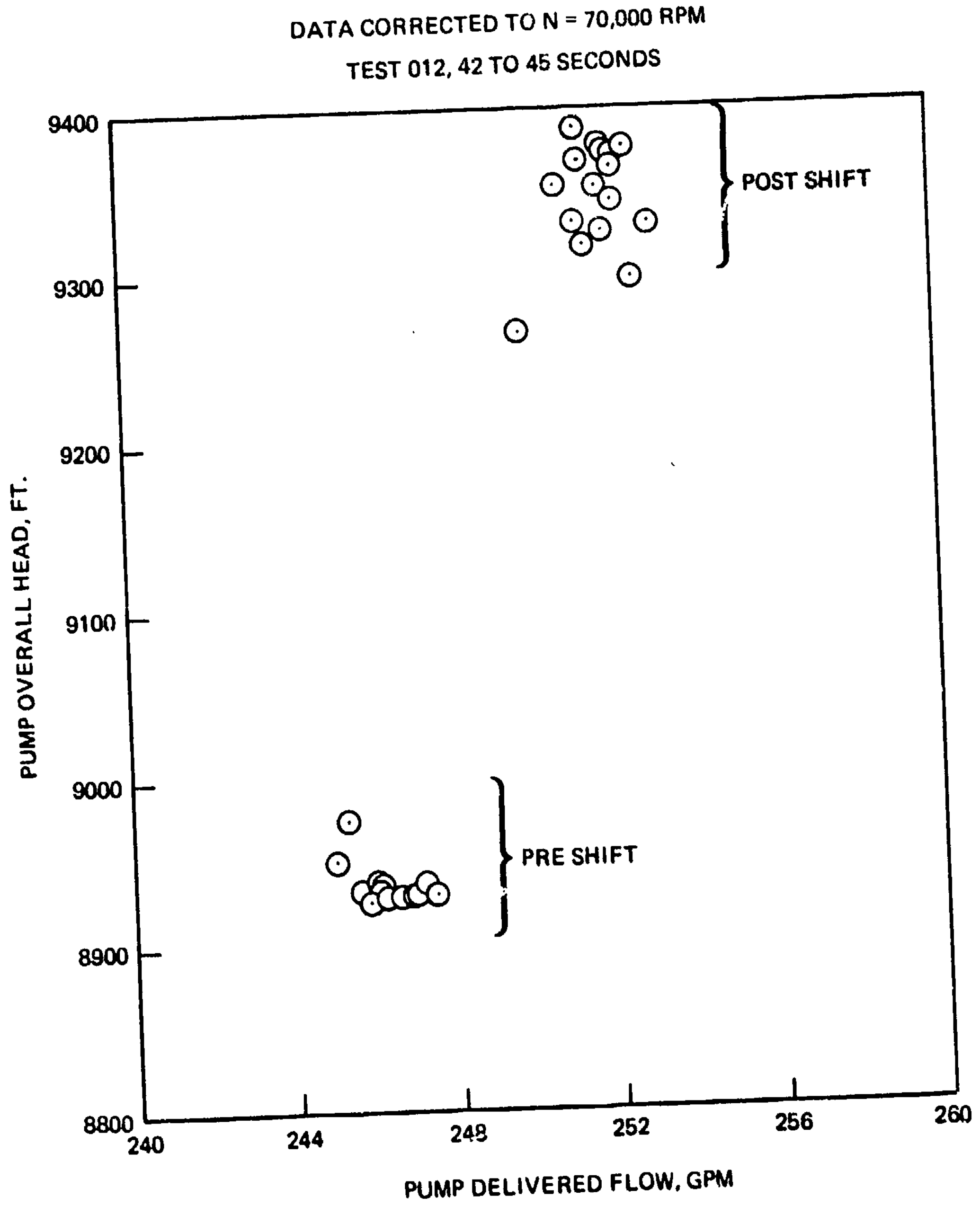

Figure 29. Mark 48-0 Pump Performance, October 1978 Test Series

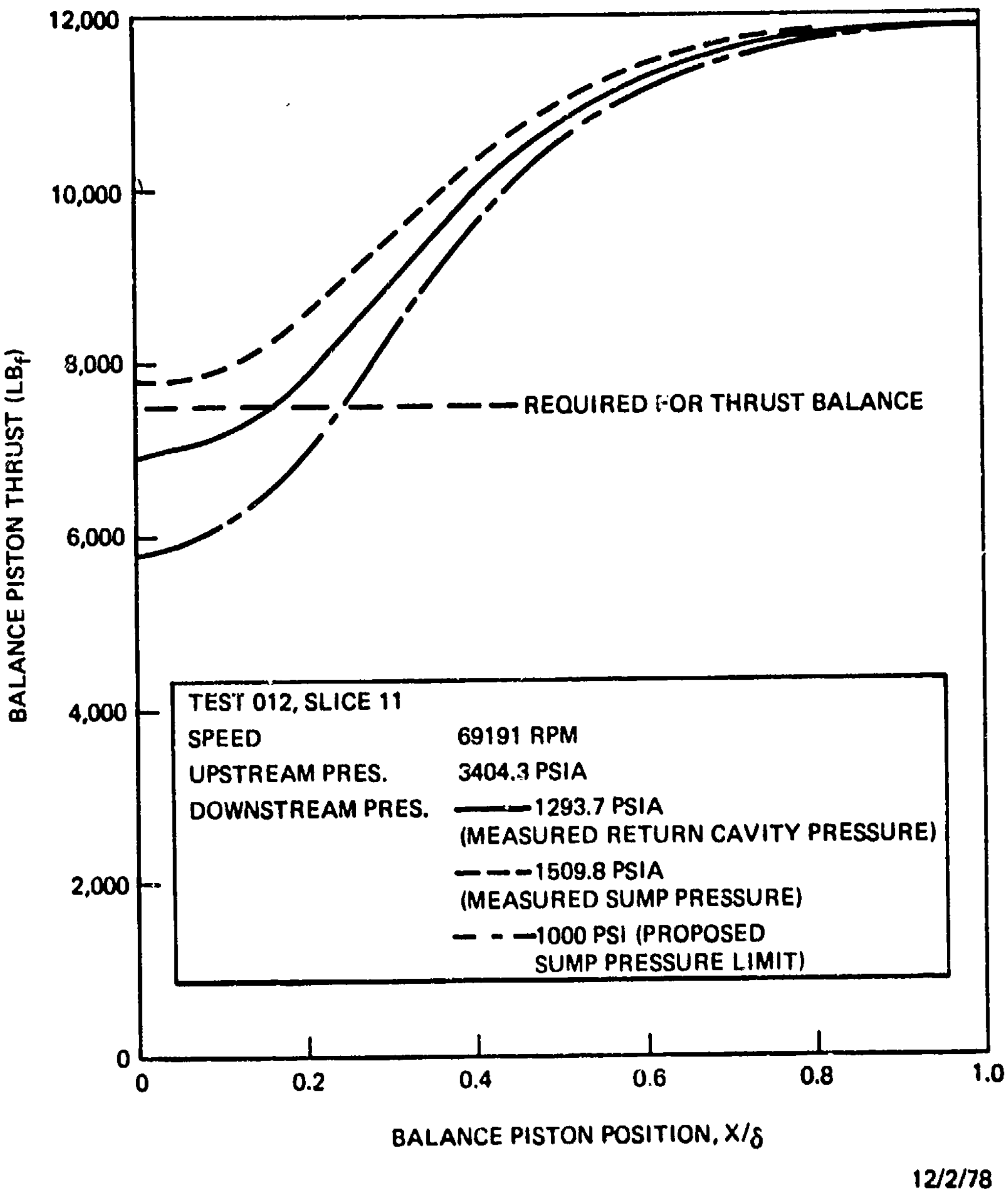

Figure 30. Mark 48-0 Pump Performances, October 1978 Test Series

Vibration Analysis. The vibration analysis indicated the levels of vibration were generally normal for tests 016-009 and 016-012 prior to the shift. The accelerometers recorded vibration levels of 1.7 to 3.7 g rms for test 009 and 012 before the shift. At the shift the maximum levels ran to 5 g rms. After the shift th data show 1.2 to 1.6 g rms. There was no subsynchronous whirl activity evident but some supersynchronous activity at 1800 Hz (1.55 times synchronous) occurred. This is a possible indication of rubbing within the turbopump. A summary of the accelerometer data is given in Fig. 31.

Bearing Analysis. Analysis of the pump and bearings condition indicated that the bearing No. 1 damage occurred just as rotation stopped. Bearing No. 2 operated normally until the balls stopped in the outer race by the slag produced by the fire. Bearing No. 1 was intact and showed no axial loads with cage loads that were excessive. Bearing No. 2 indicated an axial load in the order of 1557 N (350 lb) with no large radial loads. It was estimated that bearing life with the apparent loads would be 1.5 hours.

Conclusions and Corrective Action. Many failure modes were formulated and, in the process of investigation, were disqualified by the analysis of the data available. The most probable failure mode was inadequate axial thrust load control by the balance piston. This lead to failure of the No. 2 bearing under axial load with axial and radial rubbing of the high pressure orifice at the impeller tip and rubbing of the impeller front wear ring initiating heat and fire. It is also possible that the high pressure orifice rubbing occurred first, with subsequent blockage by debris of the low pressure rub ring, allowing the balance piston cavity pressure to go up while sump pressure was going down. Also advanced was the possibility that the pins in the internal recirculation path that were used to block the flow might have been injected into the impeller, or that a foreign object from the recirculation system caused debris, plugging the orifices and initiating failure. It became apparent from the detailed failure analysis that several modifications to the turbopump could reduce the risk of turbopump failure.

It was concluded that several design modifications were mandatory to avoid a recurrence of test 012 failure and to improve the general design of the pump. These design modifications included

1. Eliminate recirculation passages through diffuser vanes and eliminate any possibility of blockage pins entering into the pump inadvertantly
2. Increase the balance piston control margin by reduction in sump pressure. This could be done by separation of balance piston return flow and bearing coolant flow lines. This would facilitate a higher weight flow potential through the balance piston and reduce the bearing axial loads due to the high pressure drop and flow through the bearings.
3. Improve the centering of the balance piston position on the range of balance piston force. This could be done by changing the net axial force of the rest of the turbopump rotor assembly including the higher than predicted turbine wheel axial thrust.
4. Improve the accuracy of balance piston pressure measurements such that no pressure measurement transfer lines pass through flange interfaces. This also eliminates any possible leak paths in the balance piston system.

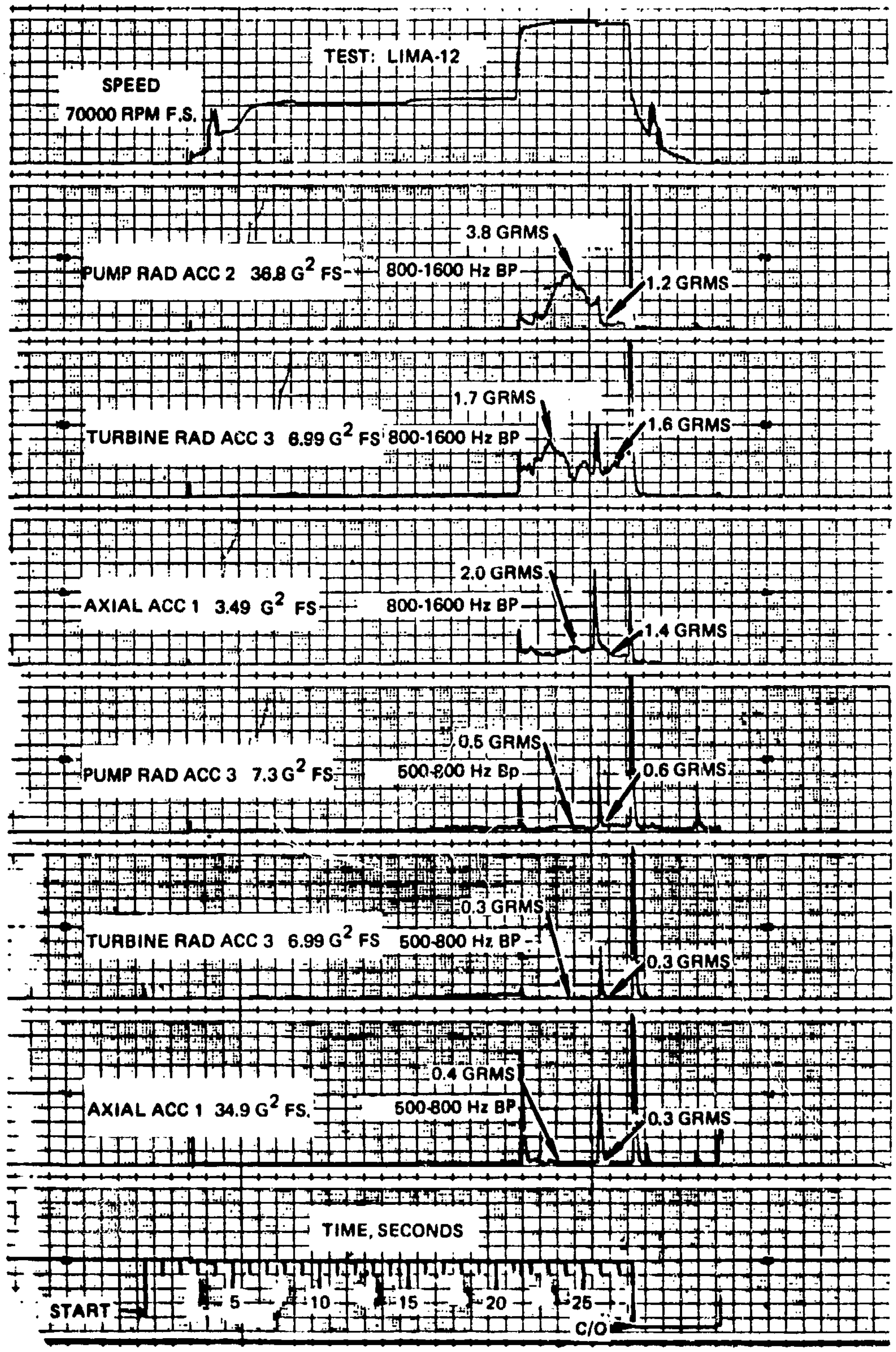

Figure 31. Summary of Accelerometer Data

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Other design changes were recommended to avoid problems not associated with the pump S/N 02-1 failure. These were the possible use of solid silver or Kel-F inducer tunnel and impeller wear rings and solid silver balance piston low and high pressure balance piston orifices. Recommendations were also given to consider the use of a bearing coolant source independent of the balance piston flow recirculation system.

Pump Hydrodynamic Performance

The pump hydrodynamic performance of test series No. 4 has been presented in part in the previous incident investigation section. Figure 27 and 28 give the head-flow performance and isentropic efficiency data. These data indicate the pump head-flow and efficiency are essentially the same as for previous tests. The isentropic efficiency for this build shows a slightly higher value than that of the series No. 3 test data. The results of pump suction performance test 009 were analyzed and are illustrated in Fig. 32. These results indicate a suction specific speed of 84210 $\{(rad/s)\ (m^3/sec)^{1/2}/(J/Kg)^{3/4}\}$ [24,000 (rpm) $(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$] with no indication of cavitation at inlet flow coefficient0.0883. This verified that the design improvements made for the pump are proper. Analysis indicated that the suction performance might be demonstrated up to a suction specific speed of 112280 $\{(rad/s)\ (m^3/sec)^{1/2}/(J/Kg)^{3/4}\}$ [32,000 (rpm) $(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$].

Seal Leakage. During the test series, special provisions were made to measure the leakage rate of the floating ring LOX primary seal to provide a basis of comparison with the performance of the hydrodynamic lift-off seal. Since the fluid emanating from the drain cavity is mixed phase, a heat exchanger was included in the drain line to convert it to gas before measurement. Flow was then established by recording the pressure drop across a sharp edge orifice. A minor complication was presented by the fact that part of the helium purge gas from the intermediate seal leaks into the primary LOX seal drain cavity; however, the amount of total purge flow into the intermediate seal was monitored, and its magnitude was so low (0.007 lb/sec) that its effect can, for all practical purposes, be neglected.

In order to improve the precision of the LOX primary seal leakage flowrate data for test 011 and 012, the flow measuring orifice was resized from 22.2 mm (0.875 inch) to 12.7 mm (0.500 inch) diameter. This increased the pressure at the flow measuring orifice inlet from approximately 5171 N/M^3 (0.75 psig) to 172369 N/M^3 (25 psig) and resulted in a more precise flow measurement. The primary LOX seal leakage measured was low and averaged 0.073 Kg/s (0.160 lb/s) at 3246 rad/s (31,000 rpm) and 0.078 Kg/s (0.172 lb/s) at 7226 rad/s (69,000 rpm). The data of test 012 is considered to be most accurate because of the orifice change. The flowrates recorded are presented in Fig. 33 as a function of the pressure levels recorded in the cavity upstream of the seal. The correlation between seal leakage and shaft rotational speed is indicated in Fig. 34.

Mechanical Performance

The mechanical performance of the turbopump during test series No. 4 could not be fully evaluated because of the damage created by the fire. The examination of the turbine end of the turbopump indicated the No. 3 and 4 turbine bearings were in

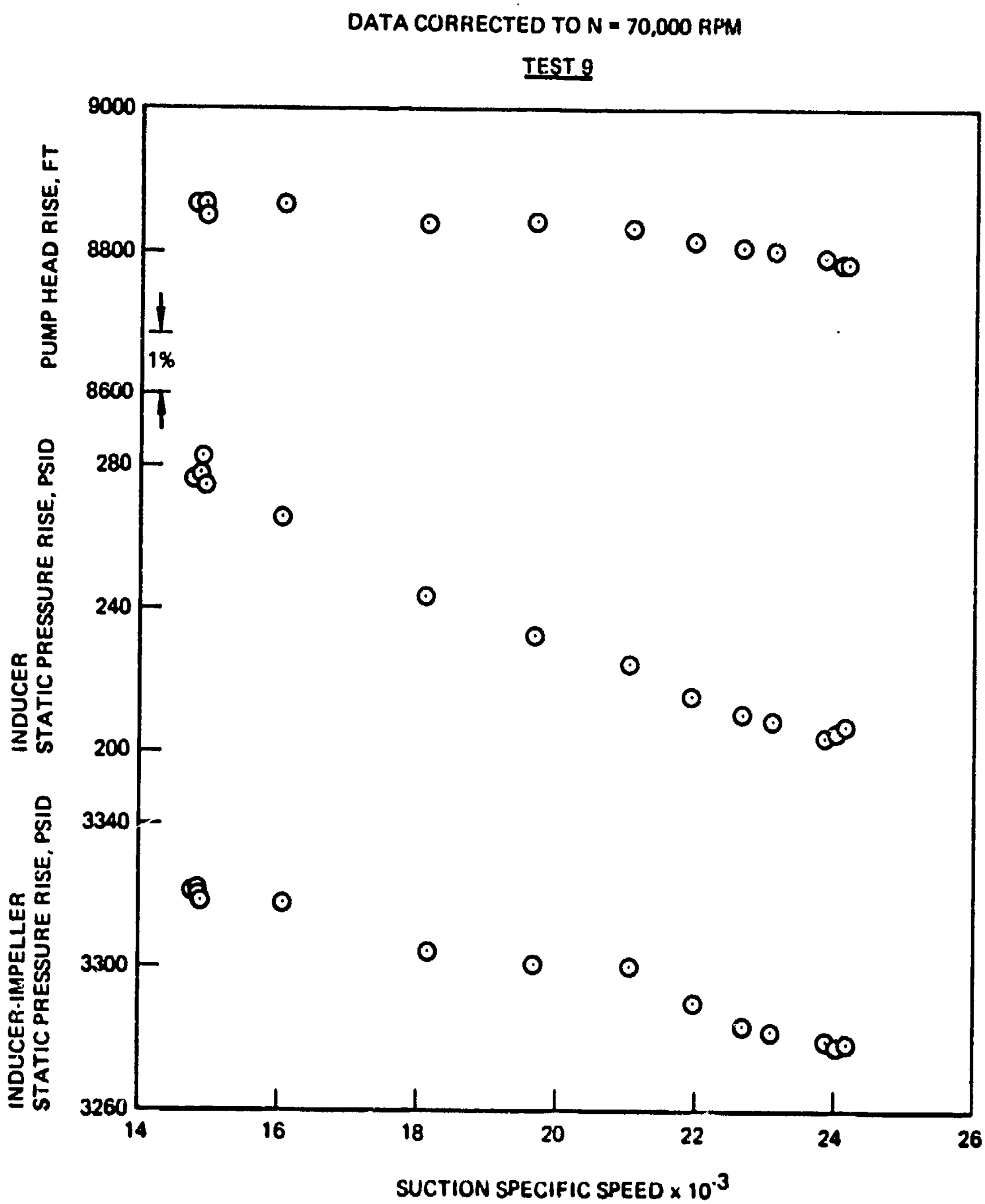


Figure 32. Mark 48-0 Pump Performance, October 1978 Test Series

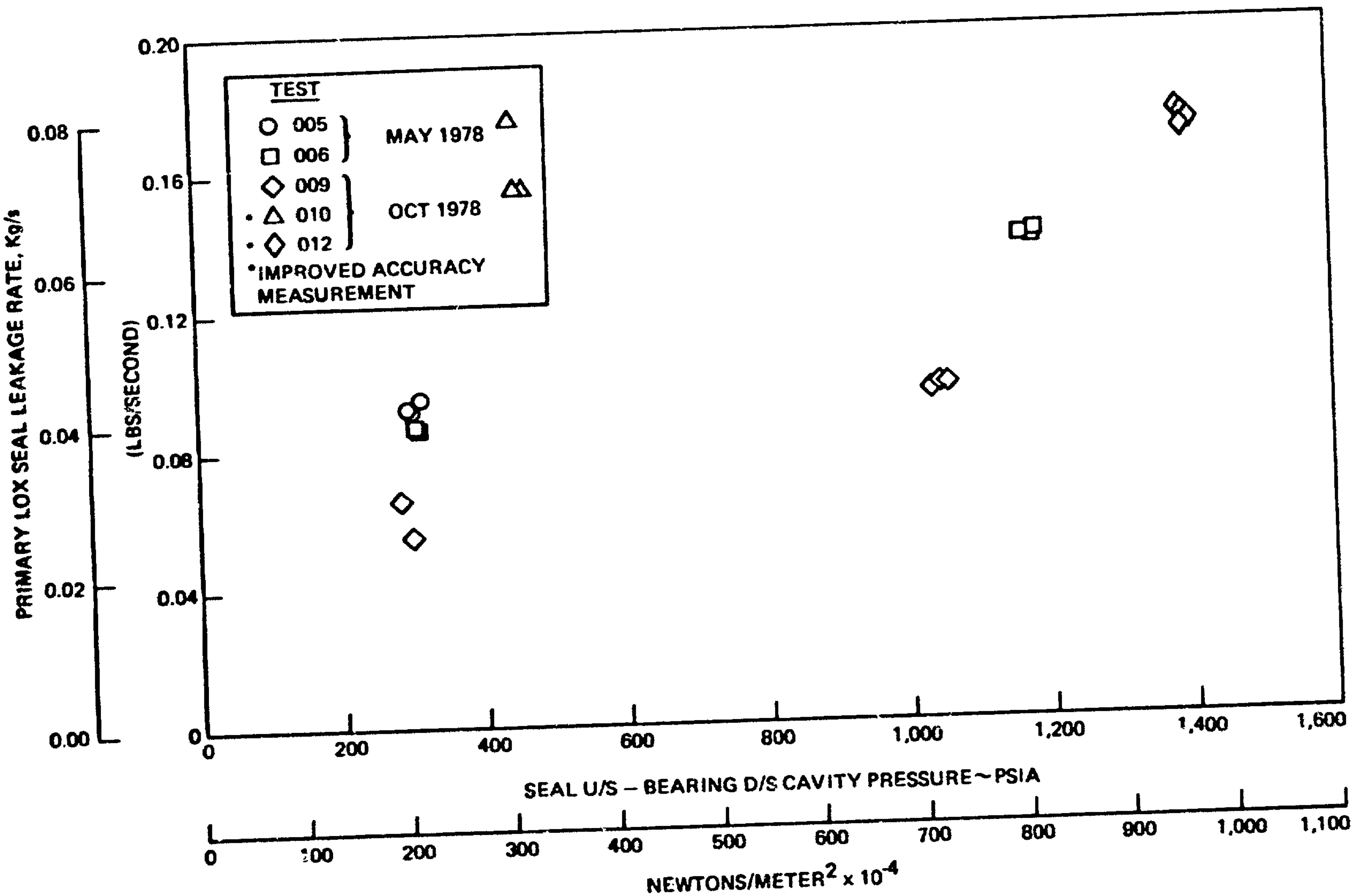


Figure 33. Mark 48-0 Turbopump Primary LOX Seal Leakage (1978 test series 3 and 4)

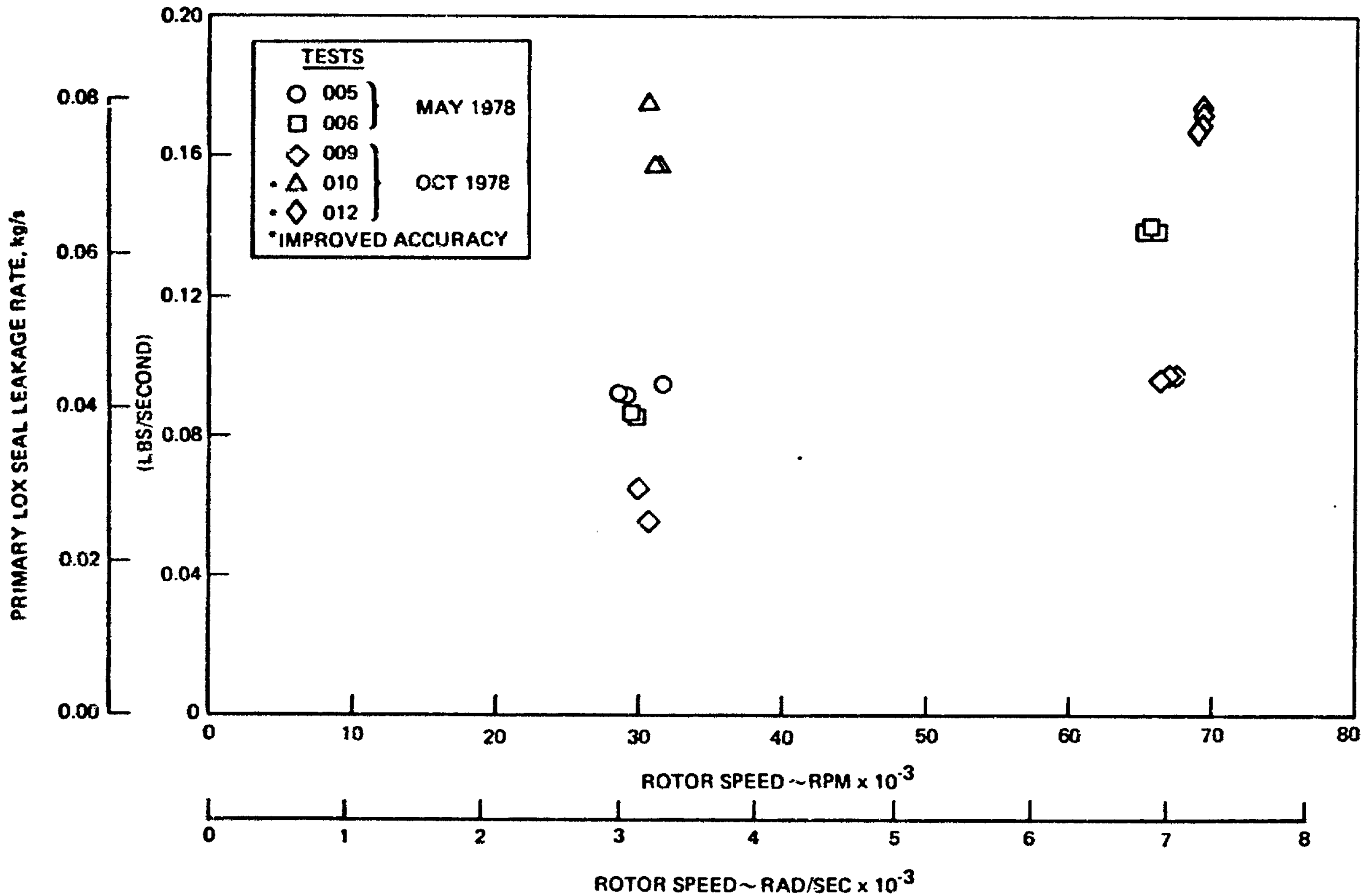


Figure 34. Mark 48-O Turbopump Primary LOX Seal Leakage (1978 test series 3 and 4)

good condition. These bearings are designed to take radial loads only and no evidence of high radial loads existed. The No. 2 bearing on the pump end is the only bearing showing failure possibility from axial load. The turbine wheel was shifted toward the pump end and deep rub had occurred on the wheel from contact with the upstream side shield. The inducer drive key on the shaft was sheared off and the inducer hub had rotated 1.57 radians (90 degrees) around the original shaft position. The aft portion (turbine end) of the turbopump was not affected by the pump failure. The turbine housing was slightly damaged at the pump volute matching face. The return cavity contained slag which came from the diffuser axial holes originally used for balance piston recirculation. The seals, with the exception of the primary LOX seal which was slightly scorched, showed no evidence of damage. The chrome plating on the shaft under the seals was in good condition. The primary LOX seal nut was tightly in place and the slinger showed slight rubbing on the pump side but none on the seal side. The aft bearing support assembly which includes the aft stub shaft, outboard seal, instrumentation sleeve, rear bearing cap and the shaft stud was clean and in good condition. In summary, all hardware aft of the primary LOX seal was in good condition. The rotor and all hardware in front of the seal was damaged beyond repair.

TURBOPUMP DESIGN CHANGES AND PROCUREMENT

Operation of the turbopump within the LOX seal Demonstration Test Program revealed a problem in maintaining satisfactory rotor axial thrust control when the test series of October 1978 ended in a pump fire with damage to most of the pump hardware. The data analysis disclosed that the cause of the failure was excessive residual thrust toward the pump inlet, which eventually overloaded the No. 2 bearing and caused internal metal-to-metal rubbing and subsequent fire.

The large residual thrust was attributable to two factors. In the original configuration in which all of the balance piston fluid passed through the pump end bearing package, the sump pressure and consequently the operating range of the piston was constrained by the maximum flowrate which the bearings could accommodate before they would be distressed by high pressure differentials. Furthermore, pressure measurements indicated that the turbine wheel was subject to an axial thrust component which theoretical approaches do not readily predict, and which therefore was not included in the original axial thrust summation.

Accordingly, a MK 48 Oxidizer Turbopump Follow-on Work Plan (RI/RD79-115) was developed and presented to NASA-LeRC for review, evaluation and acceptance. The plan incorporated modifications to the turbopump which provided sufficient rotor axial thrust control capability and would allow safe completion of the demonstration tests with a spiral groove type lift-off primary LOX seal.

In the extension of the program, corrective design modifications were introduced to enlarge the range of the balance piston and reduce the turbine wheel thrust component. A new set of hardware was fabricated which replaced that damaged in the fire and which reflected an improved configuration for test evaluation and better performance.

Design Changes

Analysis of the pump modification requirements covered many possible configuration changes which were aimed at correcting the axial thrust balance and improving the measurement of the necessary parameters within the pump. It was also desirable to separate the pump bearing flow path out of the balance piston flow path. This design change was also required to reduce the pressure downstream of the bearings in order to incorporate the spiral groove lift-off seal into the turbopump. The finalized design is represented in Drawing 9R0012300, Appendix A. Subsequent to the turbopump testing, a decision was made to test without the use of the spiral groove lift-off seal. This decision was based on technical problems encountered in spiral groove lift-off seal testing on other technology programs. As a result, the spiral groove lift-off seal was replaced with the previously designed and tested floating ring, fixed gap seal and slinger. The design of the labyrinth seal between the bearings and the seal cavity was maintained by incorporating the labyrinth rings on the slinger hub. This design change was incorporated onto Drawing 9R0014079, Appendix A. Figure 35 presents a composite of the design with the upper half showing the lift-off seal and the lower half showing the original seal. The design incorporated an external flange for the diffuser which was used to provide a separate drain for the balance piston independent of the bearing flow.

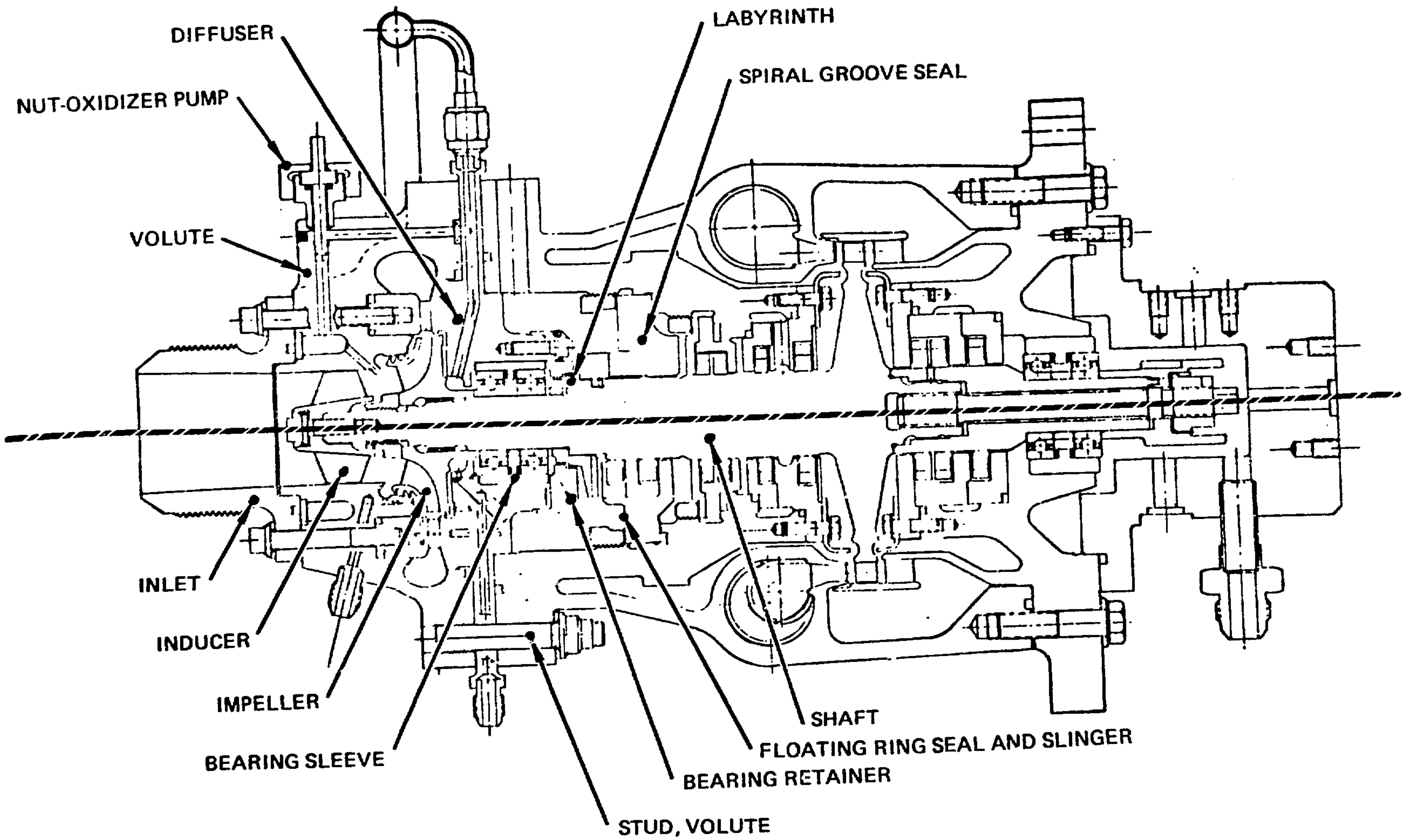


Figure 35. Mark 48-0 Turbopump

This consisted of six radial holes equally spaced around the flange and connecting internal lines around the pump scroll to transport the balance piston flow back to the impeller inlet. These holes could be blocked by pins to allow flow to be dumped overboard or the external line could be sealed and the pins removed for internal flow recirculation.

In the design, the emphasis was placed on improving the quantity and quality of instrumentation measurements. Communication across interfaces closed out with doughnut seals was eliminated where possible with only one critical measurement out of nine now requiring a seal. That measurement is the downstream bearing pressure. Table 11 lists the nine critical parameters. Items 1 and 2 are taken out through the pump volute, items 3 through 8 are taken out of the new diffuser flange between balance piston flow lines, and 9 is from an existing measurement. This instrumentation fully maps the paths for:

1. Impeller front shroud flow
2. Balance piston flow
3. Pump end bearing flow

TABLE 11. CRITICAL PUMP END HYDRODYNAMIC MEASUREMENTS

1.	BALANCE PISTON RETURN FLOW TO IMPELLER INLET PRESSURE
2.	IMPELLER LABYRINTH SHROUD U/S PRESSURE
3.	IMPELLER DISCHARGE PRESSURE
4.	BALANCE PISTON HIGH PRESSURE ORIFICE D/S PRESSURE
5.	BALANCE PISTON LOW PRESSURE ORIFICE U/S PRESSURE
6.	BALANCE PISTON LOW PRESSURE ORIFICE D/S PRESSURE (SUMP PRESSURE)
7.	PUMP END BEARING SET U/S PRESSURE
8.	PUMP END BEARING SET D/S PRESSURE (SHAFT SEAL LABYRINTH U/S PRESSURE)
9.	SHAFT SEAL LABYRINTH D/S PRESSURE

Methods to reduce the axial thrust component on the turbine wheel were analyzed. The previous test data contained static pressure measurements from the upstream and downstream sides of the turbine wheel. These data indicated a turbine axial thrust component toward the pump. The analyses concluded it was more predictable to compensate for the turbine component axial thrust than to modify the turbine to reduce it. This was done by decreasing the labyrinth diameter on the impeller front shroud and an increase in balance piston force range was also contemplated by reducing the balance piston sump pressures.

Hardware Procurement

The design changes, coupled with the damaged hardware, required a large number of component parts to be fabricated. A list of the major parts required to be fabricated is given in Table 12, along with the vendor sources. Approximately 24 other small component parts were required such as special nuts, locks and seals. Parts were procured in most part from outside supplier sources in a standard procurement practice. Minor rework of the turbine housing was required to correct minor damage. The flange face was damaged and had to be resurfaced by machining.

TABLE 12. MAJOR COMPONENT PARTS PROCUREMENT

NAME	PART NUMBER	VENDOR
SHAFT FORGING	7R0012029	ARCTURUS
SHAFT	RS009646E	CONTURA
INDUCER	RS009650E	CONTURA
SPIRAL GROOVE SEAL	R0011532X	CRANE
DIFFUSER	9R0012281	CONTURA
VOLUTE CASTING	9R0012282	MILLER CASTING
VOLUTE MACHINING	9R0012282	TRI MODELS
STUD, VOLUTE	9R0012283	TRI MODELS
BEARING SLEEVE	9R0012285	FINN TOOL
BEARING RETAINER	9R0012286	FINN TOOL
BEARING SPRING	9R009612E	ASSOCIATED SPRING
IMPELLER	9R0012287	CONTURA
LABYRINTH	9R0012288	TRI MODELS
LABYRINTH SLINGER	9R0012289	ROCKETDYNE
INLET	9R0012290	TRI MODELS
NUT, OXIDIZER PUMP	9R0012298	FINN TOOLS

Fabrication Problems

Procurement of the various component parts from various vendors went smoothly with the exception of several items. A large number of schedule delays were encountered with the diffusers and impellers. An error in the process planning of the diffuser caused the parts to be finish machined to the high tolerance requirements specified prior to the required heat treatment. This resulted in part shrinkage at the critical diameters and warpage of the flange surfaces. Due to delays in supplier capability to correct the condition, the parts were reworked under Rocketdyne engineering direction at another outside source. This rework consisted of chrome plating the undersize diameters and regrinding to the dimensions required. The flange faces were reground to a high tolerance finish. Discrepancies in the tooling used in electrical discharge machining (EDM) of the impellers resulted in scrapping the first impellers fabricated. The second set were also found to have dimensional discrepancies when they were received. The major problems encountered in the impeller machining was the extremely small passages required to be machined. Previous procurement of these parts was also a problem in the first builds of the turbopump. The impellers were made successfully but with some difficulties and scrapping of the first parts attempted occurred on the first procurement also. This indicates that the present impeller design is pushing the state of the art in fabrication. Investment castings or some other high tolerance method of fabrication should be considered on any subsequent procurements.

Inspection and Hardware Proof Testing

As the parts were received they were inspected dimensionally and approved for use. The volute required a high pressure structural proof test as did the instrumentation line welds on the diffuser. As a result, the volute and diffuser were combined with a pressure test fixture and proof tested to pressure levels of 3958 ±79 N/cm^2 (5740 ±115 psi) in the high pressure zone of impeller discharge to volute discharge and in the inlet low pressure zone in front of the impeller front wear ring of 534 ±11 N/cm^2 (775 ±16 psi). The parts were cycled five times with no leakage or structural failures.

Molds were taken of the impeller passages to determine how smoothly the passages blended. The dimensional inspection revealed that the front shroud thickness requirements were not met. The drawing required a constant shroud thickness of 1.524 mm (0.060 inch). The minimum thickness distribution of the shroud was measured in each impeller passage. The shroud thickness was very consistent between passages. The minimum thickness found was 0.229 mm (0.009 inch) and was located in the pressure side passage of the partial blade adjacent to the partial leading edge. The passage located on the pressure side of the full blade indicated a minimum shroud thickness of 0.889 mm (0.035 inch). The shroud minimum thickness distribution for the two respective passages is compared to the print dimensions in Fig. 36 and 37. The blade thickness distribution developed in the analysis of inspection data indicated the minimum full blade thickness was averaging approximately 85% of the nominal print thickness from the leading edge back to approximately 35 degrees from the trailing edge. The areas near the trailing edge was indicated as being above nominal thickness. It should be noted that the fillet radius requirements for the blade are 1.524 mm (0.060 inch) all over.

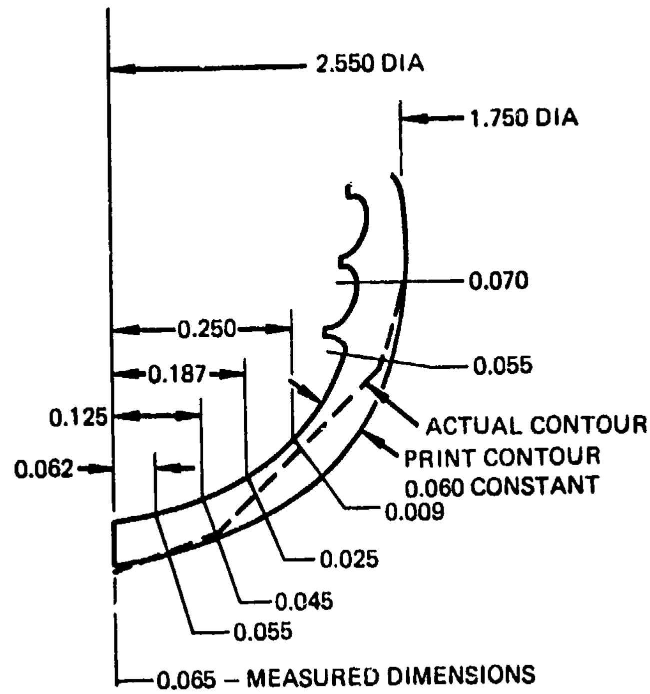


Figure 36. Partial Blade Pressure-Side Passage

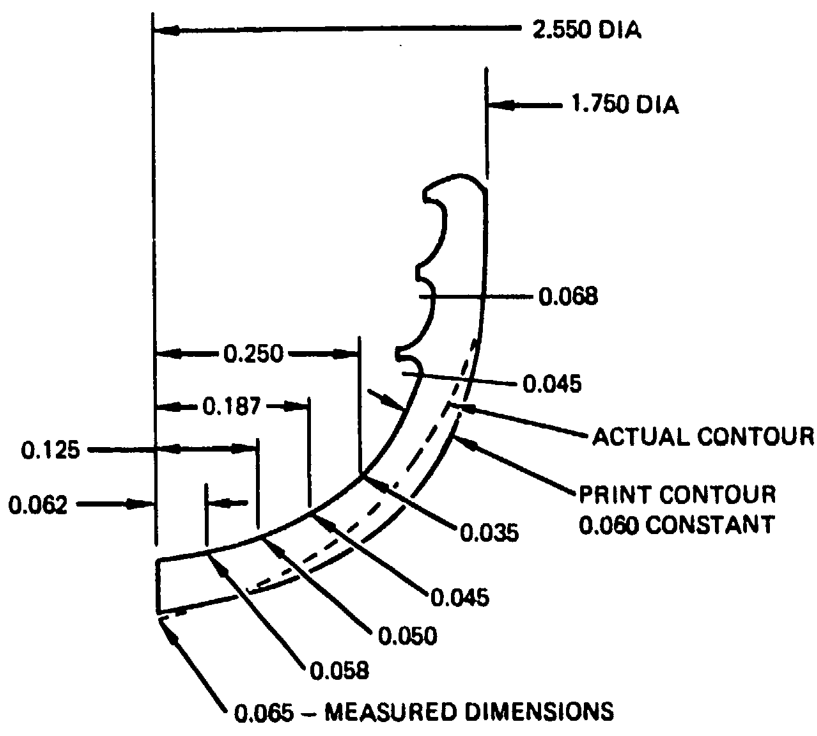


Figure 37. Full Blade Pressure-Side Passage

This causes the fillet radius to cover all but 0.762 mm (0.030 inch) (20%) of the blade at the impeller discharge and approximately 70% of the blade at the leading edge. This adds considerably to the impeller blade shroud strength.

A stress analysis was performed to determine the acceptability of the parts. The analysis indicated that it was feasible to spin test the impellers as a way of proof testing their structural acceptability. Analytical evaluation would be difficult and time-consuming and required very detailed geometry input, which is not easily obtained in the smaller impeller passages. It was determined analytically that the stresses in the shroud and blade due to the centrifugal loading were large compared to the blade pressure loading stresses. It was, therefore, considered feasible to nearly duplicate operation of the impeller in the turbopump by using a high speed spin test to proof the shroud and blades as to their acceptability. The stress analysis summary is presented in Fig. 38.

An arbor for spin test of the impellers was designed and fabricated. The impeller-arbor assembly was balanced and successfully spin-tested to a proof speed of 8210 rad/s (78,000 ±300 rpm). This proof-test speed was determined by accounting for the strength ratio of the impeller material between turbopump testing in liquid oxygen and proof testing in the ambient vacuum test facility. Posttest penetrant inspection revealed no cracks or damage from the proof test.

Rotor S/N 1 failed a proof spin test in the Rocketdyne spin test facility. Dimensional inspection of the rotor and shaft had indicated the parts were acceptable. Proof spin testing of the rotor was required to a speed of 9362 rad/s (89,400 rpm) in order to qualify it for operation at design point conditions on the turbopump. The test was conducted on shaft S/N 1 in the spin pit. The test fixture shown in Fig. 39 spins the shaft by hanging it on a small spindle in a free spin mode. Any appreciable loads developed would generally act on the spindle failing it, and the rotor would drop onto a nylon bushing to protect it from damange. The rotor balance was accomplished by attaching a balancing arbor on each end of the part and balancing the assembly. When the rotor reached a speed of 8021 rad/s (76,600 rpm), the small end of the shaft failed between the spline section and the threaded section as shown in Fig. 39. The failure launched an investigation into the cause of the failure and the possible loads involved.

The investigation determined the fracture to be intergranular caused by tension or bending. Further material analyses indicated an excessive grain size. The repeatability of the intergranular fracture (unusual for this material) and the large grain size was found by test of a small prolongation of the failed shaft left from the machining. The second shaft (S/N 2) prolongation showed transgranular fracture (normal fracture mode) and smaller grain size. All material still exhibited a high ultimate strength of 141,348 N/cm^2 (205,000 psi), a yield strength of 105,500 N/cm^2 (153,000 psi) and an elongation of 20.5%. It was concluded that rotor shaft S/N 2 properties were acceptable for use if the fatigue limit could be reduced by 20% and the number of cycles by one order of magnitude. Also, the static strength of the turbine end only should be reduced by 10% due to the high local grain size found.

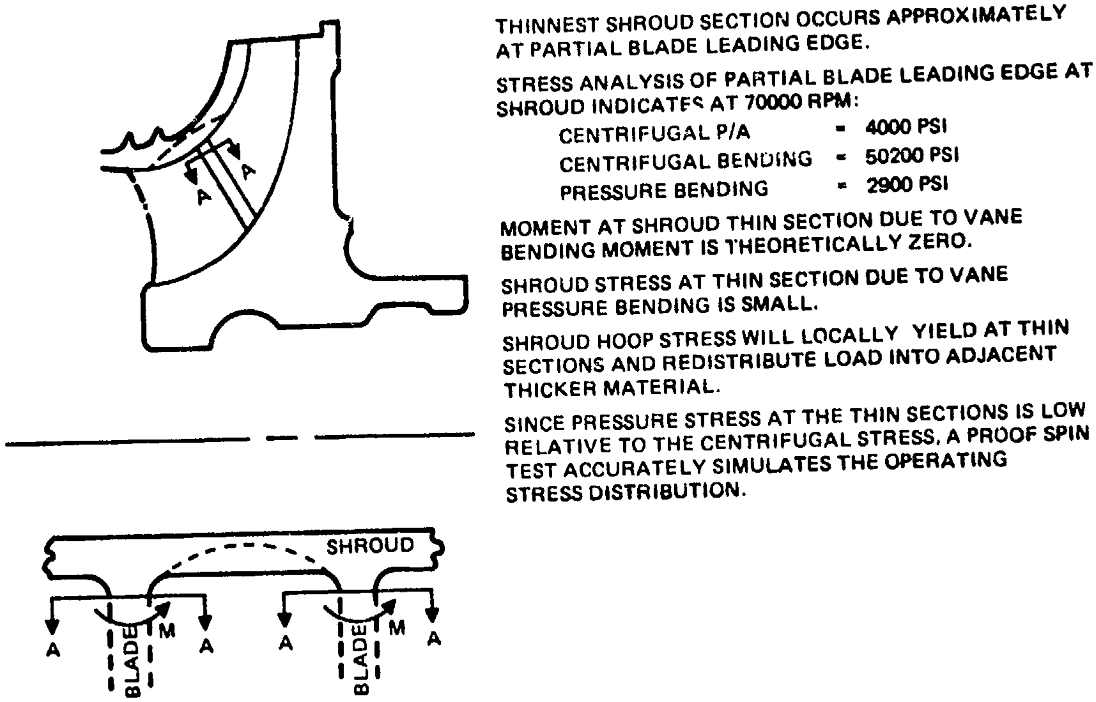


Figure 38. Impeller Blade Stress Analysis Summary

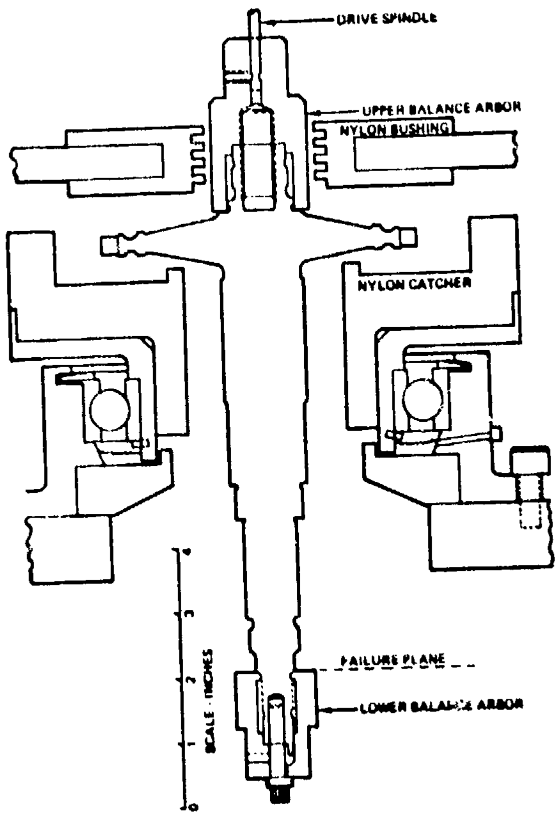


Figure 39. Mark 48-0 Shaft Spin Test Setup

The dynamic analysis of the shaft consisted of developing a dynamic model for determination of the critical speed characteristics and bending modes of the shaft with balance arbors attached. Further development of a dynamic response model was made to assess the possible loading caused by dynamic imbalance in a critical speed bending mode shape. The analysis resulted in the critical speed occurring at speeds which coincide with the speed at shaft failure. The range of critical speeds of 7540 to 8378 rad/s (72,000 to 80,000 rpm) was found by using three different cases of spin arbor attachments. The speed at which failure occurred was 76,600 rpm. The typical mode shape of shaft at the critical speed was determined but the bending stress developed for the shaft bending mode shape was found not to be sufficient to cause failure. Development of the response model allowed calculation of the effect of the weights used to balance the shaft and which are redistributed about the center of rotation by the critical speed bending mode. The analysis was taken over the full critical speed range with the balance weights located both angularly and radially as they were on the shaft spin test. The analysis was made for several joints or segments of the shaft. The data show the loads at locations near the failure plane are high at 7540 rad/s (72,000 rpm) and much reduced at 8378 rad/s (80,000 rpm). Similar results are seen at several other locations at those speeds. Conversion of the moment loads to stresses within the part indicate the maximum stress levels occur at the location of the failure. The results clearly showed the highest stresses occurred at the failure plane and that more than adequate stress levels had been reached to cause a bending failure mode.

This data quite conclusively showed the failure mode. The next effort planned was to design an arbor to place on the small end of the shaft which would stiffen the shaft and drive the critical speeds to well above the 9362 rad/s (89,400 rpm) proof test speed. The arbor was designed to put tension in the small end of the shaft by loading it with the impeller nut. This added stiffness drove the calculated critical speed up to 12,043 rad/s (115,000 rpm) which is well above the proof test speed required. The arbor mass was kept low to aid also in keeping the critical speed high. The arbor design is shown in Fig. 40.

Some material discrepancies have been indicated in the material evaluations of the shaft failure analysis. The discrepancy showed a large grain size in the material in the rotor wheel of the remaining shaft. Property reductions estimated due to the visibly large grain size reduce the calculated allowable shaft speed at hot turbine drive conditions to 7247 rad/s (69,200 rpm) and to 7938 rad/s (75,800 rpm) at ambient gaseous hydrogen drive conditions. The shaft was successfully tested at ambient test conditions to 8734 rad/s (83,400 rpm) to qualify it for maximum test speeds with a gaseous hydrogen drive of 7938 rad/s (75,800 rpm) or 8.3% above the planned maximum target speed of 7330 rad/s (70,000 rpm).

The problem encountered here is caused basically by the very high speed requirements of this small rotating assembly. It is interesting to note that two previous dimensionally similar shafts had been successfully proof tested on the early design balance arbor without incident. This incident does indicate the need for thorough dynamic analysis of proof spin assemblies at the high test speeds required of these turbopump designs. It is also interesting to note that the bending mode of the shaft and the imbalance response were such as to generate high bending loads within the shaft and not transmit enough load to fail the small 3.18 mm (0.125 inch) diameter drive spindle. This failure mode was very unusual and highly unpredictable.

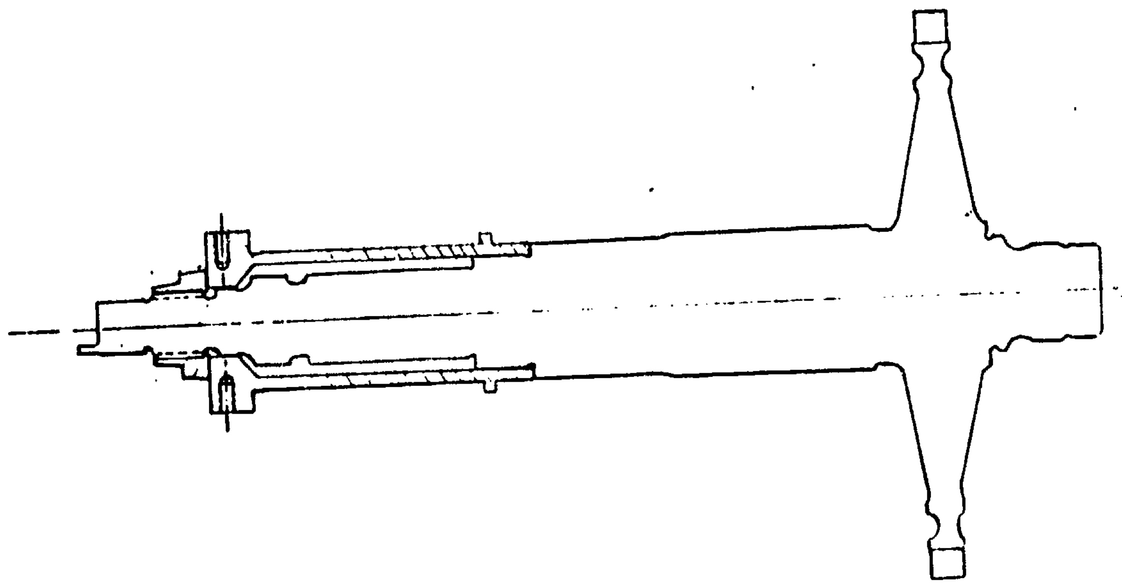


Figure 40. Mark 48-0 Shaft Spin Test Arbor, Redesigned

TURBOPUMP S/N 03-0 ASSEMBLY AND TEST

Specific objectives planned for turbopump S/N 03-0 test program included verification of the redesigned balance piston capability to provide adequate thrust control over a wide flow range and determination of the turbopump suction performance capability. The overall turbopump performance was to be evaluated as well using appropriate instrumentation. The previous objective to use the spiral groove, lift-off seal design and to determine its performance capability was deleted. Testing of a lift-off seal similar to that designed for the turbopump had encountered technical problems with the design concept. After test rig failures, it was determined that these problems required resolution by further component testing before the seal could be considered sufficiently reliable for turbopump operation. As a result, the turbopump program had been redirected to test the turbopump with the floating ring seal while verification of axial thrust control and suction performance definition was pursued.

Assembly and Installation

Procurement of the hardware was completed and the necessary inspection and proof tests were completed. The rotor assembly was balanced on the Gisholt balance machine. The machine has a capability of detecting 6×10^{-4} mm (25 μ-inch) radial motion. The rotor mass of 2.84 Kg (6.25 lb) gives a machine accuracy of 0.18 gm-cm (0.07 gm-inch). This is equivalent to a radial load of 98 N (22 lb) at a speed of 7330 rad/s (70,000 rpm). The rotor was balanced by being supported in the balance cradle with two pairs of axially preloaded bearings, just as would occur in the turbopump assembly. The balancing was done by using the main rotor and rear stub shaft assembly first with wax corrections applied in the plane of the turbine wheel and stub shaft. This was followed by the slinger, impeller, inducer and instrumentation sleeves making wax corrections in the plane of each component before the next part was added. A relatively large imbalance was evidenced on the impellers. This slowed the balance due to a lack of available material in the shrouds for balancing. Several repeatability checks were made with the rotor disassembled and reassembled to satisfactory repeatability and runouts were taken on the assembly components. The final runout values are given in Fig. 41. Permanent balance was completed by grinding material in the required areas of the component parts.

The assembly of turbopump S/N 03-0 was accomplished in accordance with the procedure described in Ref. 1 . The front and rear bearing inner race thicknesses were selected to provide a minimum bearing preload of 245 N (55 lb), and to obtain a total bearing travel within each cartridge of 0.23 mm (0.009 inch).

The measurements were made during the assembly of the turbopump to establish critical clearances and fits. The diametral fits obtained relative to the bearings are noted in Fig. 42. Critical clearances in the pump, shaft seals, and turbine area are included in Fig. 43 through 45.

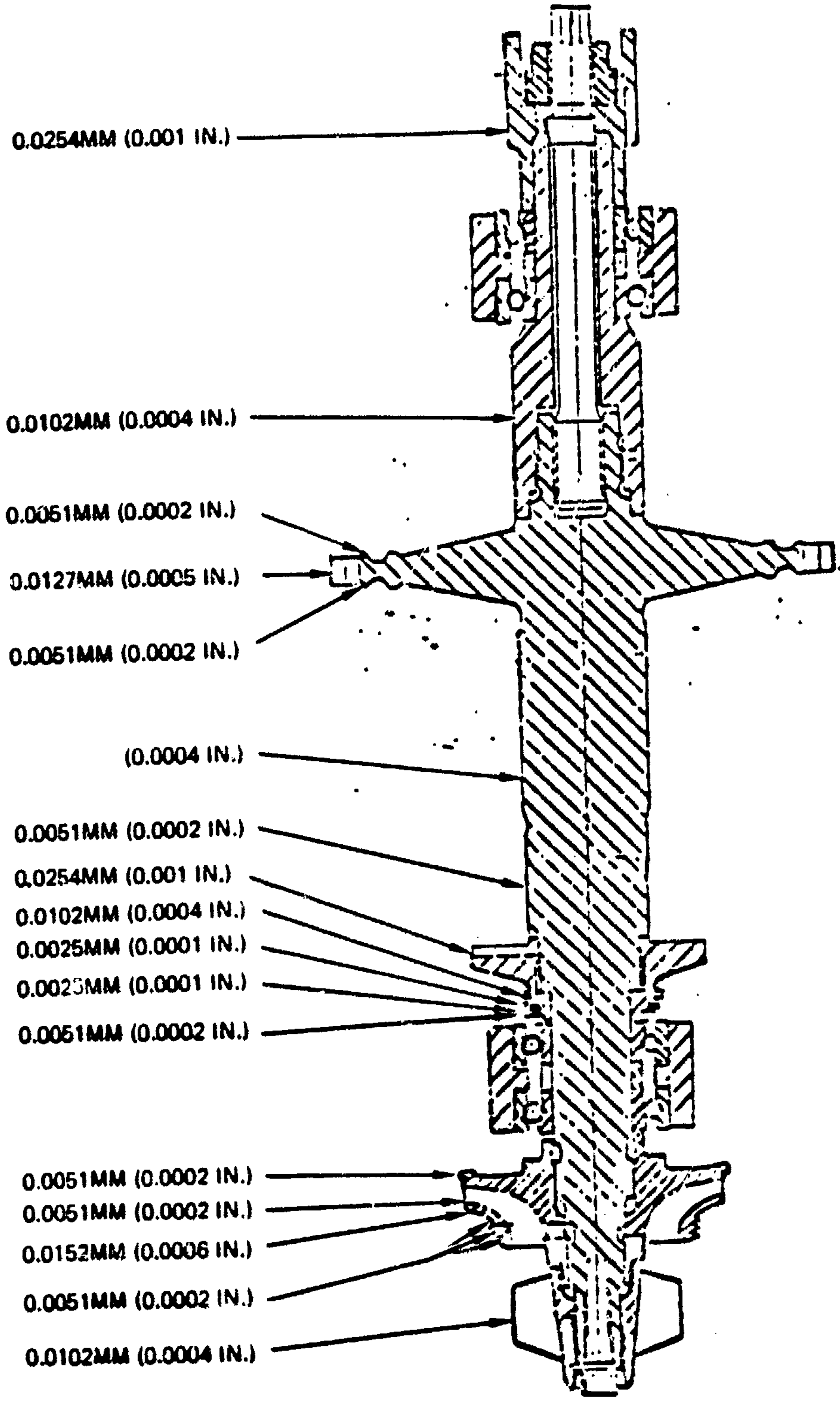
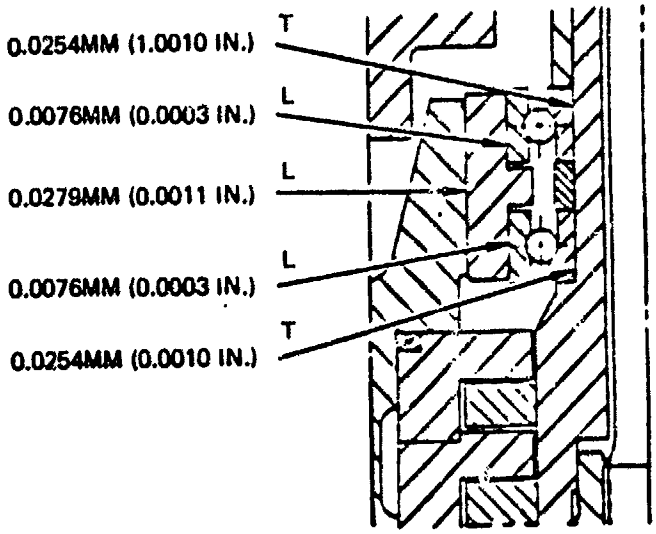


Figure 41. Mark 48-0 Turbopump S/N 03-0 Balance Assembly Runouts



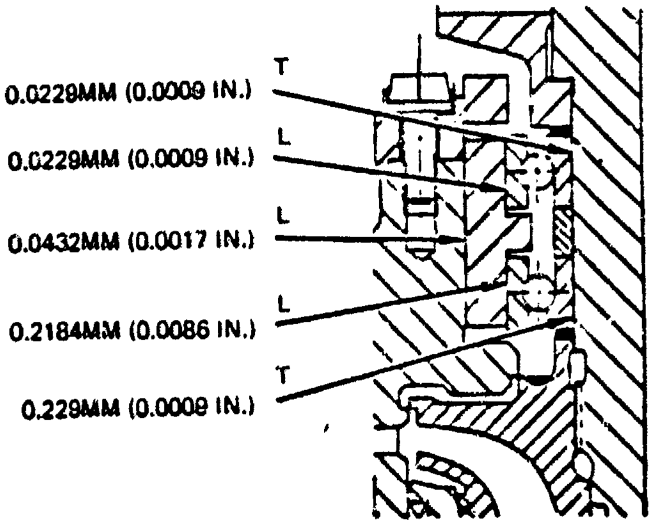


Figure 42. Mark 48-0 Turbopump S/N 03-0 Bearing Diametral Clearances and Fits

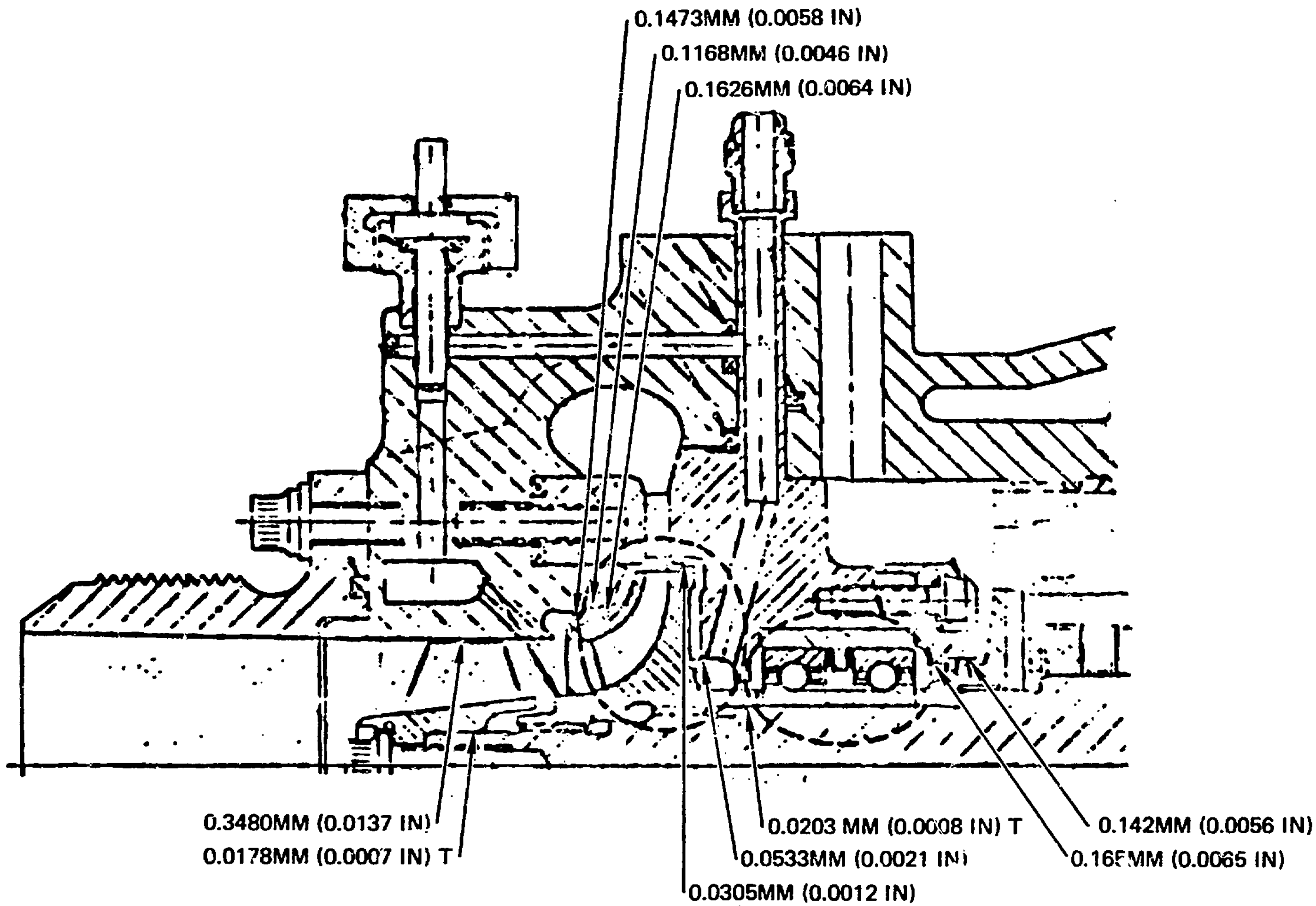


Figure 43. Mark 48-0 Turbopump S/N 03-0 Pump Seal Diametral Clearances and Pilot Fits

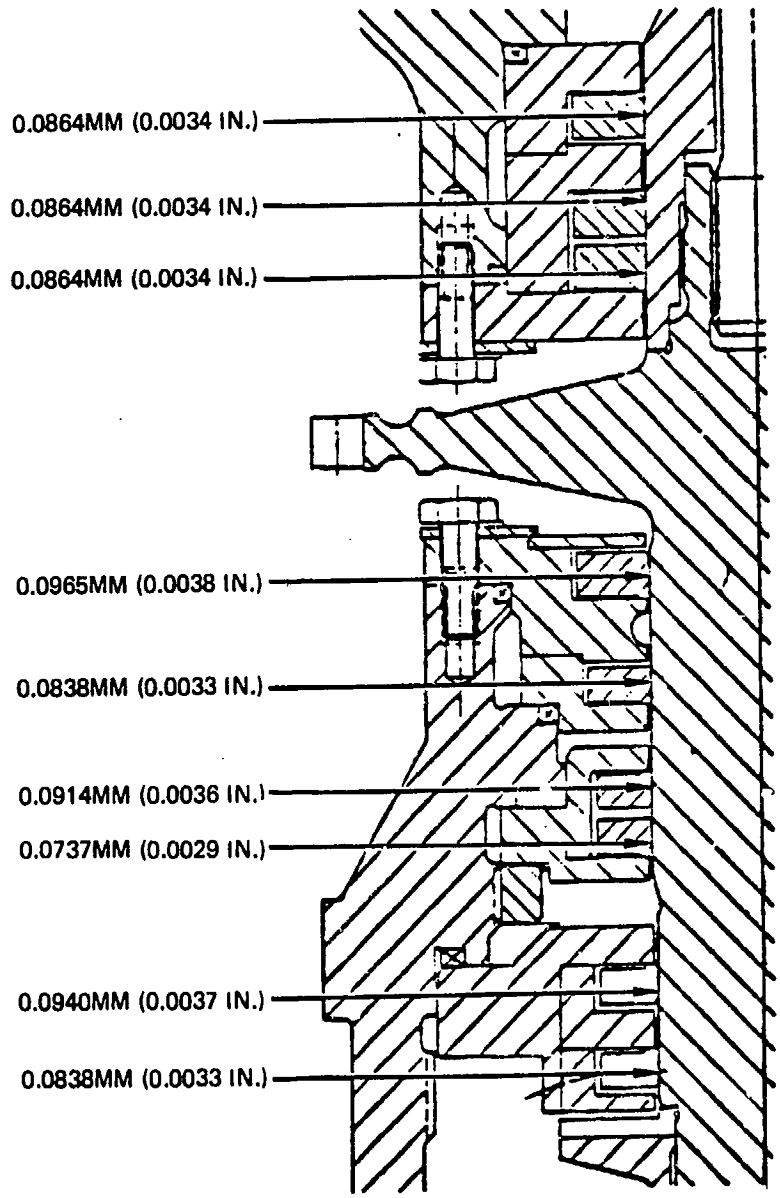


Figure 44. Mark 48-0 Turbopump S/N 03-0 Seal Diametral Clearances

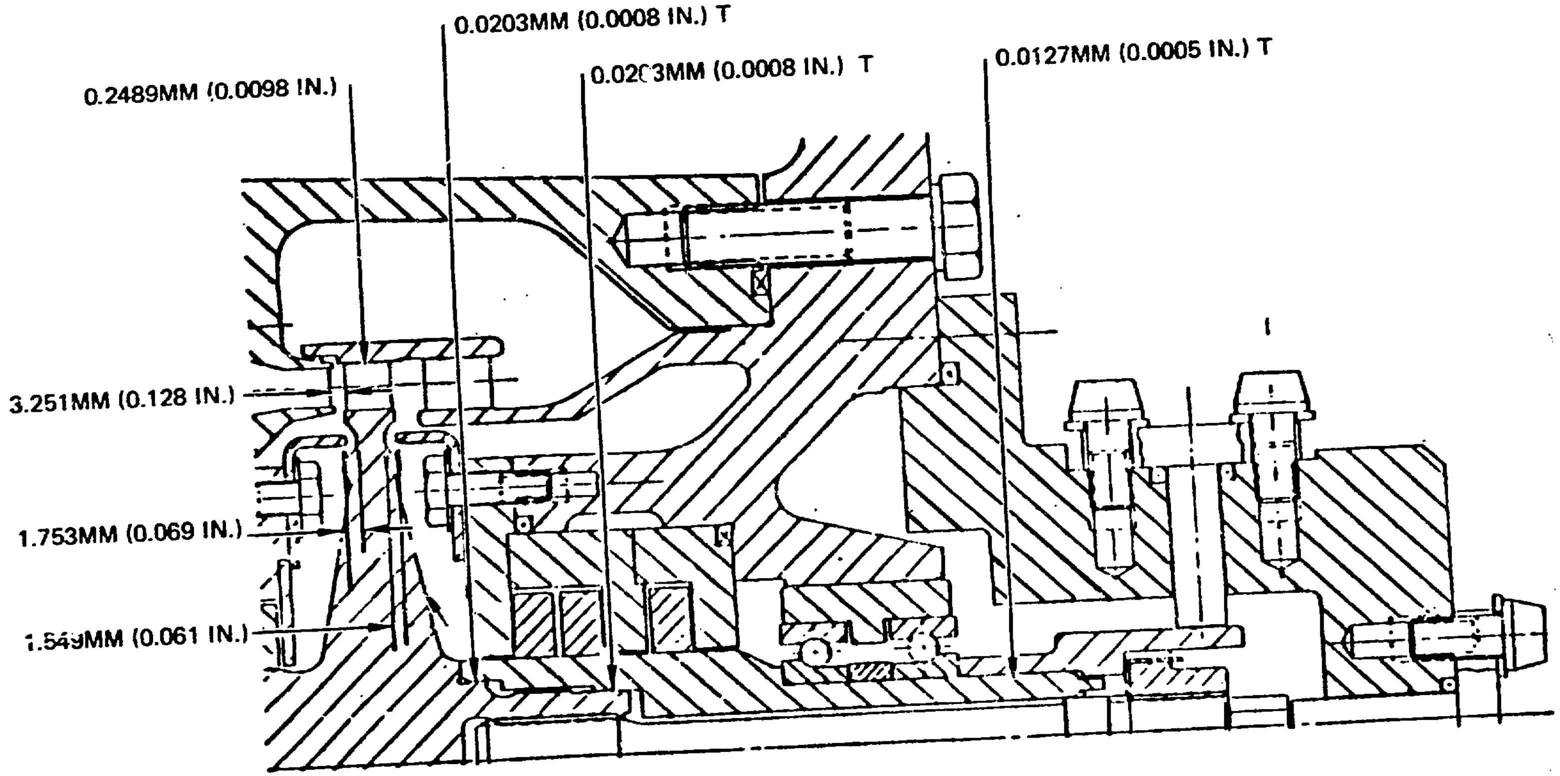


Figure 45. Mark 48-0 Turbopump S/N 03-0 Turbine Component Diametral Clearances and Fits

After the turbopump was assembled, a push-pull test was performed on the rotor to establish the external loads which the bearings support as a function of rotor position with respect to the balance piston orifice positions. The curve which was obtained is shown in Fig. 46. The symbols h_1 and h_2 refer to the balance piston high- and low-pressure orifice axial clearances, respectively. As indicated by the curve, the bearing stops were positioned such that the balance piston orifices would be well past totally closed before a sizeable load (1780 N) (400 lb) would be imposed on the bearings.

One problem area developed during the balancing of the assembly that had not been encountered on previous builds. An impeller nut failed during a disassembly which initiated an investigation into the cause. The failure was due to two factors. The torquing slot depth on the nut was found to be larger than print requirements, thus not allowing the tool to bottom properly, and the torque requirements were marginally high. Further analysis on the shaft indicated that the print torque requirements were excessive. This put a tensile load on the shaft greater than allowed for the previously reduced properties given for the shaft. The high torque requirements were a result of the large range of friction factors used in the calculations. The values used were necessary to ensure the impeller, bearings and slinger stackup carried enough compression to remain fixed through all operating conditions. A process of using strain gages attached to the impeller to ascertain the compressive load on the stackup was developed. The process was verified in a tensile machine including removal and LOX cleaning after the completed assembly. Analysis indicates the impeller nut torque could be reduced to acceptable levels with this method and allow assembly to proceed. A major activity during assembly was directed to developing the strain gaging process and running calibration tests of the strain gages to be used in final assembly. This was required to ensure proper preload could be applied to the impeller stackup without overloading the shaft with reduced properties. The final assembly was completed with good results from the strain gages and the procedures involved. The assembled turbopump is shown in Fig. 47 and 48.

After initial turbopump assembly, it was found by helium leak check that the seals in the balance piston recirculation lines were leaking. The volute was removed from the turbopump and a combination of polishing the flange face and using liquid teflon on the seals eliminated the leakage. The assembled turbopump was installed in the LIMA test cell at the Advanced Propulsion Test Facility (APTF) of Rocketdyne's Santa Susana Field Laboratory. A simplified schematic of the facility has been shown in Fig. 20. The turbopump installation in the LIMA test cell is shown in Fig. 49 and 50.

<u>Test Series No. 5, April 1981</u>

The purposes of the test plan were to verify the turbopump balance piston axial thrust control capability and to determine the suction performance of the turbopump. The test plan called for a series of four tests. The plan called for driving the turbopump turbine with high pressure gaseous hydrogen. Instrumentation was similar to previous turbopump testing. A detailed instrumentation list is given in Table 13, with specific turbopump instrumentation illustrated in Fig. 51. The facility instrumentation was similar to that previously used and shown in Table 8 and allowed recording of all the required parameters necessary.

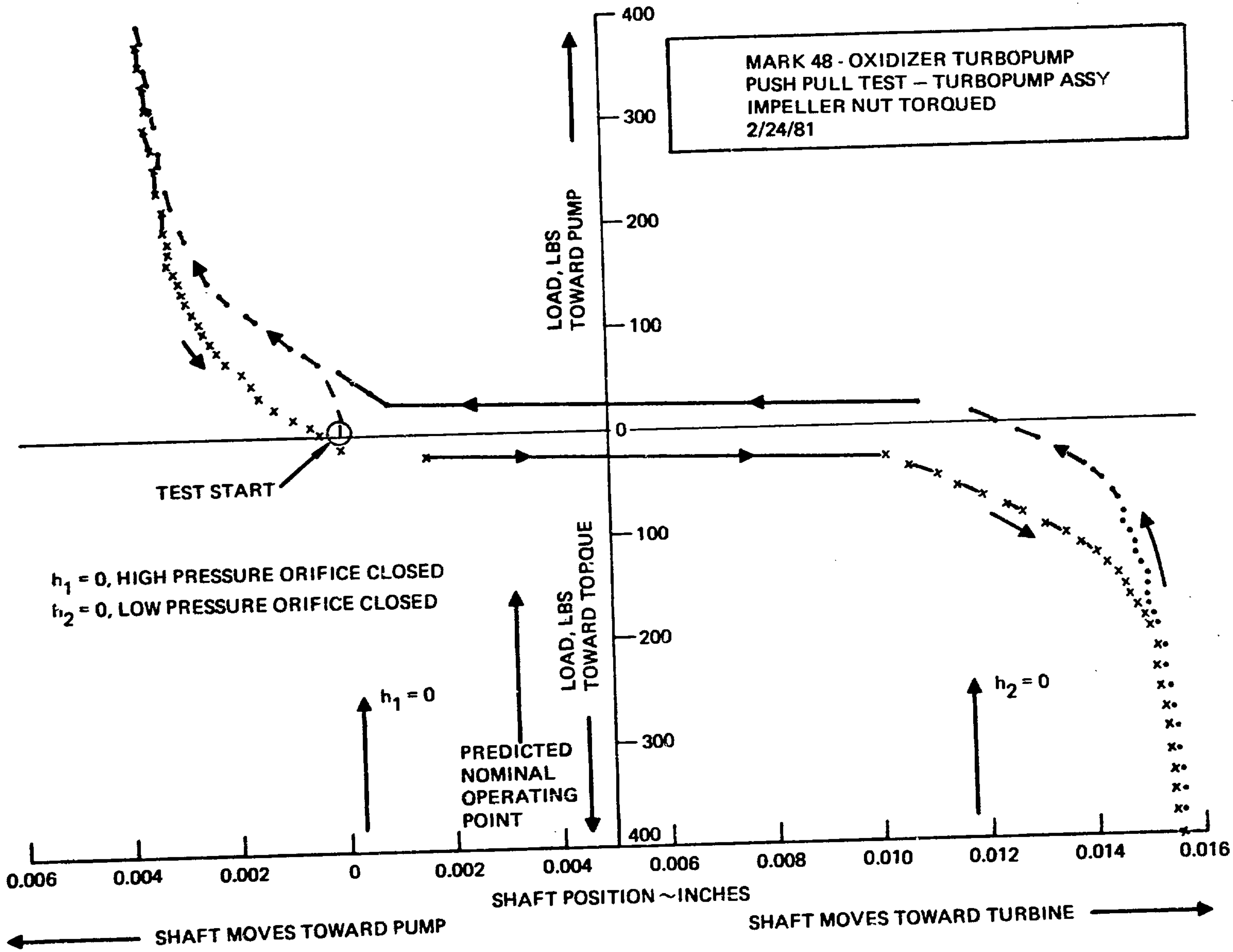
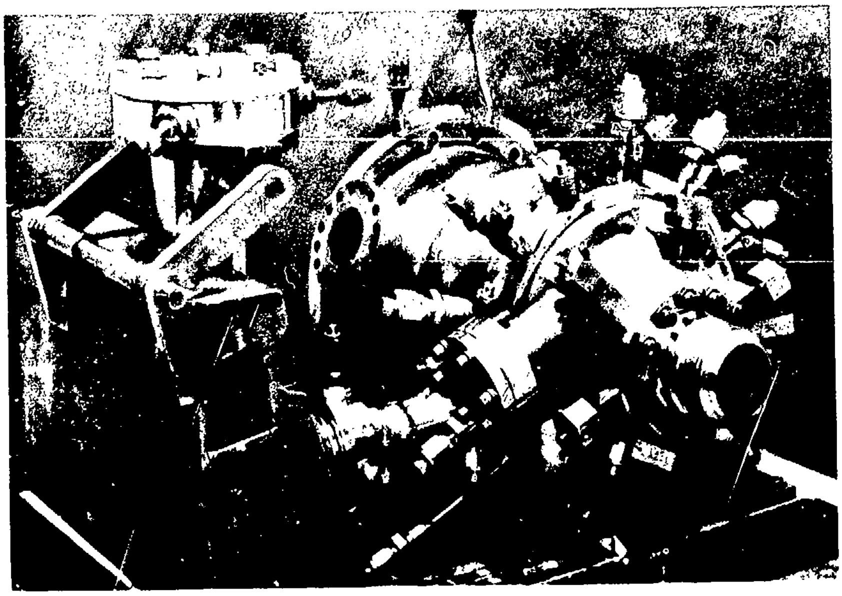
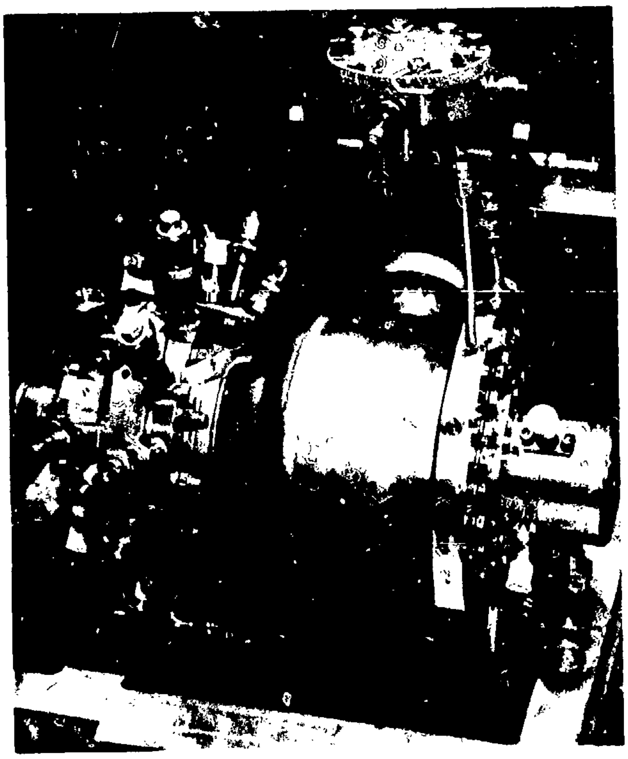


Figure 46. Mark 48-0 Turbopump Push-Pull Test, 24 February 1981



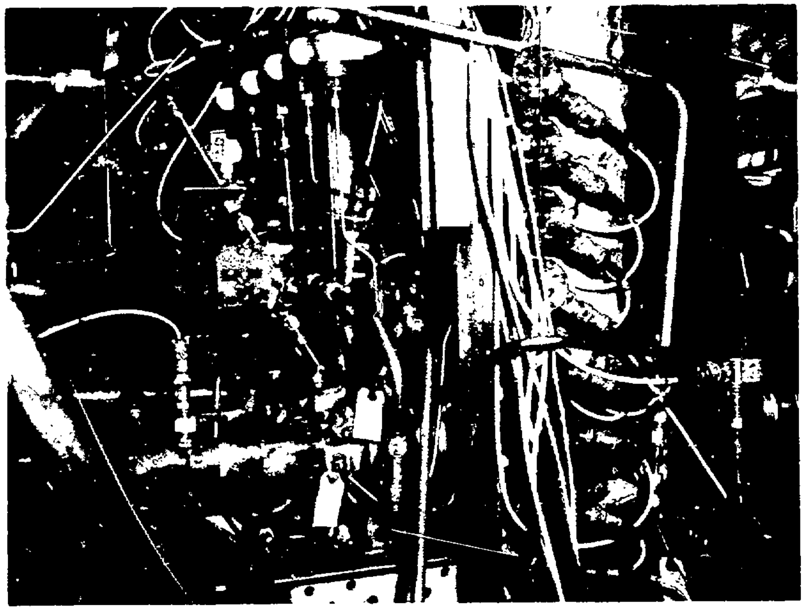
1XY52-5/18/81-C1A

Figure 47. Mark 48-0 Turbopump S/N 03-0 Assembly



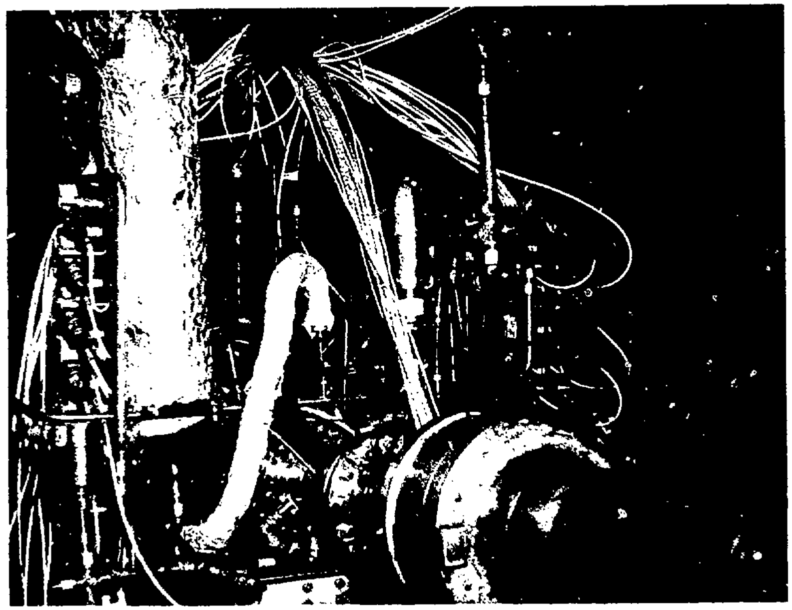
1XY52-5/18/81-C1E

Figure 48. Mark 48-0 Turbopump S/N 03-0 Assembly



5AJ45-3/31/81-S1D

Figure 49. Mark 48-0 Turbopump S/N 03-0 Installed in Test Stand



5AJ45-3/31/81-S1E

Figure 50. Mark 48-0 Turbopump S/N 03-0 Installed in Test Stand

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TABLE 13. INSTRUMENTATION LIST

(GASEOUS HYDROGEN TURBINE DRIVE)
(TEST SERIES 5)

SYSTEM	PARAMETER	ID	PID	RANGE	REDLINE	BE' MAN	DIGR	OSC	FM TAPE	LOCATION	COMMENTS
GH_2	REGULAR U/S PRESSURE	PGHR	062	5000 PSIG		X	X			FACILITY LINE	
	VENTURI U/S PRESSURE	PGHV	071	5000 PSIG		X	X			FACILITY LINE	VENTURI S/N 9731 P/N VP031200-SGR
	VENTURI U/S TEMPERATURE	TGHV	047	0 TO 200 F		X				FACILITY LINE	THERMOCOUPLE
	VENTURI ΔP	PGHD	06[illegible]	50 PSID		X	X			FACILITY LINE	
	GH_2 SPIN VALVE U/S PRESSURE	PSVI	082	5000 PSIG		X	X			FACILITY LINE	
	GH_2 SPIN VALVE D/S PRESSURE	PSV2	106	5000 PSIG		X	X			FACILITY LINE	
	GH_2 SPIN VALVE POSITION	GHSV	055	TRACE		X		X		FACILITY LINE	METER DISPLAY FOR DIGR REQUIREMENT
TURBOPUMP LOX OUTLET CONTROL	THROTTLE VALVE POSITION	TVP	057	TRACE		X		X		FACILITY LINE	METER DISPLAY FOR DIGR REQUIREMENT
	THROTTLE VALVE OUTLET PRESSURE	PDTP	100	2000 PSIG		X				FACILITY LINE	
GENERAL	LH_2 HIGH PRESSURE, TANK PRESSURE	PHT	087	5000 PSIG		X	X			FACILITY LINE	
	FACILITY DUCT PRESSURE D/S TURBINE ORIFICE PLATE	PFX	069	500 PSIG		X				FACILITY LINE	
	FACILITY DUCT TEMPERATURE D/S TURBINE ORIFICE PLATE	TFX	029	0 TO [illegible]90 F		X				FACILITY LINE	THERMOCOUPLE
	AXIAL PROXIMITY INDICATOR	BAP	TAPE	TAPE FM				X	X	TURBOPUMP COVER	
	RADIAL PROXIMITY INDICATOR 1	BRP	TAPE	TAPE FM	X			X	X	TURBOPUMP COVER	
	RADIAL PROXIMITY INDICATOR 2	BTP	TAPE	TAPE FM	X			X	X	TURBOPUMP COVER	90 DEGREES FROM NO. 1
	PUMP AXIAL ACCELERATION	PAA	TAPE	TAPE FM	X				X		
	PUMP RADIAL ACCELERATION	PRA	TAPE	TAPE FM	X				X		
	TURBINE RADIAL ACCELERATION	TRA	TAPE	TAPE FM	X				X		
	PUMP SPEED	RPM	083	100,000 RPM	X	X	X	X	X	TURBOPUMP COVER	
	HELIUM SUPPLY PRESSURE	PHUS	104	0 TO 500 PSIG		X				FACILITY LINE	
LOX PUMP	LOW PRESSURE, TANK PRESSURE	PØXT	068	500 PSIG		X	X			FACILITY LINE	
	INLET PRESSURE	PØIN	098	200 PSIG	X	X	X	X		FACILITY LINE	PIEZOMETER RING
	INLET TEMPERATURE	TØIN	043	-259 TO -300 F	X	X	X			FACILITY LINE	RTB
	INDUCER DISCHARGE PRESSURE	PIND	072	1000 PSIG		X				VOLUTE TAP	
	IMPELLER	PIPS	059	5000 PSIG		X	X			VOLUTE TAP	
	IMPELLER DISCHARGE PRESSURE	PIDP	067	5000 PSIG		X				DIFFERENTIAL TAP	
	BALANCE PISTON CAVITY HIPR 1	P10	096	5000 PSIG	X	X	X			DIFFERENTIAL TAP	
	BALANCE PISTON CAVITY LOPR 2	P11	084	5000 PSIG		X				DIFFERENTIAL TAP	
	BALANCE PISTION SUMP PRESSURE	P12	086	1000 PSIG	X	X	X			DIFFERENTIAL TAP	
	PUMP BEARING U/S PRESSURE	PPBUS	093	1000 PSIG		X				DIFFERENTIAL TAP	
	PUMP BEARING D/S PRESSURE	PPBDS	099	1000 PSIG		X				DIFFERENTIAL TAP	
	PUMP DISCHARGE PRESSURE	PDP	089	5000 PSIG	X	X	X	X		FACILITY LINE	PIEZOMETER RING X-Y PLOTTER
	PUMP DISCHARGE TEMPERATURE	TPD	045	-100 TO -300 F		X				FACILITY LINE	RTB
	DISCHARGE VENTURI U/S PRESSURE	PUVP	088	5000 PSIG		X	X			FACILITY LINE	VENTURI S/N 8877, P/N V321059-SGR
	DISCHARGE VENTURI U/S TEMPERATURE	TUVP	046	-200 TO -300 F		X	X			FACILITY LINE	RTB
	DISCHARGE VENTURI ΔP	PVDP	063	250 PSID		X	X			FACILITY LINE	X-Y PLOTTER

TABLE 13. (Continued)

SYSTEM	PARAMETER	ID	PID	RANGE	REDLINE	BECKMAN	DIGR	OSC	FM TAPE	LOCATION	COMMENTS
LOX PUMP (CONTINUED)	BEARING SUMP SLINGER PRESSURE	PBSS	094	200 PSIG		X				HOUSING TAP	
	BEARING SUMP SLINGER TEMPERATURE	TBSS	036	0 TO -300 F	X	X	X			HOUSING TAP	
TURBINE	INLET STATIC PRESSURE	PTIS	065	5000 PSIG		X	X	X		COMBINED BODY	
	INLET TOTAL PRESSURE	PTIT	080	5000 PSIG		X				COMBINED BODY	KLEL PROBE SUPPLIED
	TURBINE INLET TEMPERATURE	TTI	024	0 TO 100 F		X	X			COMBINED BODY	WALL + 0.150 INCH
	NOZZLE D/S PRESSURE	PND	077	3000 PSIG		X				TURBOPUMP HOUSING	
	TURBINE WHEEL EXHAUST PRESSURE	PWD	076	3000 PSIG		X				TURBOPUMP SUPPORT	
	TURBINE DISCHARGE TOTAL PRESSURE	PTDT	079	3000 PSIG		X				FACILITY LINE	
	TURBINE DISCHARGE STATIC PRESSURE	PTDS	070	3000 PSIG		X				FACILITY LINE	
	TURBINE DISCHARGE TEMPERATURE	TTD	023	-100 TO +200 F		X					THERMOCOUPLE
SEALS	PRIMARY LOX SEAL DRAIN LINE PRESSURE	P14	031	100 PSIG	X	X	X			EXTERNAL TURBOPUMP	CLOSE COUPLED TO TURBOPUMP TURBOPUMP
	PRIMARY LOX SEAL DRAIN LINE TEMPERATURE	TLSD	011	-300 TO +100 F		X	X			EXTERNAL TURBOPUMP	THERMOCOUPLE
	BEARING OVBD FLOW ORIFICE U/S PRESSURE	PPBOUS	109	100 PSIG		X	X			D/S HEAT EXCHANGE	EXHAUST TO ATM
	BEARING OVBD FLOW ORIFICE U/S TEMPERATURE	TPBOUS	022	-300 TO +100 F		X				U/S HEAT EXCHANGE	THERMOCOUPLE
	PRIMARY HOT GAS SEAL DRAIN ORIFICE U/S PRESSURE	P15	102	100 PSIG		X				EXTERNAL TURBOPUMP	EXHAUST TO ATM
	PRIMARY HOT GAS SEAL DRAIN ORIFICE U/S TEMPERATURE	THGPOD	028	-300 TO +100 F		X				EXTERNAL TURBOPUMP	THERMOCOUPLE
	SECONDARY HOT GAS SEAL DRAIN LINE PRESSURE	P16	091	500 PSIG	X	X	X			EXTERNAL TURBOPUMP	
	SECONDARY HOT GAS SEAL DRAIN LINE TEMPERATURE	TSHGD	026	-300 TO +100 F		X				EXTERNAL TURBOPUMP	THERMOCOUPLE
	SECONDARY HOT GAS SEAL DRAIN ORIFICE U/S PRESSURE	P17	097	100 PSIG		X				EXTERNAL TURBOPUMP	EXHAUSE TO ATM
	SECONDARY HOT GAS SEAL DRAIN ORIFICE U/S TEMPERATURE	TSHGDO	027	-300 TO +100 F		X				EXTERNAL TURBOPUMP	THERMOCOUPLE
PURGE INLET LINE	INTERMEDIATE SEAL PURGE ORIFICE U/S TEMPERATURE	TISP	012	-100 TO +100 F		X				FACILITY LINE	THERMOCOUPLE
	INTERMEDIATE SEAL PURGE ORIFICE D/S PRESSURE	P18	092	500 PSIG	X	X	X			FACILITY LINE	CLOSE COUPLED TO TURBOPUMP

TABLE 13. (Concluded)

SYSTEM	PARAMETER	ID	PID	RANGE	REDLINE	BECKMAN	DIGR	OSC	FM TAPE	LOCATION	COMMENTS
REAR BEARING	REAR BEARING COOLANT SUPPLY PRESSURE	P19	095	5000 PSIG	X	X				FACILITY LINE	INLET LINE
	REAR BEARING COOLANT SUPPLY TEMPERATURE	TBC	035	-450 TO -250 F		X	X			FACILITY LINE	RTB
	REAR BEARING COOLANT DRAIN PRESSURE	P20	103	1000 PSIG	X	X				FACILITY LINE	EXHAUST LINE
	REAR BEARING COOLANT DRAIN TEMPERATURE	TBCD	014	-450 TO -250 F	X	X				FACILITY LINE	THERMOCOUPLE
	REAR BEARING COOLANT ORIFICE D/S PRESSURE	P22	066	500 PSIG		X	X			FACILITY LINE	
PUMP OVBD FLOW	PUMP BEARING OVBD FLOW U/S PRESSURE	PBFU	107	100 PSIG		X	X			FACILITY LINE	
	PUMP BEARING OVBD FLOW U/S TEMPERATURE	TBFU	042	+100 TO -300 F		X				FACILITY LINE	THERMOCOUPLE
	BALANCE PISTON OVBD FLOW U/S PRESSURE	PBPØUS	073	2000 PSIG		X	X			FACILITY LINE	
	BALANCE PISTON OVBD FLOW U/S TEMPERATURE	TBPØUS	044	-100 TO -300 F	X	X	X			FACILITY LINE	THERMOCOUPLE
	BALANCE PISTON OVBD FLOW DELTA PRESSURE	PBPØDP	105	500 PSIG		X	X			FACILITY LINE	

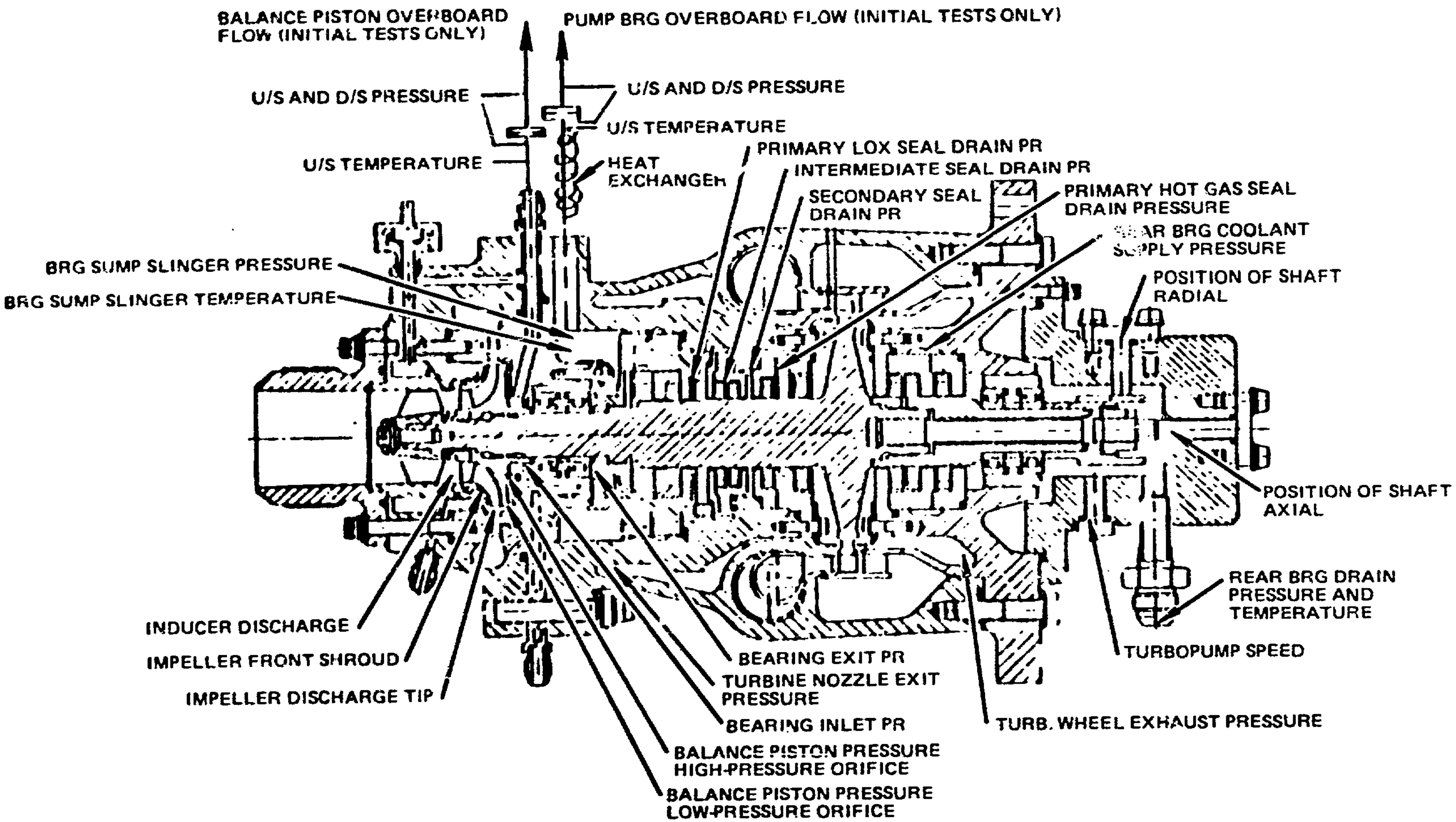

Figure 51. Mark 48-0 Instrumentation, Test Series

A set of redlines was determined and used as a safety precaution, and required the turbopump and system to operate within specified ranges of speed, pressure, temperature and vibration levels. The redline parameters used for Series No. 5 testing are given in Table 14.

Balance piston overboard flow was measured by an orifice differential pressure utilizing the same system as used for the balance piston and bearing coolant overboard flow on test series No. 4. The bearing coolant flow was measured by utilizing the primary LOX seal flow discharge line and heat exchanger used in the previous test series. This arrangement is shown schematically in Fig. 52. Shaft speed and radial movement were measured as in previous tests.

A total of six tests were conducted on the turbopump in April 1981 with a total operating time of 749 seconds. Of that time, 146 seconds was at 3141 rad/s (30,000 rpm) and 35 seconds near 7228 rad/s (69,000 rpm). A summary of the testing is given in Table 15. All other time was at speeds below 3141 rad/s (30,000 rpm) or in transient operation.

The first planned test was a head-flow test at 3141 rad/s (30,000 rpm). In test 016-001, a turbopump start was made to idle mode at 524 rad/s (5,000 rpm). At that point a check was made on instrumentation before proceeding. Several problems with controller instrumentation caused the test to be terminated. The second pump start was test 002 where the pump was brought to idle mode, then up to 3141 rad/s (30,000 rpm) for 27 seconds. At this point the flowrate and speed was adjusted manually to start a head-flow sweep. Upon switching to automatic speed control set point, the rapid response of the system caused the speed to shoot up to a 3874 rad/s (37,000 rpm) redline and an automatic cutoff was initiated. This was caused by starting at a lower than normal flow and the pump power absorption was lower than programmed.

The next test, 003, was a successful head-flow test at 3141 rad/s (30,000 rpm) of 56 seconds duration and covered a flow range of 79 to 117% of design flow. For this test the balance piston flow was routed overboard. The test 004 was targeted for a high-speed head-flow test at 7016 rad/s (67,000 rpm). The speed was set at slightly under the design speed of 7330 rad/s (70,000 rpm) because the lower speed data indicated that at low flows the pump discharge pressure would exceed the pressure transducer limits of 3448 N/CM^2 (5000 psig), and the test would be automatically terminated by the redline limits. This high pressure would also overdrive the transducers and cause damage. The test speed on test 004 was brought up to the 3141 rad/s (30,000 rpm) operating point by the automatic control system which controls turbine drive pressure. At that speed it was found that the speed pickup on the turbopump had failed, and the test had to be terminated. The speed achieved was determined after the test by counting the frequency of the proximity probe signal changes which record one step per revolution. Also, during the test at speed, a segment of head-flow variation data from 100 and 119% of nominal flow was obtained. The speed probe was replaced after it was verified it shorted out at low temperatures while it operated satisfactorily at ambient conditions.

TABLE 14. LO_2 TURBOPUMP REDLINES, AMBIENT HYDROGEN TURBINE DRIVE, TEST SERIES 5

CUTOFF MONITOR	REDLINE IDENTIFICATION	REDLINE LIMIT
AUTOMATIC	LOX INLET TEMPERATURE	180 R MAXIMUM
AUTOMATIC/OBSERVER	LOX PUMP INLET PRESSURE	92 PSIA MINIMUM
AUTOMATIC	TURBOPUMP SPEED	77,000 RPM MAXIMUM
OBSERVER	PUMP BEARING OVBD FLOW TEMPERATURE	ΔT = 25 R MAXIMUM AFTER STABILIZATION
OBSERVER	REAR BEARING DRAIN TEMPERATURE	ΔT = 25 R MAXIMUM AFTER STABILIZATION
OBSERVER	BALANCE PISTON CAVITY PRESSURE	SPECIFIC RANGE EACH TEST
AUTOMATIC	LOX PUMP DISCHARGE PRESSURE	5000 PSIG MAXIMUM
AUTOMATIC	PRIMARY LOX SEAL DRAIN LINE PRESSURE	30 PSIG MAXIMUM***
AUTOMATIC	TURBINE SECONDARY SEAL DRAIN LINE PRESSURE	30 PSIG MAXIMUM***
AUTOMATIC	INTERMEDIATE SEAL PURGE (HELIUM) PRESSURE	150 PSIG MINIMUM
OBSERVER	BENTLY TRANSDUCER RADIAL	0.010 INCH MAXIMUM DEFLECTION
OBSERVER	BENTLY TRANSDUCER AXIAL	0.013 INCH MAXIMUM DEFLECTION
AUTOMATIC	TURBOPUMP RADIAL ACCELEROMETER*, **	15 G RMS
OBSERVER	BALANCE PISTON SUMP PRESSURE	SPECIFIC RANGE EACH TEST
AUTOMATIC	REAR BEARING SUPPLY PRESSURE	3100 PSIG MINIMUM
AUTOMATIC	REAR BEARING DRAIN PRESSURE	500 PSIG MAXIMUM

* 2 KHz LOW PASS FILTER
** VIBRATION SAFETY CUTOFF DEVICE
*** CONDITION MUST EXIST FOR MORE THAN 2 SECONDS

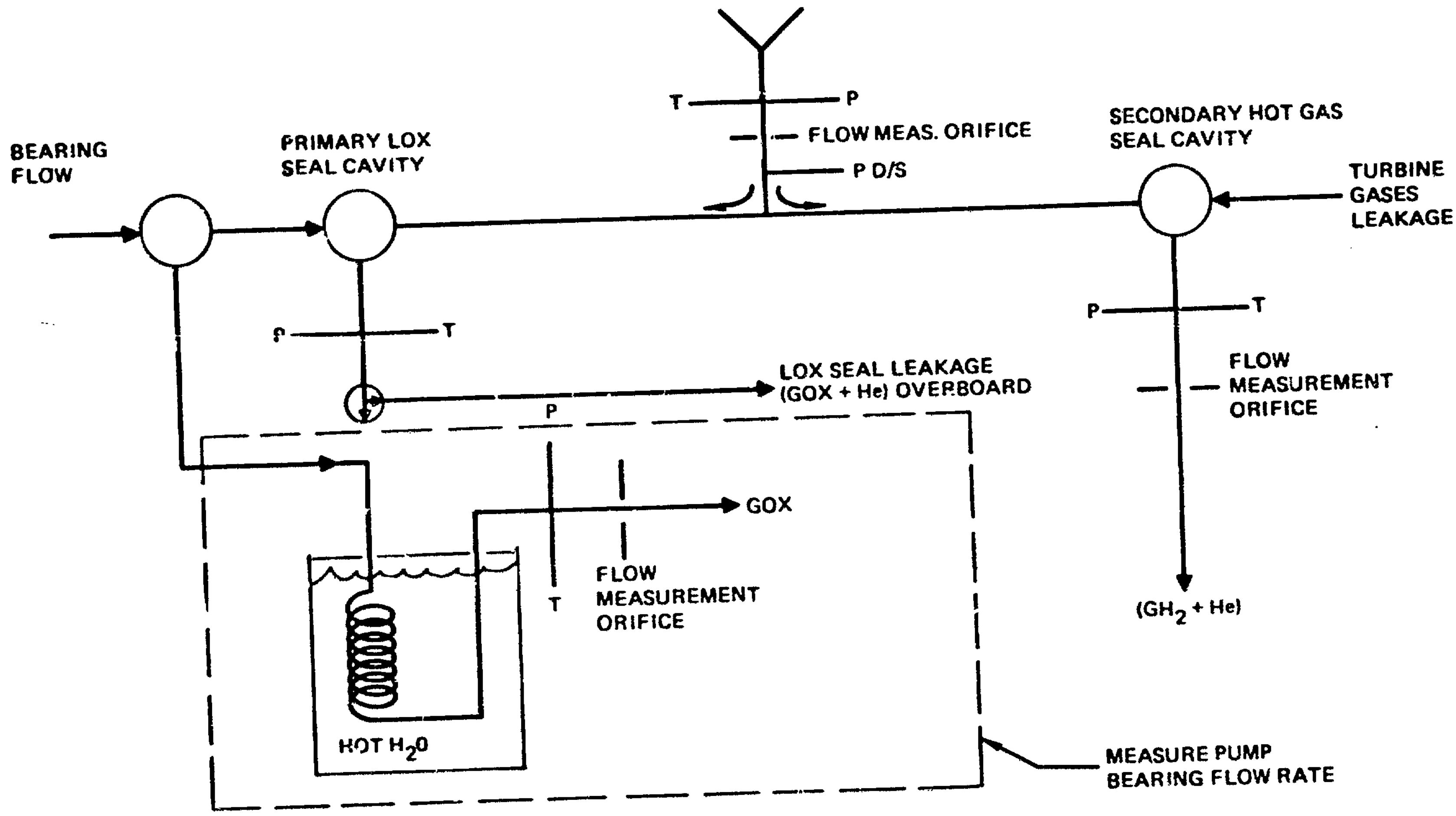

Figure 52. Bearing Flowrate Measurement System

TABLE 15. MARK 48-0 TURBOPUMP TEST SERIES NO. 5 SUMMARY, TURBOPUMP S/N 03-0

TEST NUMBER	TEST DATE	TEST DURATION SECONDS	ACCUMULATED		REMARKS
			STARTS	DURATION SECONDS	
016-001	4-9-81	246	1	246	PLANNED HEAD FLOW TEST AT 3141 RAD/S (30,000 RPM) WITH BALANCE PISTON FLOW ROUTED OVERBOARD. DURATION OF TEST AT 524 RAD/S (5000 RPM). SEVERAL PROBLEMS WITH OBSERVER AND CONTROLLER INSTRUMENTATION CUT TEST.
016-002	4-13-81	137	2	383	PUMP START IN IDLE MODE 524 RAD/S (5000 RPM). RAN PUMP TO 3141 RAD/S (30,000 RPM) FOR 27 SECONDS. TEST CUT ON OVERSPEED REGULATOR WHEN SWITCHED OVER TO AUTOMATIC REGULATOR CONTROL.
016-003	4-13-81	72	3	455	BROUGHT SPEED UP TO 3141 RAD/S (30,000 RPM) FOR 56 SECONDS. HEAD FLOW TEST AT 3141 RAD/S (30,000 RPM) FROM 79 TO 117% DESIGN FLOW. BALANCE PISTON FLOW ROUTED OVERBOARD.
016-004	4-15-81	105	4	560	BROUGHT SPEED UP TO 3141 RAD/S (30,000 RPM) FOR 41 SECONDS, TARGET SPEED WAS 7016 RAD/S (67,000 RPM) FOR H-Q TEST. LOST SPEED SIGNAL - GOT HEAD-FLOW DATA POINTS AT 100% AND 119%.
016-005	4-16-81	121	5	681	TARGET SPEED 7016 RAD/S (67,000 RPM) FOR H-Q TEST. BROUGHT SPEED UP TO 3141 RAD/S (30,000 RPM) FOR 16 SECONDS. LOST ΔP SIGNAL USED FOR FLOW CONTROL. BALANCE PISTON FLOW OVERBOARD WITH REDUCED RESISTANCE IN ORIFICES.
016-006	4-28-81	68	6	749	TARGET SPEED 7016 RAD/S (67,000 RPM) H-Q TEST WITH BALANCE PISTON FLOW ROUTED TO COMBINED RECIRCULATION AND OVERBOARD DRAIN TO MINIMIZE SUMP PRESSURE. 35 SECONDS AT 7120 RAD/S (68,000 RPM) COMPLETE HEAD-FLOW TEST FROM 87% TO 112% DESIGN FLOW PUMP DISCHARGE PRESSURE REDLINE CUTOFF AT 524 RAD/S (5000 PSIG) AND 87% NOMINAL FLOW.

C-2

Analysis of the data at 3141 rad/s (30,000 rpm) had indicated the balance piston/sump pressures were marginally too high. The balance piston overboard drain line consisted of six lines exiting the turbopump at the diffuser flange. These were manifolded together by 12.3 mm (0.50 inch) connecting lines. The resulting single 12.5 mm (0.50 inch) line then ran through a flow measuring orifice and then a flow control orifice before exiting into a 7.62 cm (3 inch) line which dumped overboard. A pressure and temperature measurement was taken upstream of the flow measurement orifice and a differential pressure was measured across it. This enabled the pressure to be monitored upstream of the flow control orifice. On the tests prior to test 005, the flow control orifice diameter was set at 6.15 mm (0.242 inch) and the flow measurement orifice diameter was set at 5.61 mm (0.221 inch). The data from test 004 indicated a small pressure drop occurring across the flow measurement orifice with high pressure losses downstream. This was an indication of choking downstream. In an attempt to reduce the balance piston sump pressure for test 005, the downstream flow control orifice was removed from the line.

The test 005 objective was to operate at 7016 rad/s (67,000 rpm) for a head-flow test with the balance piston flow overboard. Test speed was brought to 3141 rad/s (30,000 rpm) when the signal of pressure differential across the pump flow venturi failed, thus losing monitoring capability of the pump flow rate. This caused the test to be terminated.

The low speed data from test 005 indicated that due to choking in the balance piston flow overboard drain line, it was impractical to attempt to reduce the sump pressure appreciably by reducing the drain line resistance since choking would still occur at some point in the line. Test 005 data indicated the choking point had moved to the flow measurement orifice. Therefore, the next step to reduce the resistance as low as possible was to allow recirculation to occur, as well as to allow overboard drain line flow. The recirculation blocking pins were removed to allow the balance piston flow to return to the impeller inlet. The flow measurement orifice was set at 6.70 rpm (0.2636 inch) and the flow control orifice was set at 7.62 mm (0.300 inch).

Test 006 was run successfully to a target speed of 7016 rad/s (67,000 rpm) with the balance piston flow routed overboard and recirculated to minimize sump pressure. The turbopump operated for 35 seconds near 7120 rad/s (68,000 rpm) while a complete head-flow sweep was made from 112% design to 87% design. At the low flow point, the pump discharge pressure reached 3448 N/cm^2 (5000 psig) and the test was terminated by exceeding the redline limit for that measurement.

At the conclusion of test 006, posttest torque checks on the rotor assembly indicated excessive torque on the shaft. Previous checks had indicated low magnitudes in the order of 14.12 N-cm (20 oz-in.) breakaway and 10.6 N-cm (15 oz-in.) running. The high torque levels were up to 9.03 to 11.30 N-m (80 to 100 in.-lb.) initially with the rotor essentially freezing up after several revolutions. Boroscope examination and audio checks at the turbine wheel tips clearly showed excessive rubbing. All attempts to reduce the torque, including simultaneously heating and chilling parts, failed. This left no choice but to remove the turbopump and disassemble it to correct the condition. Due to budget limitations, additional testing had to be terminated.

Removal and Disassembly

The turbopump was removed from the test stand and the facility was secured. The turbopump was shipped to the Rocketdyne Engineering Development Laboratory in Canoga Park for disassembly and hardware analysis. The turbopump was completely disassembled and inspected for evidence of wear or distress. A complete layout of the disassembled turbopump is shown in Fig. 53. On disassembly, dimensional checks were made on all components and recorded. A report of the mechanical condition and performance of the components is presented later in this report.

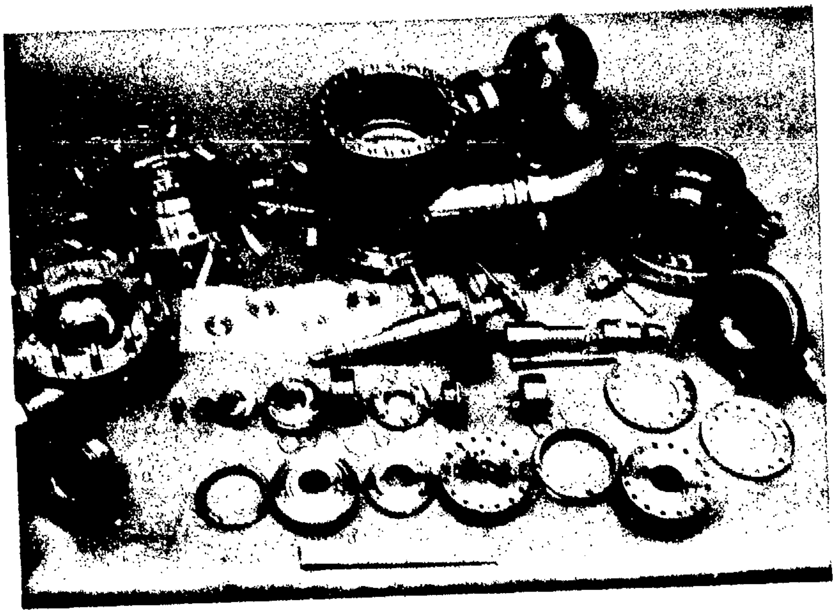

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Figure 53. Mark 48-0 Turbopump S/N 03-0 After Disassembly

Turbine Performance

Six tests were run in test series 5 on the Mark 48-0 turbopump, using gaseous hydrogen as the turbine working fluid and liquid oxygen in the pump. Only test 6 achieved high speed (7121 rad/s, 68,000 rpm) and was a pump head-flow test.

Test 6 was studied for turbine performance at 3141 and 7121 rad/s (30,000 and 68,000 rpm).

Turbine test efficiency is shown in Fig. 54. Turbine efficiency was determined using a delivered power equal to the pump fluid power divided by the pump isentropic efficiency. Turbine available power was calculated from the turbine measured flowrate and the turbine available energy determined using NBS Technical Note 617 for gaseous hydrogen properties. Turbine predicted efficiency and calibration tests efficiency characteristics are shown in Fig. 54. For the 7121 rad/s (68,000 rpm) test points, the average efficiency was 59.0% at an average velocity ratio of 0.384. This compares well with the predicted efficiency of 61.5% at the same velocity ratio and is significantly higher than the performance indicated by the calibration tests of Ref. 1. The efficiency averaged 74% using the turbine temperature drop measurements. This is higher than expected, probably due to the seal purge and rotor coolant hydrogen flows reducing the turbine outlet temperature. The effect of these flows on turbine outlet temperature could be assessed if rear bearing supply flow were measured. Rear bearing coolant discharge flow is measured and the difference would be the flow into the turbine.

Turbine flow parameter data are shown in Fig. 55. Turbine flow parameter relates inlet flow, pressure, temperature, and nozzle area to turbine pressure ratio and the speed parameter. Previous tests have shown the turbine flow parameter to be relatively independent of turbine speed parameter for this partial admission turbine. The flow parameter equation in Fig. 55 is the standard nozzle flow equation. The test data at 7121 rad/s (68,000 rpm) show good agreement with the prediction being within 2.4% of the equation value.

Rotor upstream and downstream hub static pressure measurements indicate a pressure rise across the rotor of from 3 to 5% of the turbine pressure drop. This trend has been indicated in previous tests and possibly is caused by the rotor blade pumping in the inactive arc with the nonsymmetrical rotor blades. In general, the performance of the turbine is as expected.

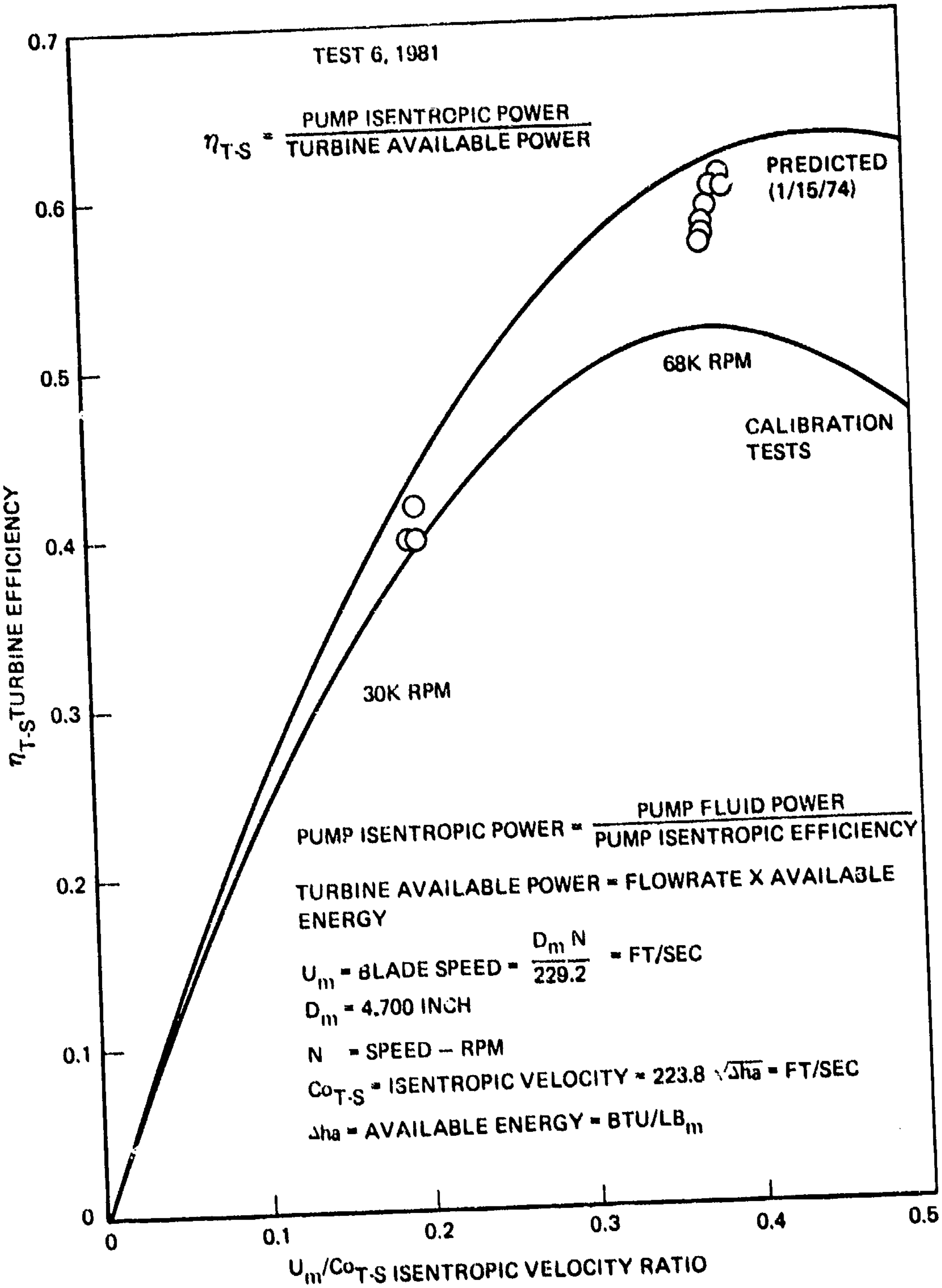

Figure 54. Mark 48-0 Turbine Test Performance

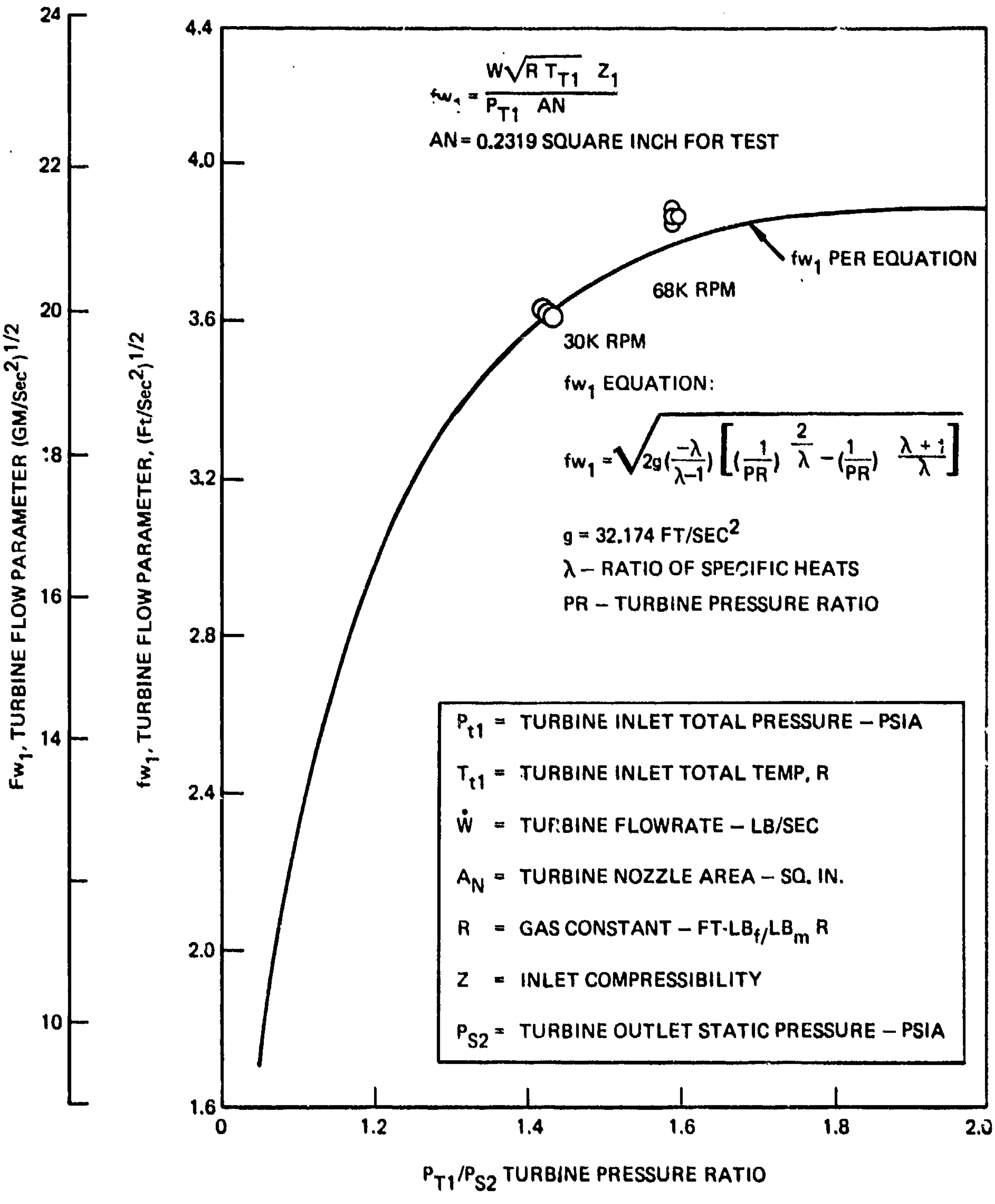

Figure 55. Mark 48-0 Turbine Test Performance

Pump Hydrodynamic Performance

Pump Head Rise. The pump head rise was derived from the same basic measurements as used in previous test series, namely the pump inlet and discharge duct static pressures and the measured flow. There had been no design changes in the hydrodynamic passages through the primary pumping elements since the previous test series in May 1978, thus the results from this previous series (Ref. 2) would be expected to be repeated in the current series. However, it should be pointed out that the hardware being tested is new hardware that had not been previously tested. Also, the new hardware had experienced some machining discrepancies in the fabrication phase leading to thin sections of blades and shrouds on the impeller. The effect of these discrepancies on the blade angle distribution and the resultant impact on hydrodynamic performance was expected to be relatively minor, but this can only be verified via tests.

Figure 6 presents the head-flow characteristics derived from previous tests in 1977 and 1978. The data from both series appear to define a single characteristic and, using a least squares curve fit procedure, the equation shown on the curve was derived to represent these data. This characteristic provides a basis for comparison of the recent data. Figure 56 shows the H-Q data from test 3, 4, and 5 of the current test series and compares the data with the curve-fit characteristic. The data are scaled to 7330 rad/s (70,000 rpm), but the tests were actually run at approximately 3141 rad/s (30,000 rpm). All three tests show consistent trends, and the resulting H-Q characteristic is seen to be higher in head than in the previous series. The head is approximately 6% higher varying from approximately 4.5% at the lowest flow tested to 10% at the highest.

There is no obvious explanation for the higher head rise. The pumps are by design identical as far as the pumping elements are concerned. The flow through the balance piston could be different because of the changes made in the downstream flow system. However, to make the data consistent with the previous H-Q data, the flow through the balance piston in the current build would have to be approximately $1.26 \times 10^{-3} M^3/s$ (20 gpm) less at 7330 rad/s (70,000 rpm) than on the previous test series which represents approximately a 50% reduction, but the fact is that the balance piston flow is actually higher on the current system as measured and by design. Thus, this cannot explain the higher head. The only other potential explanation is that the new impeller has sufficient differences in actual blade layout to produce the higher head. The effective blade angle at the impeller discharge would have to be off by 0.07 radians (4 degrees) to account for this much head increase.

The design flowrate at 7330 rad/s (70,000 rpm) is $1.46 \times 10^{-2} M^3/s$ (232 gpm) so the test data cover a range of flow from approximately 80 to 120% of design flow. This can be seen in Fig. 57, which shows the same head rise but as a function of the ratio of Q/N divided by the design value. The same data are also plotted in Fig. 58 as the dimensionless parameter of head coefficient (ψ) versus inlet flow coefficient (ϕ) where these coefficients have their normal definition.

Similar data analyses were performed for test 6 which included testing near 7330 rad/s (70,000). There were problems encountered with the transducers for test 6 in that drifts were encountered between the pre- and posttest calibrations.

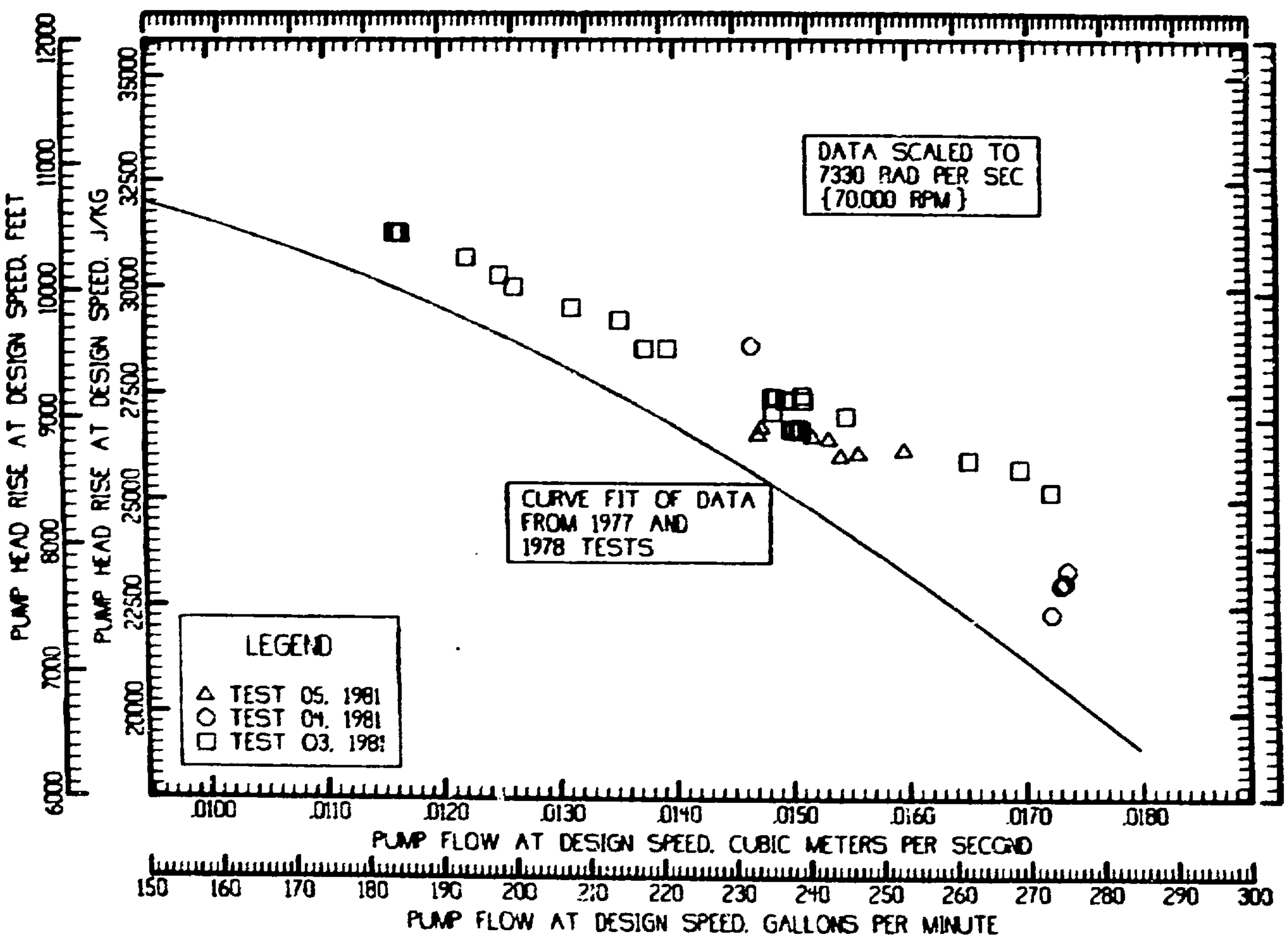

Figure 56. Pump Head-Flow Curve Scaled From 1981 Low-Speed Tests

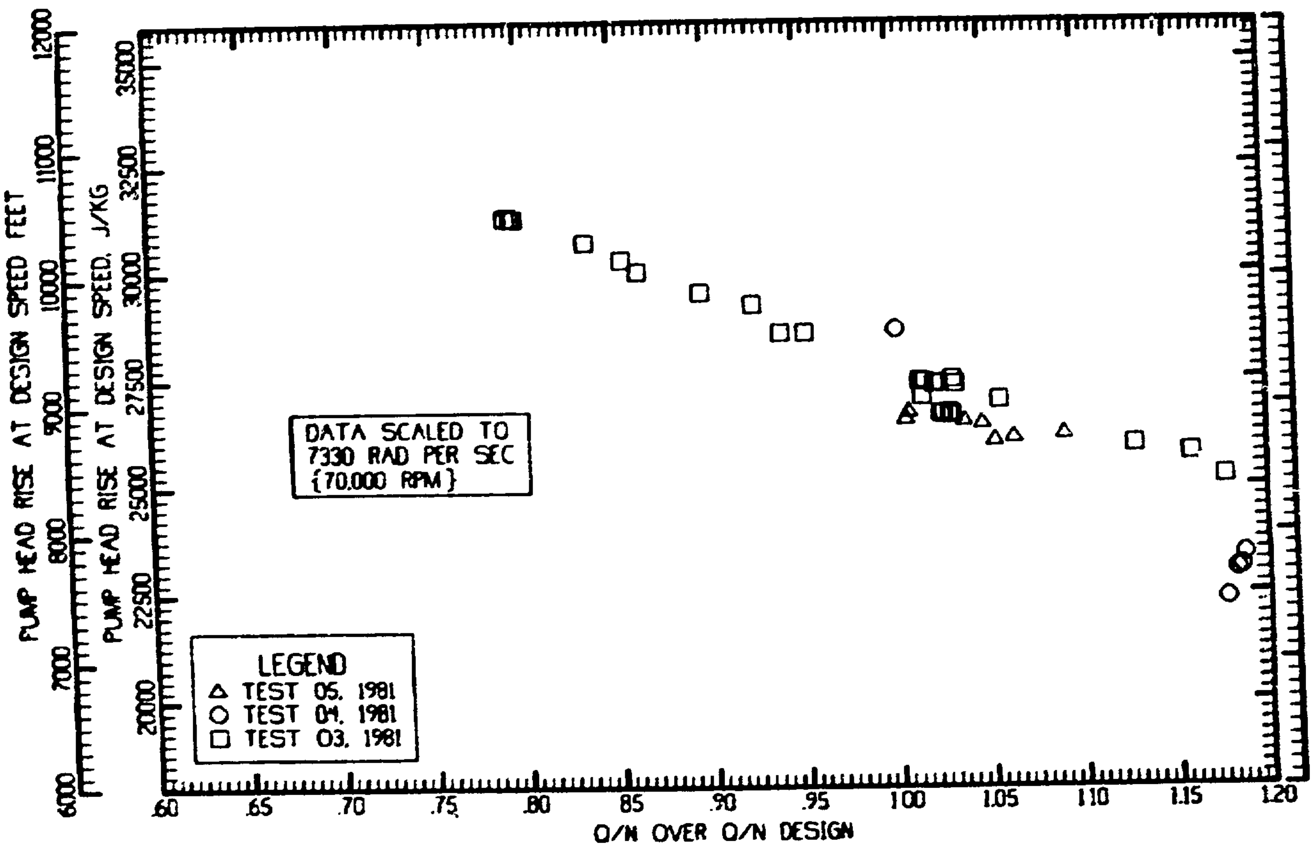

Figure 57. Pump Head as a Function of Dimensionless Q/N (1981 Low-Speed Tests)

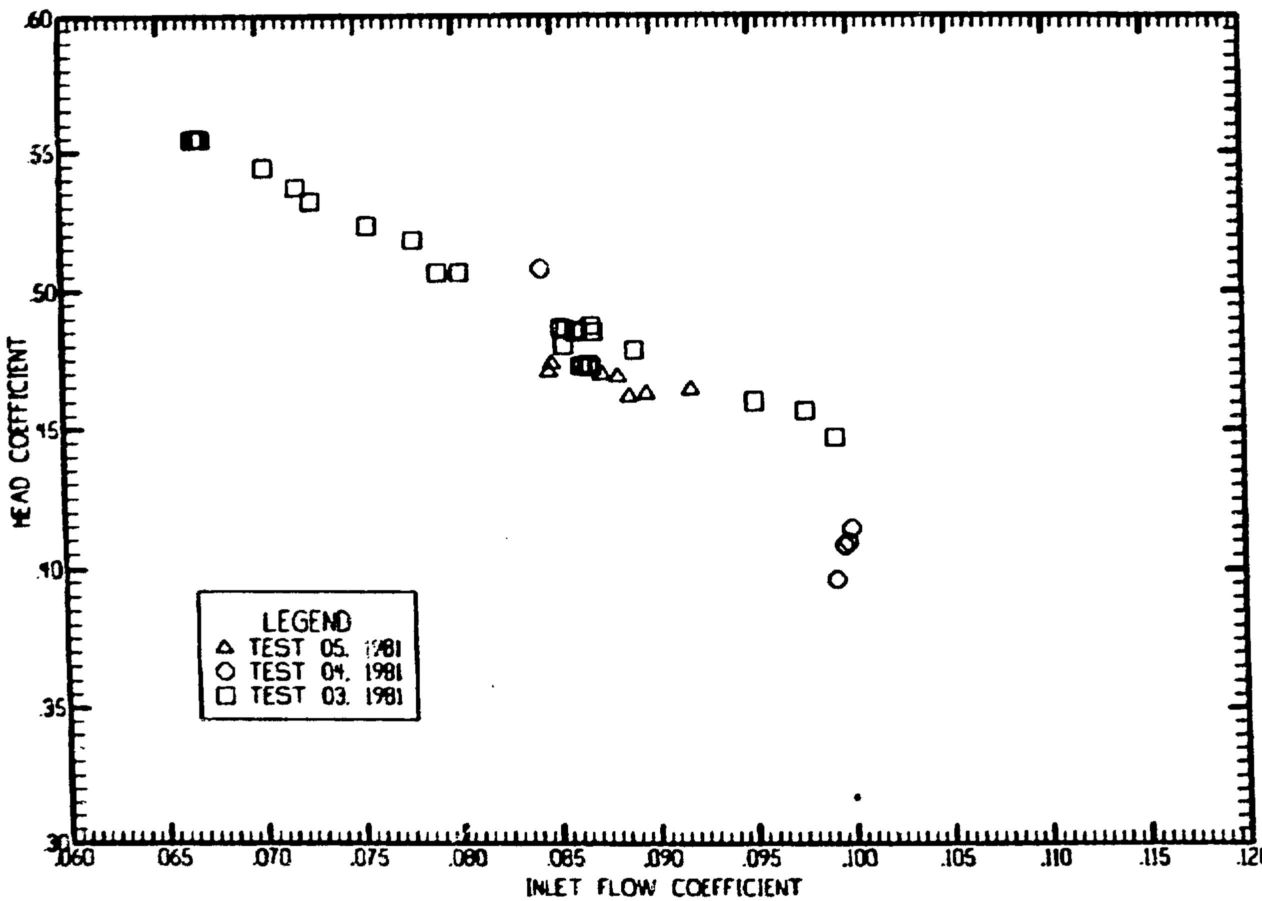

Figure 58. Pump Head Coefficient vs Inlet Flow Coefficient (1981 Low-Speed Tests)

The data were reduced using both the precalibration and postcalibration signals, but neither resulted in consistent trends compared with test 3, 4, and 5. It was finally established that the best general agreement of the data for the four tests was achieved using a calibration signal that was the average of the pre- and postcalibration. The results were scaled to 7330 rad/s (70,000 rpm) and are plotted in Fig.59. There are several points of interest in these data. First, the data in the low flow region show reasonably good agreement with the data from tests 3, 4 and 5, as can be seen by comparing Fig. 59 and 56. This agreement appears to hold up to a flow of approximately 1.50 x 10^{-2} M^3/s (240 gpm) which is 3% above the design flow. The data at higher flows show a continual decrease in head until at the highest flow the head is actually 20% below its scaled value from tests 3, 4, and 5. This characteristic is typical of cavitation induced head loss, and these results are discussed further in the section below entitled Suction Performance.

A third point of interest in the data of Fig. 59 is the presence of three data points in the flow range of 1.45 to 1.52 x 10^{-2} M^3/s (225 to 236 gpm) that are near or below the curve fit of the previous test series data. These three points were from the beginning of test 6 and were obtained at a test speed near 3141 rad/s (30,000 rpm). Figure 59 had shown that data from this speed range actually scaled to a higher head rise, and these 3 points reflect some of the inaccuracy associated with the calibration problems that occurred on this test. These data would agree with the results of tests 3, 4, and 5 if the flow were actually higher than the measured value. If the calibration problem has resulted in a flow error that is more prominent in the beginning of the test (when the 3141 rad/s (30,000 rpm) data and high flow data were obtained) but is essentially zero at the end of the test, the apparent cavitation fall off could actually be occurring at higher flows than the measured value shown in the figure. However, there is no way to verify this other than retesting.

Figure 60 and 61 present results for test 6 that compare with Fig. 57 and 58 for tests 3, 4 and 5. The same observations made with regard to Fig. 59 would, of course, also apply to these two figures.

In conclusion, the head rise of the tested pump is higher than the previous pump by about 6% as long as a noncavitating flow condition exists. However, the present pump appears to be more sensitive to cavitation. This will be discussed more fully below.

<u>Pump Efficiency.</u> The efficiency of the pump can be determined in two ways:

1. Using the measured pressure and temperature at the pump inlet and discharges, the pump isentropic efficiency can be calculated

2. Using the calibration curve for the turbine efficiency and the turbine inlet available energy, the pump efficiency can be derived from the calculated input power and measured output power

Of the two approaches, the first has generally been shown to have less data scatter and to provide a more reliable measurement. Both approaches were used to reduce the data from the current tests, and both results are presented below.

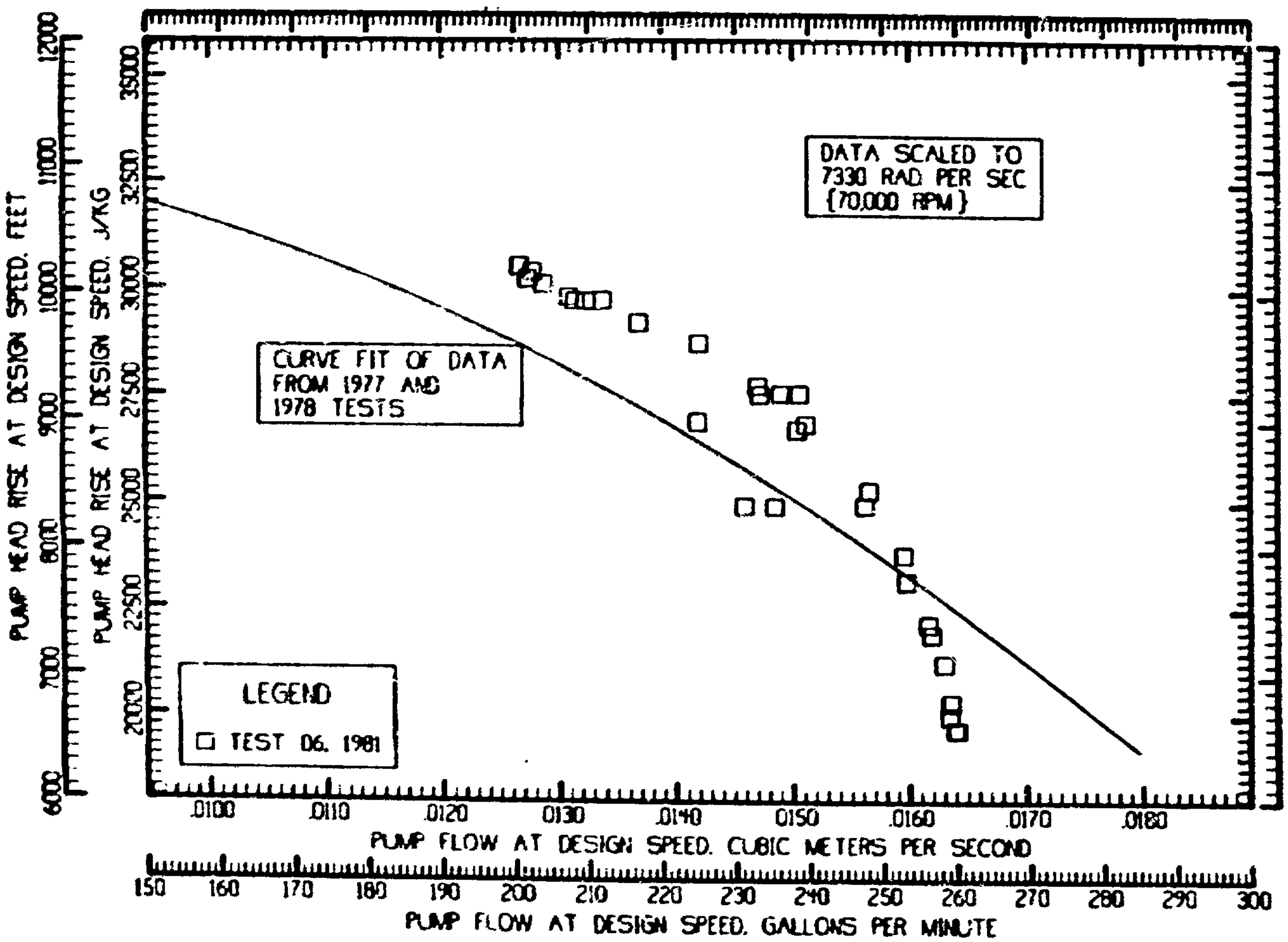

Figure 59. Pump Head-Flow Curve Scaled From 1981 High-Speed Test

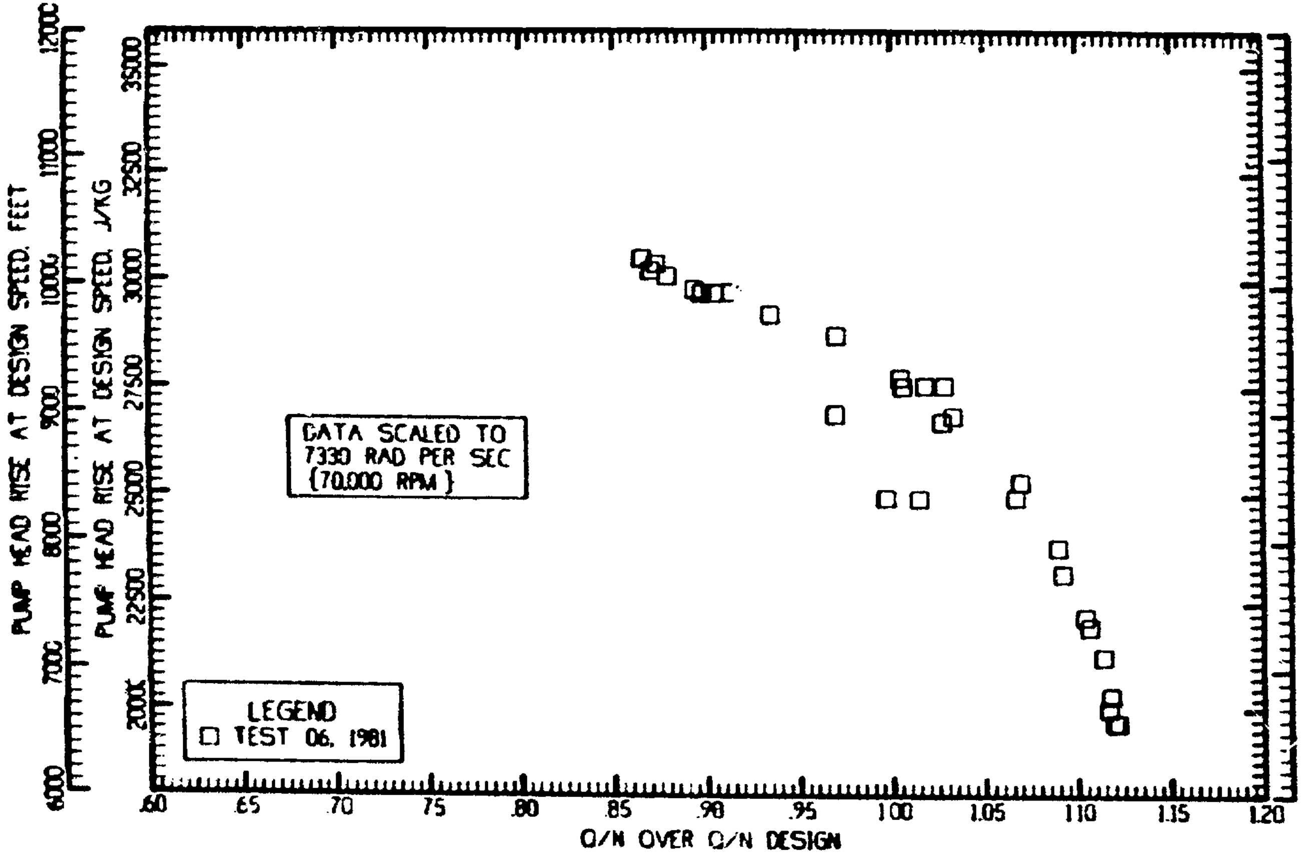

Figure 60. Pump Head-Flow as a Function of Dimensionless Q/N (1981 High-Speed Test)

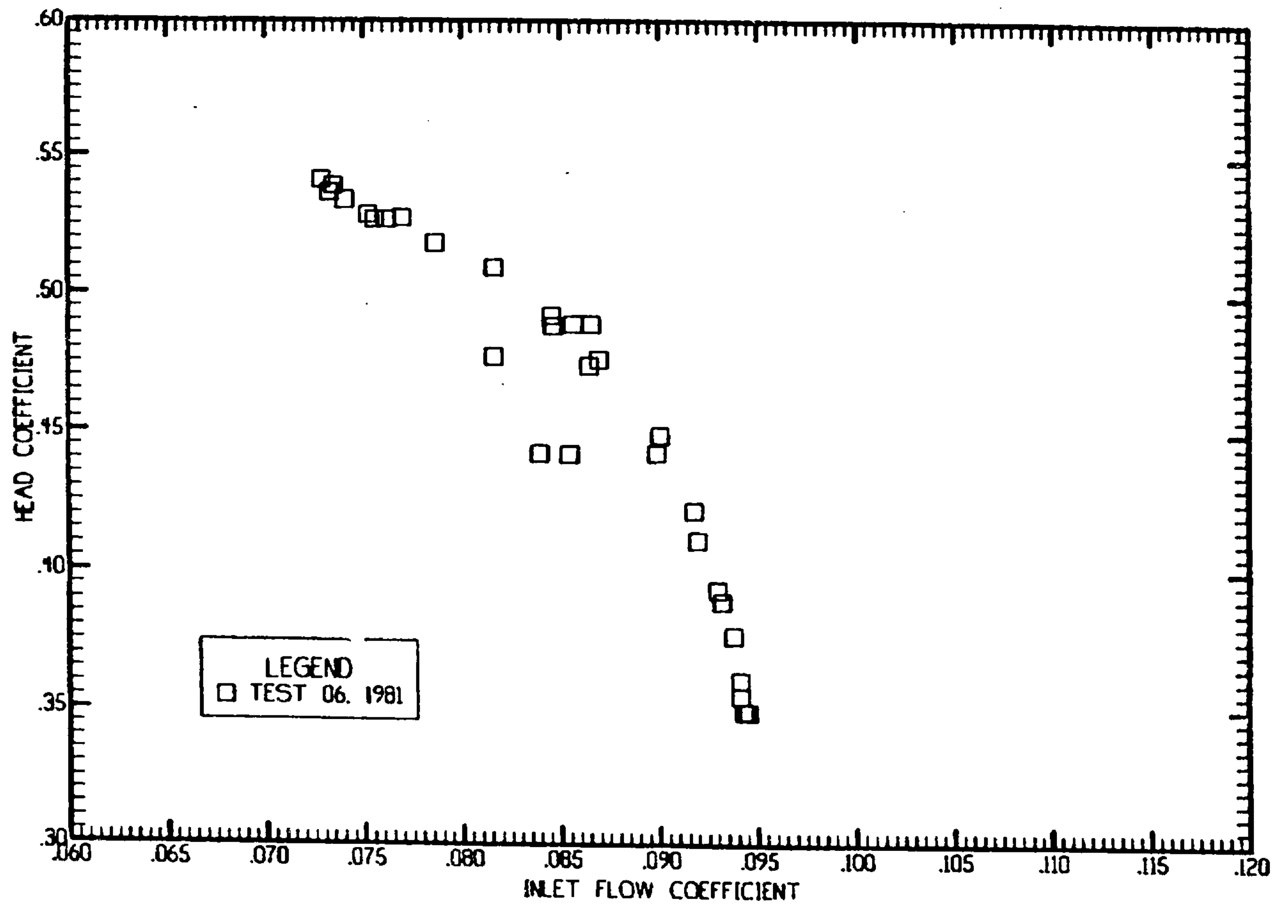

Figure 61. Pump Head Coefficient vs Inlet Flow Coefficient (1981 High-Speed Test)

The isentropic efficiency for tests 3, 4, and 5 is shown in Fig. 62. Tests 3 and 4 show good agreement, both with each other and with the 3141 rad/s (30,000 rpm) data from the 1978 test series.

The efficiency for test 5 is clearly lower by approximately 5 points out of 63, or 8% lower. Before test 5, some orifice size changes made to the balance piston flow overboard dump lines to purposely reduce the sump pressure and increase the axial thrust range of the balance piston. These changes also cause a substantial increase in the flowrate through the balance piston. Using the measured overboard flow and the measured flow through the pump bearing from test 2, 4, and 5 (the bearing flow measurement was not correct on test 3), the ratio of balance piston flow to pump delivered flow can be calculated. The average values for these tests are shown in Table 16.

TABLE 16. AVERAGE PISTON BALANCE FLOW AS A PERCENT OF THROUGH FLOW N=3141 RAD/S (30,000 RPM)

TEST	NO. SLICES	AVERAGE FLOW RATIO (%)
2	2	11.8
4	5	10.8
5	7	20.1

The results show that the balance piston flow actually increased by 8 to 9% of the throughflow for test 5. Because the balance piston flow is a parasitic flow loss, such an increase would result in an 8 to 9% loss in efficiency and, indeed, an 8% drop was experienced. It should also be noted that the magnitude of the flow ratio presented in Table 16 is large as compared with most rocket engine pumps which are generally much larger in size. One of the main reasons it is difficult to achieve the higher efficiencies for a small low-flow pump is that clearances between rotating seals cannot generally be scaled down proportional to the pump diameter and the leakage flows become a much larger percentage of the throughflow.

Figure 63 presents the efficiency for the same three tests using the drive horsepower from the turbine based on turbine efficiency from calibration tests. The efficiency is seen to be higher for this approach but with more scatter and without a distinct difference between test 5 and the other two tests. (This is approach 2 presented above). It is believed that the calibration curve for the turbine is actually too low in efficiency, based on the test data from the current test series which unduly penalizes the turbine and makes the pump look more efficient than it actually is.

At low speeds, the temperature rise from the pump inlet to the pump exit is very small, as shown in Fig. 64. Any instrumentation errors in the temperature measurements will cause a large error in the isentropic horsepower calibration at low speed. Any instrumentation errors at high speed will cause less error in the isentropic horsepower calculation because of the higher temperature rise at those speeds.

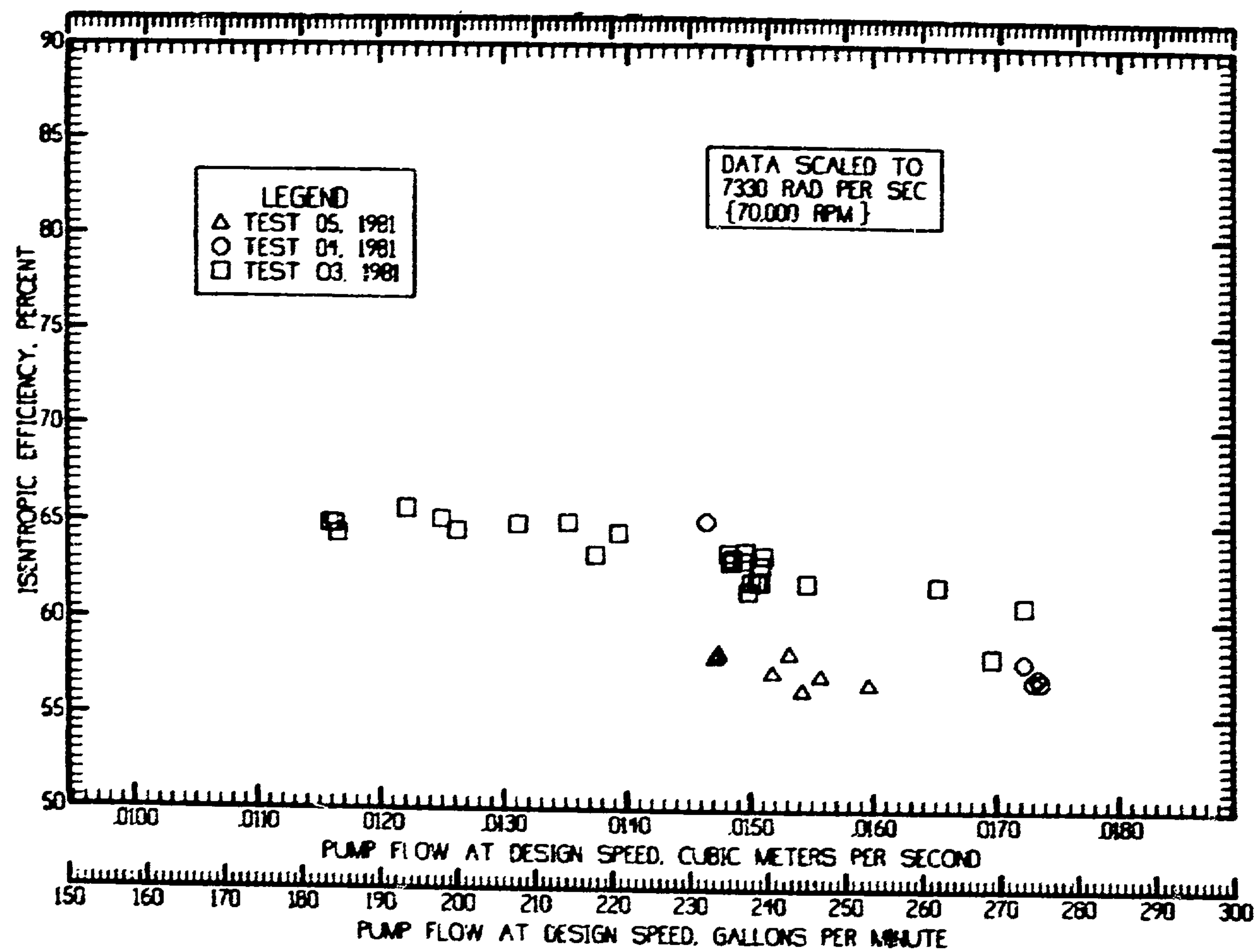

Figure 62. Pump Isentropic Efficiency Based on 1981 Low-Speed Tests

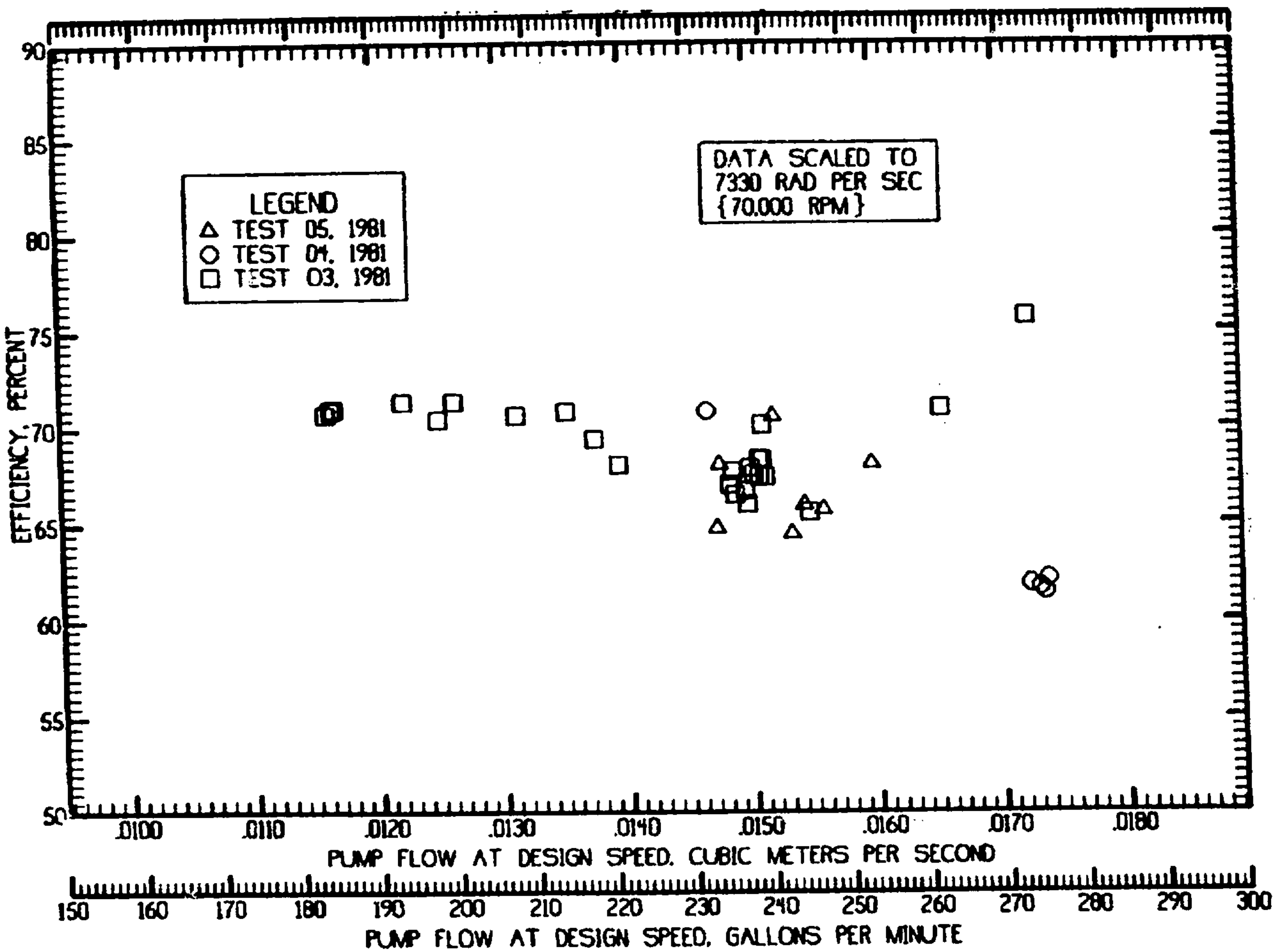

Figure 63. Pump Efficiency Based on Turbine Calibration Curve (1981 Low-Speed Tests)

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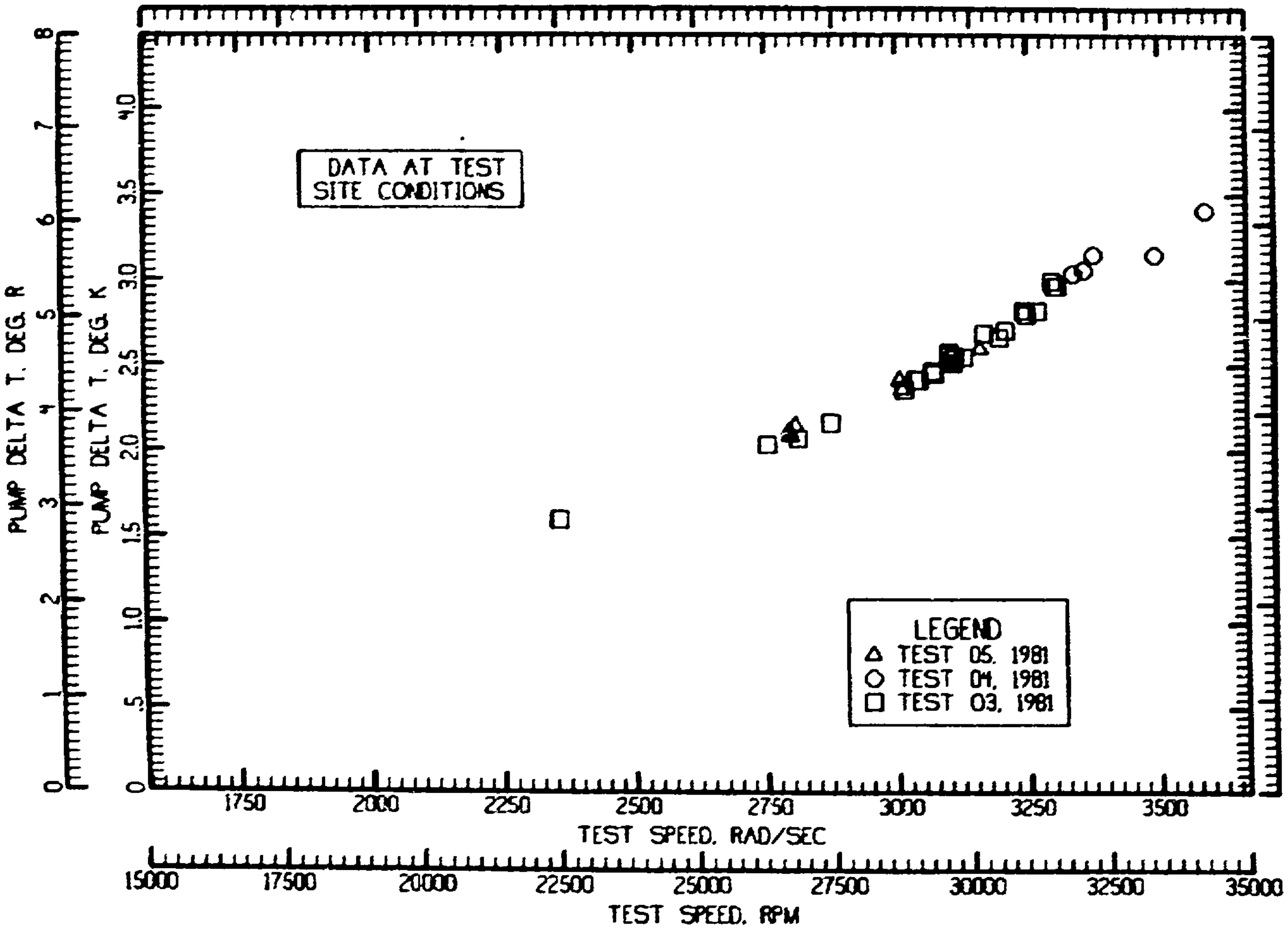

Figure 64. Pump Temperature Rise During 1981 Low-Speed Tests

Therefore, more confidence can be placed upon the data at speeds near 7330 rad/s (70,000 rpm). The isentropic efficiency calculated from the measured parameters at high speeds (test 6) are presented in Fig. 65. Note that the three points between $1.46 \times 10^{-2} M^3/s$ (226 gpm) and $1.518 \times 10^{-2} M^3/s$ (235 gpm) that are below the data trend are the three data points obtained at the beginning of the test near the 3141 rad/s (30,000 rpm) operating speed. The data at or below the design flow are consistent with the data previously obtained near 7330 rad/s (70,000 rpm), and the efficiencies achieved are considered to be very good for this size pump. The peak efficiency is over 68% at the lower flows, and the efficiency at the design point is over 67%. The design point efficiency had been predicted at 70% with the peak efficiency occurring at the design flow. However, previous tests had shown the same deviations from the predicted values as observed for the current test series. The data suggest that at least one element of the pump (i.e., either the inducer, impeller, vaned diffuser, or volute) is undersized so it matches better with the lower flow. Based on the loss coefficients for these elements (Ref. 1) the diffuser losses are predominant, making it more suspect as the cause of the lower design point efficiency. Also, the diffuser was designed structurally to withstand very large tensile stresses due to the high volute pressures attempting to separate the volute. Thus, the blade blockage for the diffuser is relatively large. However, more extensive studies would have to be conducted to try to identify the actual cause of the peak efficiency occurring at a lower flow.

The temperature rise through the pump for the higher speed operation is shown in Fig. 66. The temperature rise is approximately 6 times as high at the higher speed providing much better data accuracy such that the isentropic efficiency based on test 6 is believed to be a much more accurate value. The falloff of efficiency at the higher flows is due to the same phenomenon as caused the head falloff presented in previous figures. The efficiency for test 6 based on the turbine calibration is shown in Fig. 67. Again, the results are higher than for the isentropic efficiency and, in fact, are obviously too high, exceeding 84%. Thus, the isentropic efficiency is still believed to be a better value.

The head and efficiency data can be used to generate the power curve for the pump. The results are shown in Fig. 68 for tests 3, 4, and 5 and in Fig. 69 for test 6. This power is defined as the pump input horsepower

$$h_p = \Delta H \, \dot{w}/(550 \, \eta)$$

where ΔH is the head rise, $\dot{w}$ the weight flowrate, and η is the pump efficiency. The most representative results are the values from test 6 at or below design flow based on the accuracy arguments presented above.

Inducer Static Pressure Rise. One of the special parameters measured during the test series is the inducer discharge static pressure. The measurement is intended to provide an evaluation of inducer performance to permit identification of any potential inducer problem. It also identifies the downstream pressure boundary condition for analyzing the balance piston recirculating flow, because the balance piston flow that does not pass through the bearings is dumped back into the flowstream between the inducer discharge and impeller inlet. (even the bearing flow can be routed to return to this same dump location.)

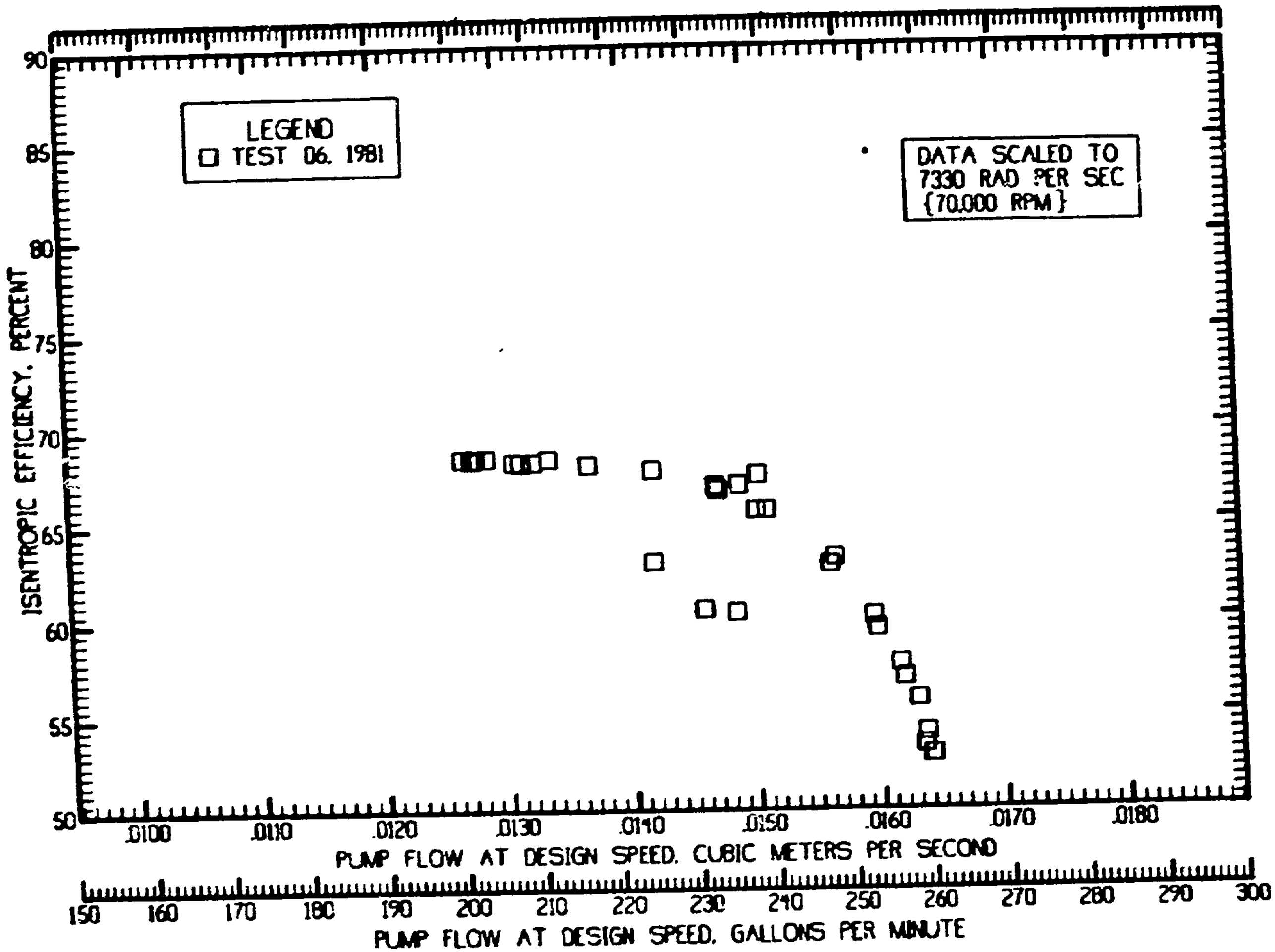

Figure 65. Pump Isentropic Efficiency Based on 1981 High-Speed Test

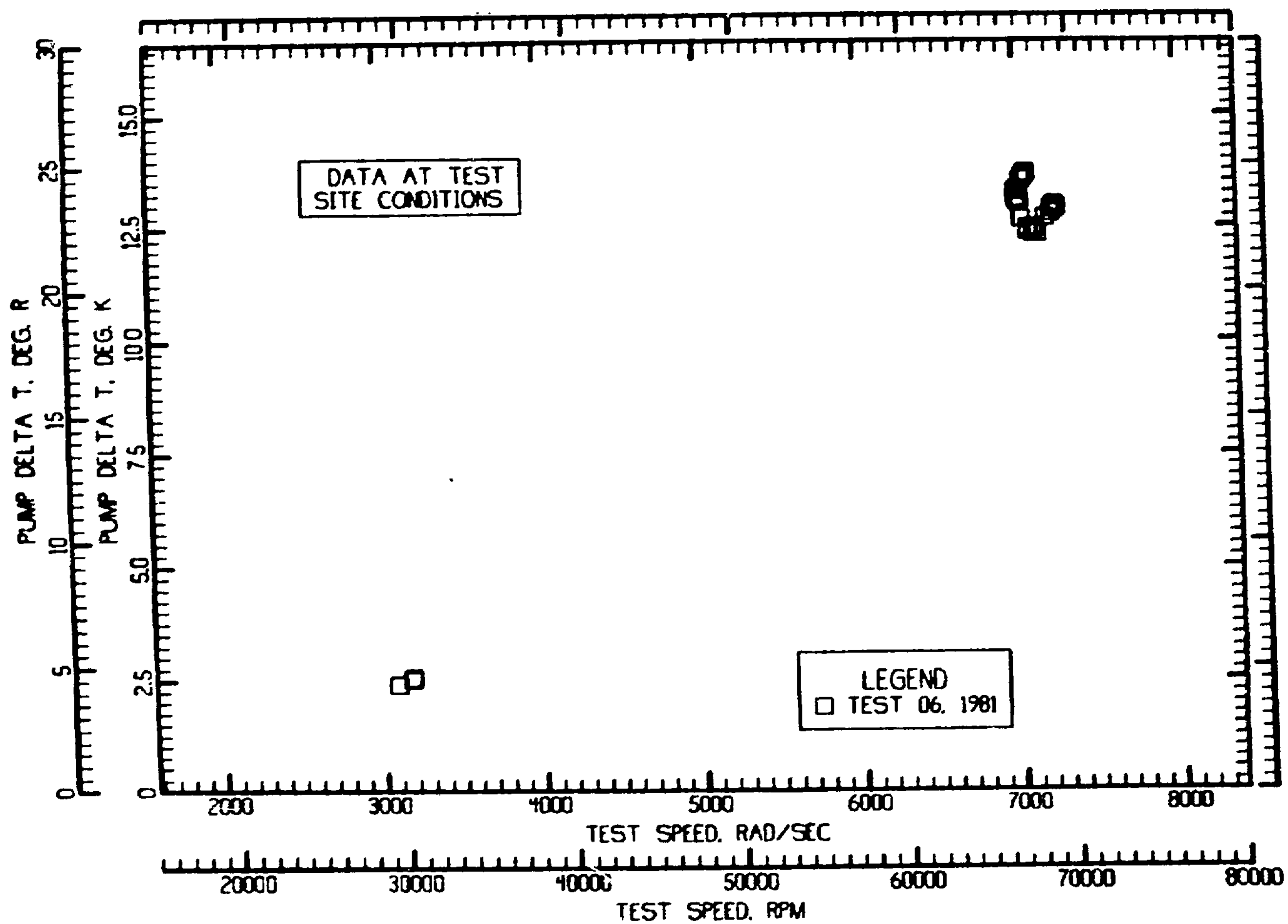

Figure 66. Pump Temperature Rise During 1981 High-Speed Test

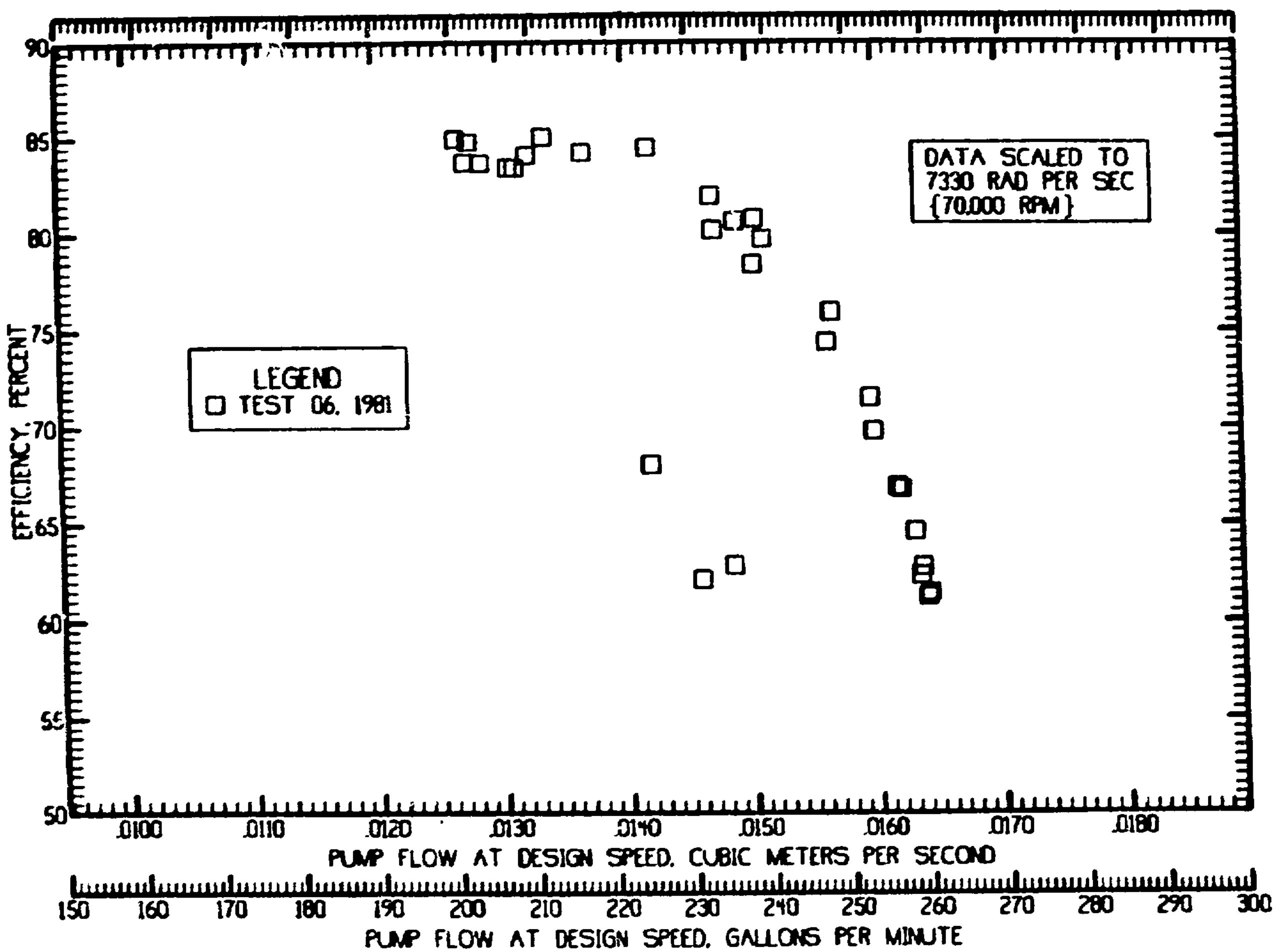

Figure 67. Pump Efficiency Based on Turbine Calibration Curve (High-Speed Test, 1981)

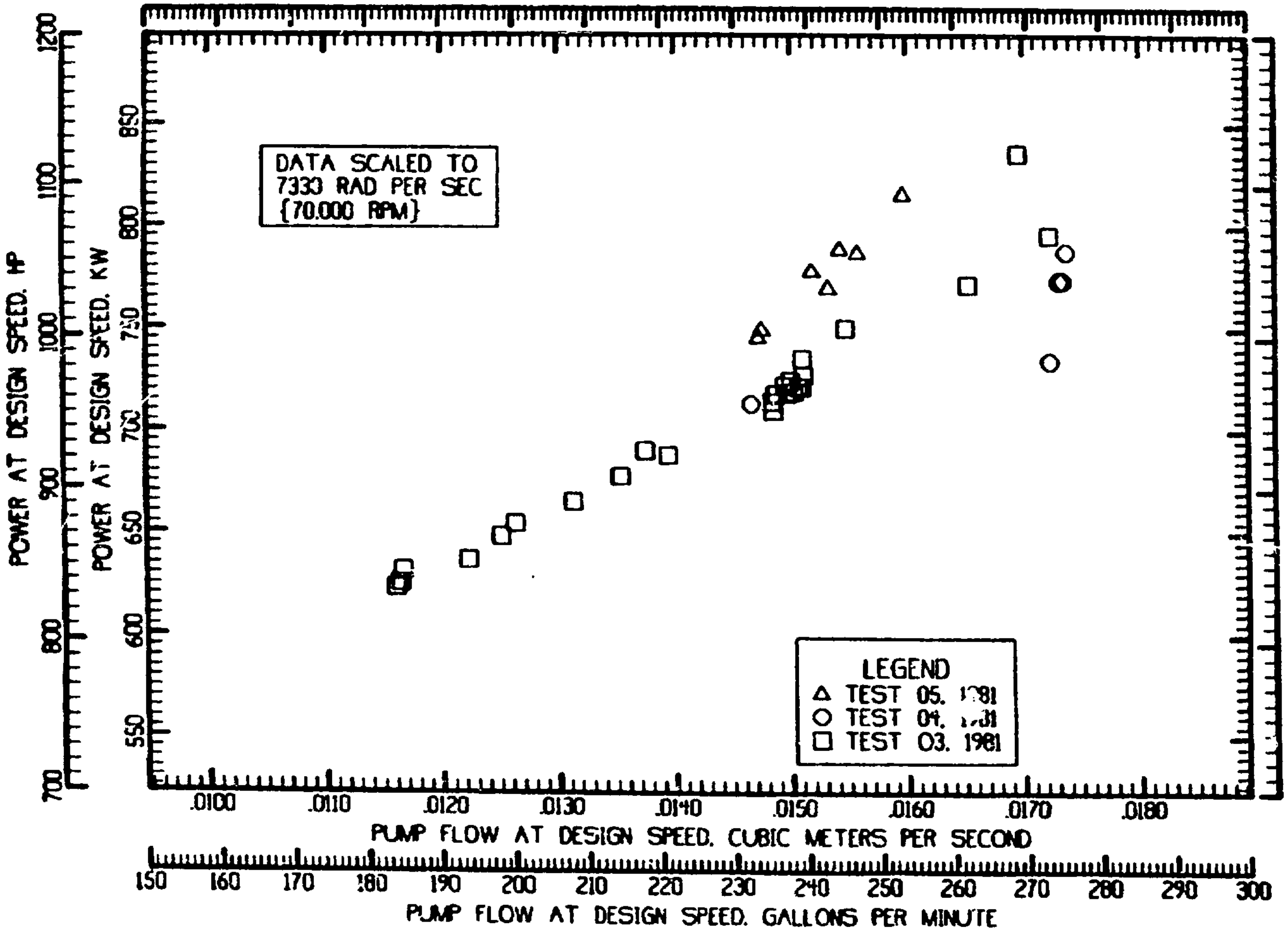

Figure 68. Pump Input Horsepower Scaled From 1981 Low-Speed Tests

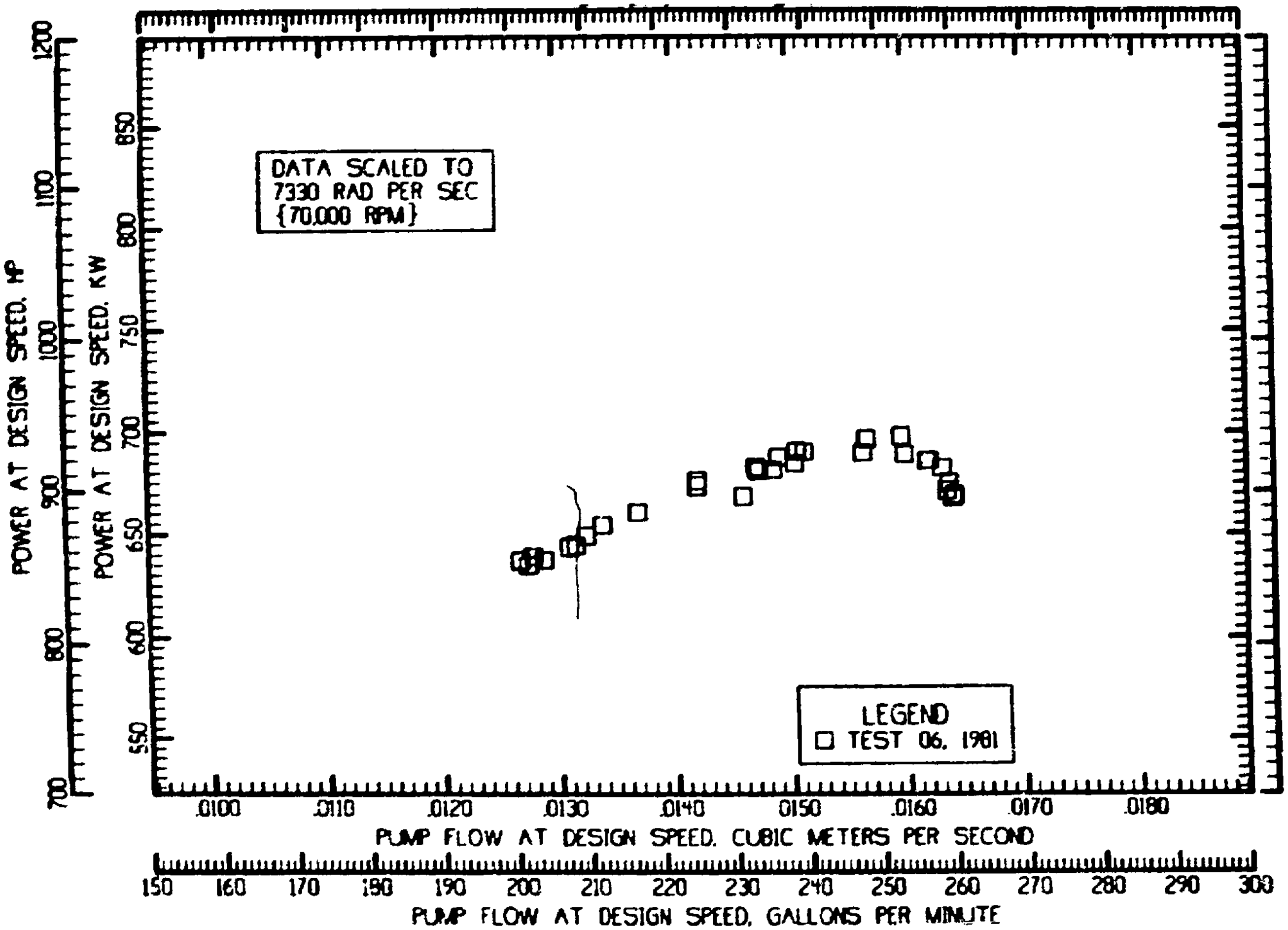

Figure 69. Pump Input Horsepower Scaled From 1981 High-Speed Tests

During the 1977 and 1978 test series, this measurement was located flush with the wall at the tip of the inducer. Thus, it was intended to measure the tip static pressure at the inducer discharge. The test had shown this pressure to be significantly lower than the predicted value (Ref. 2). It was pointed out at the time that the low value could be due either to a faulty measurement of a hydrodynamic deficiency, and if the latter were the case, it could seriously affect the suction performance of the impeller.

In the current test series the measurement location was moved to the area where the front wear ring flow dumps into the impeller inlet as shown in the sketch of Fig. 70. This measurement position provides a more direct measurement of the dump pressure for the balance piston recirculating flow, but it is not as accurate for the inducer discharge pressure because any vortex gradient occurring in the fluid between the measurement and the inducer tip will result in a pressure differential between these two locations.

The inducer static pressure rise for tests 3, 4, and 5 and for test 6 are shown in Fig. 71 and 72, respectively. In both cases the data have been scaled to 7330 rad/s (70,000 rpm) so they can be compared to each other. The pressure rise is defined as the measured discharge static pressure minus the measured pump inlet static pressure. In comparing the results of Fig. 71 with those of Fig. 72, it can be seen that the data are only in fair agreement with the higher speed data giving almost 9% higher pressure rise until the drop in pressure above design flow is experienced. This is caused in part by the recirculation of the balance piston flow on the high speed test. Comparison of the pressure rise from either Fig. 71 or 72 with the measurement from the 1978 test series (Ref. 1) shows that the current measurement is significantly higher. The 1978 series data indicated a pressure rise of only 2088 N/M^2 (303 psi) at design flow and 7380 rad/s (70,000 rpm) based on the high speed data and only 271 psi at the same conditions based on low speed data. The data from Fig. 71 and 72 show a pressure rise of 4.350 N/M^2 (631 psi) and 4.736 N/m^2 (687 psi), respectively, at the design flow and 7330 rad/s (70,000 rpm). In fact, the values presented in Fig. 71 and 72 actually exceed the design pressure rise which was 3.612 N/m^2 (524 psi) at design flow and 7330 rad/s (70,000 rpm). Thus, the existence of a pumping gradient between the measurement location and the inducer tip is certainly indicated as would be expected.

Assuming that the front wear ring flow has a tangential velocity that is 1/2 the wheel speed and that this velocity relationship is preserved downstream of the wear ring, the pressure gradient between the measurement and inducer tip can be calculated. Using a LOX density of 1121 Kg/m^3 (70 lb/ft^3) and a speed of 7330 rad/s (70,000 rpm), this pressure gradient would actually have a magnitude of 2.00 N/m^2 (290 psi). Subtracting this value from the 4.74 N/m^2 (687 psi) measured pressure rise of Fig. 72 gives a resultant of 2.74 N/m^2 (397 psi). This latter value is closer to but higher than the previous measured values of the 1978 test series. If the fluid swirl in this region were at only 40% of wheel speed (K = 0.40), the pressure gradient would have a magnitude of only 1.28 N/m^2 (186 psi) and the resulting inducer static pressure rise would be 3.45 N/m^2 (501 psi) at design flow which is within approximately 4% of the design value. With the expected leakage flows of the front wear ring, a fluid swirl of only 40% of wheel speed, or even lower, is certainly possible as has been shown in numerous studies where the flow coefficient was increased for flow between a rotating and stationary disk.

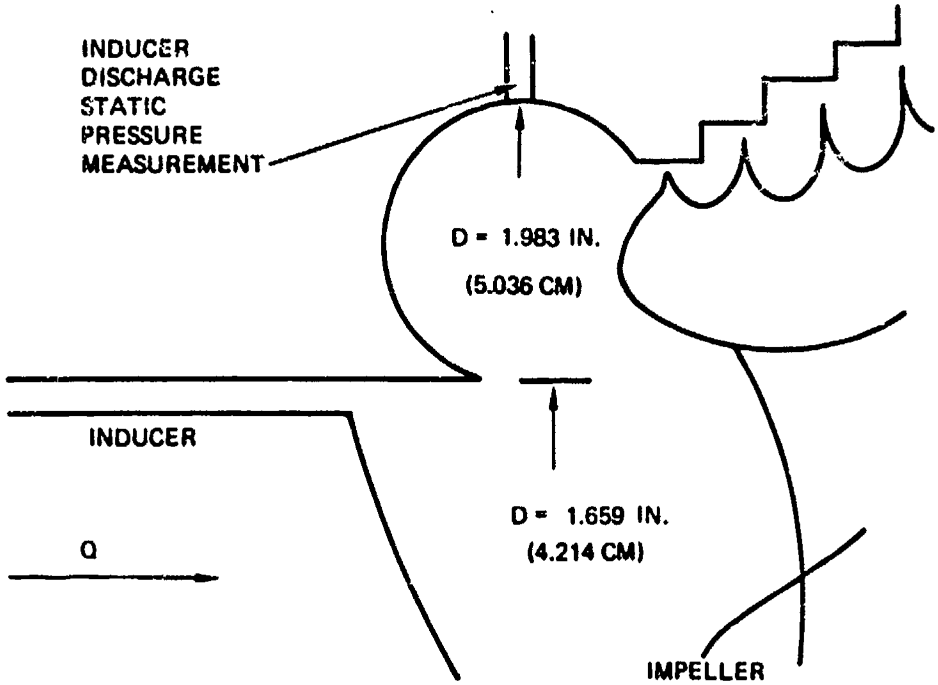

Figure 70. Inducer Discharge Static Pressure Measurement

Also, the test data during test 6 at high test speed show a minimum inducer static pressure rise at high flowrate of only 1.33 N/m^2 (193 psi) (scaled to 7330 rad/s (70,000 rpm). Thus, the pumping gradient is not likely to exceed this value unless a low density exists in this pocket. Thus, the current measurements indicate that the static pressure rise approaches and could very well agree with the predicted pressure rise value, but the exact magnitude of the pressure cannot be determined with the available data.

Another interesting observation from test 17 is that the inducer static pressure rise for test 5 is obviously lower than the data for tests 3 and 4. However, it was previously pointed out that the balance piston flow was higher for test 5 by some 1.26 x $10^{-3}m^3/s$ (20 gpm). Thus, the inducer flow is higher by that magnitude, but Fig. 71 and 72 are plotted as a function of delivered flow rather than inducer flow. If the test 5 data in Fig. 71 were moved horizontally to a flow that is 1.26 x $10^{-3}m^3/s$ (20 gpm) higher they would show excellent agreement with the data for tests 3 and 4.

The data at high test speed from Fig. 72 show the same significant decrease in pressure rise at approximately 3% above design flow as was observed in both the overall pump head and efficiency. This is extremely important because if the falloff is due to cavitation, as it appears to be, it is important to know if the cavitation problem originates in the inducer or in the impeller. The data of Fig. 72 definitely show that something is occurring in the inducer.

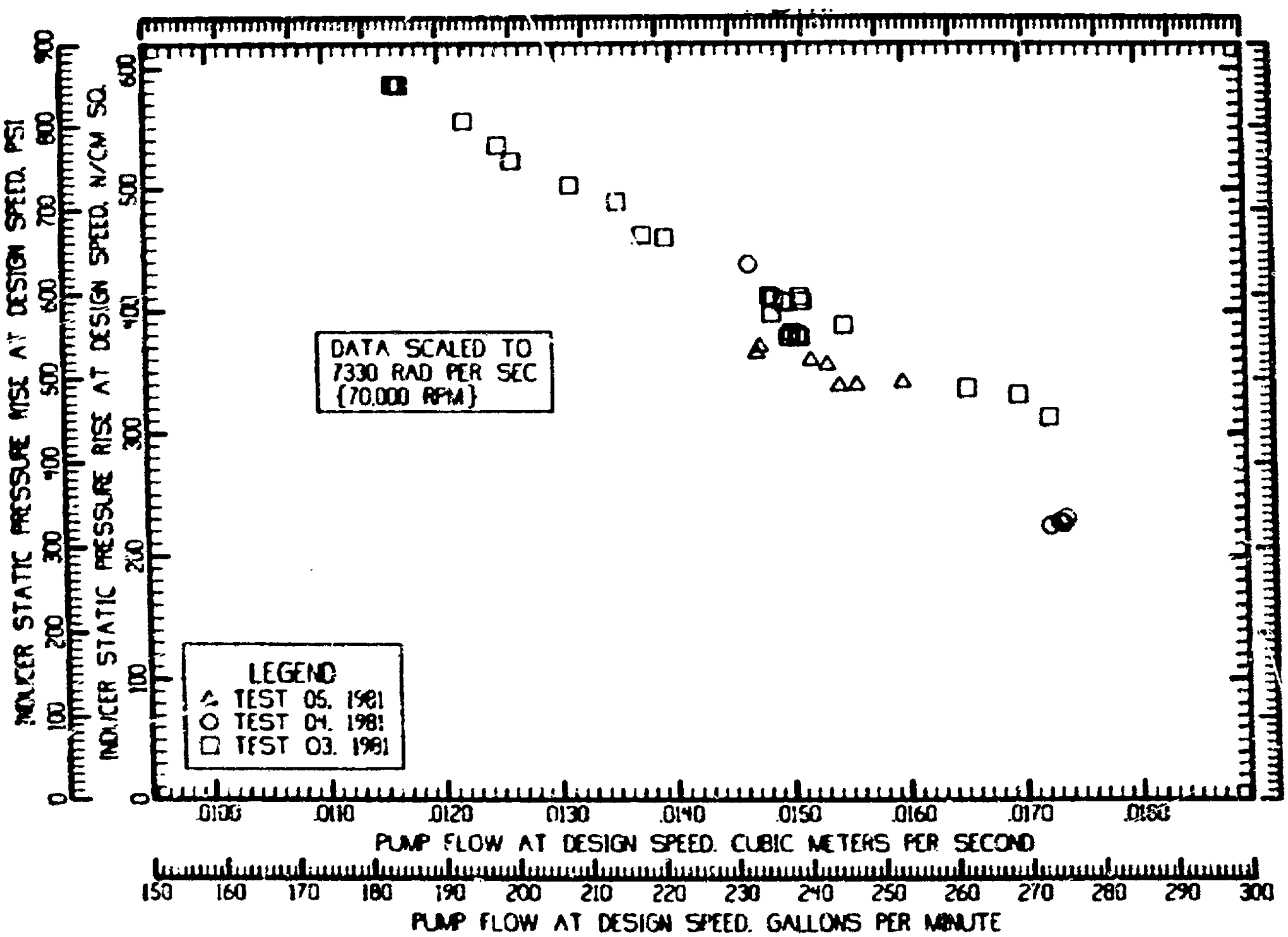

Figure 71. Inducer Static Pressure Rise as a Function of Flow Scaled From 1981 Low-Speed Tests

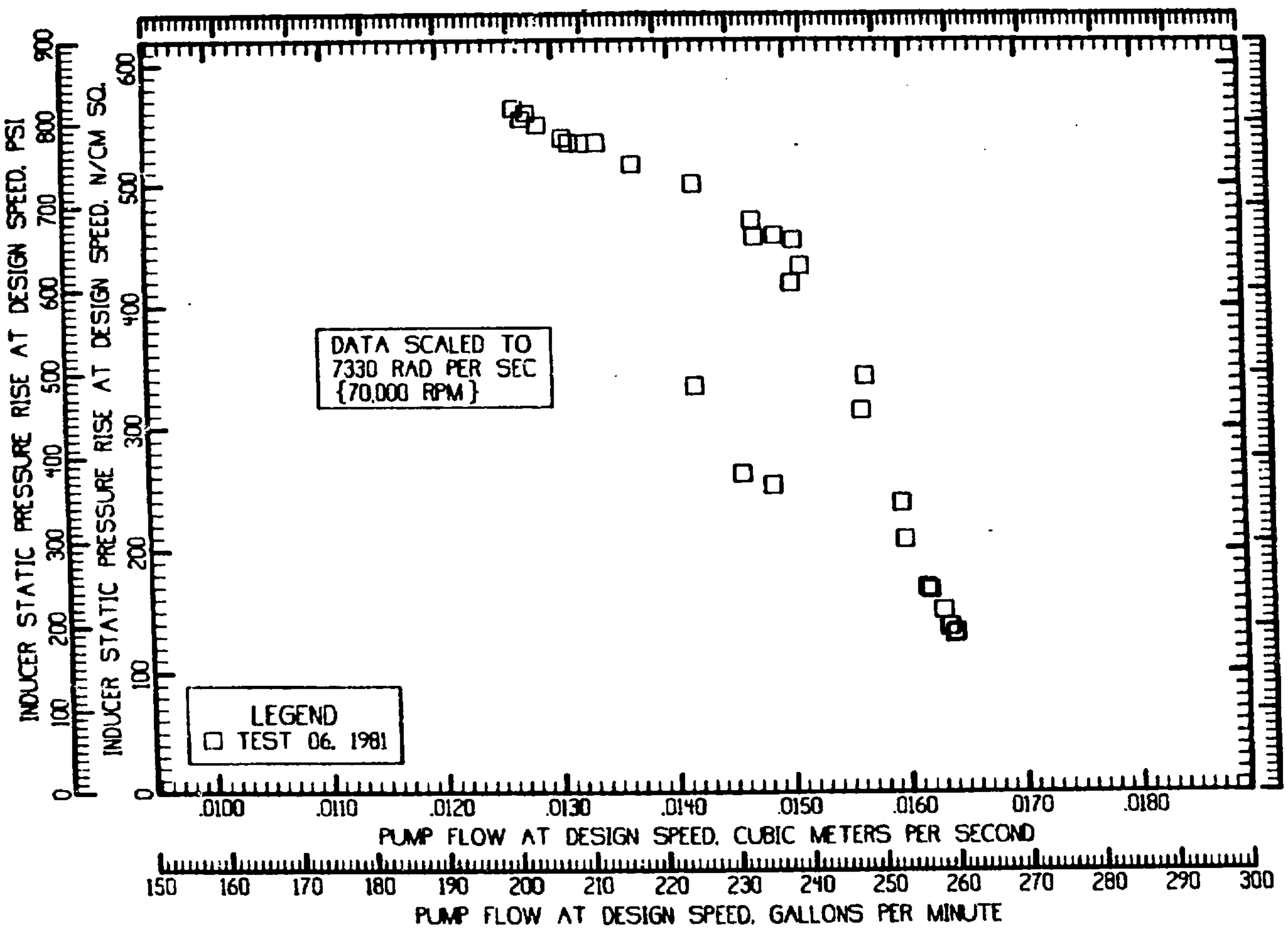

Figure 72. Inducer Static Pressure Rise as a Function of Flow Scaled From 1981 High-Speed Test

Such a significant dropoff could certainly trigger impeller cavitation, but the inducer is at least experiencing its own problem. This problem is discussed further in the following section.

Suction Performance. It was intended for cavitation tests to be performed at selected flows during the current test series to quantitize the suction performance over the flow range. However, test time limitations did not permit these tests to be performed. Nevertheless, the data from the last test at high speed have shown indications of head loss due to cavitation. This effect has been noticed and referred to with regard to Fig. 59, 60, 61, 65, 68, 69, and 72. It has been pointed out that the head falloff is occurring in both the inducer and overall pump. It is of interest to investigate the cavitation related data and attempt to identify the specific cause of the head falloff.

The data from the overall pump and for the inducer pressure rise have been analyzed to calculate the percent of head falloff as a function of flowrate. The results were very interesting and are shown in Fig. 73. The figure contains four curves which are identified as follows:

1. The percent head falloff of the overall pump as a function of flow (curve 1)

2. The percent falloff of the static head rise of the inducer vs flow without any correction to the inducer discharge static pressure measurement (curve 2)

3. The percent falloff of the static head of the inducer vs flow using a correction of 1.28 N/m^2 (186 psi) (corresponding to k = 0.40 at 7330 rad/s (70,000 rpm)) to represent the pumping gradient between the inducer tip and the static pressure measurement downstream of the inducer.

4. Inducer suction specific speed based on inducer inlet pressure vs flow for the high speed test data portion of test 6.

The curves show that the inducer head starts to fall off at a lower flow than the overall pump. Secondly, assuming that the corrected curve 3 is the most representative of the inducer behavior, the inducer static head has fallen by 23% by the time the pump head falloff is 1%. (It should be pointed out that the inducer static head falloff will occur at a faster rate than the inducer total head falloff). Note also that at the highest flow, the inducer static head falloff is almost 100%. Thus, it is apparent that the inducer falloff is the first to occur, and it is probably the primary cause of the falloff of the pump head.

Examining the suction specific speed curve of Fig. 73 shows that the inducer head begins to falloff at a suction specific speed of approximately 15,000 for a flow about 3% above design flow. At the design flow, the predicted suction specific speed was approximately 105260 {rad/s(m^3/s)$^{1/2}$/(J/Kg)$^{3/4}$} (30,000 (rpm)(gpm)$^{1/2}$/(ft-lbf/lbm)$^{3/4}$), and previous designs of large size have been able to achieve the higher suction performance.

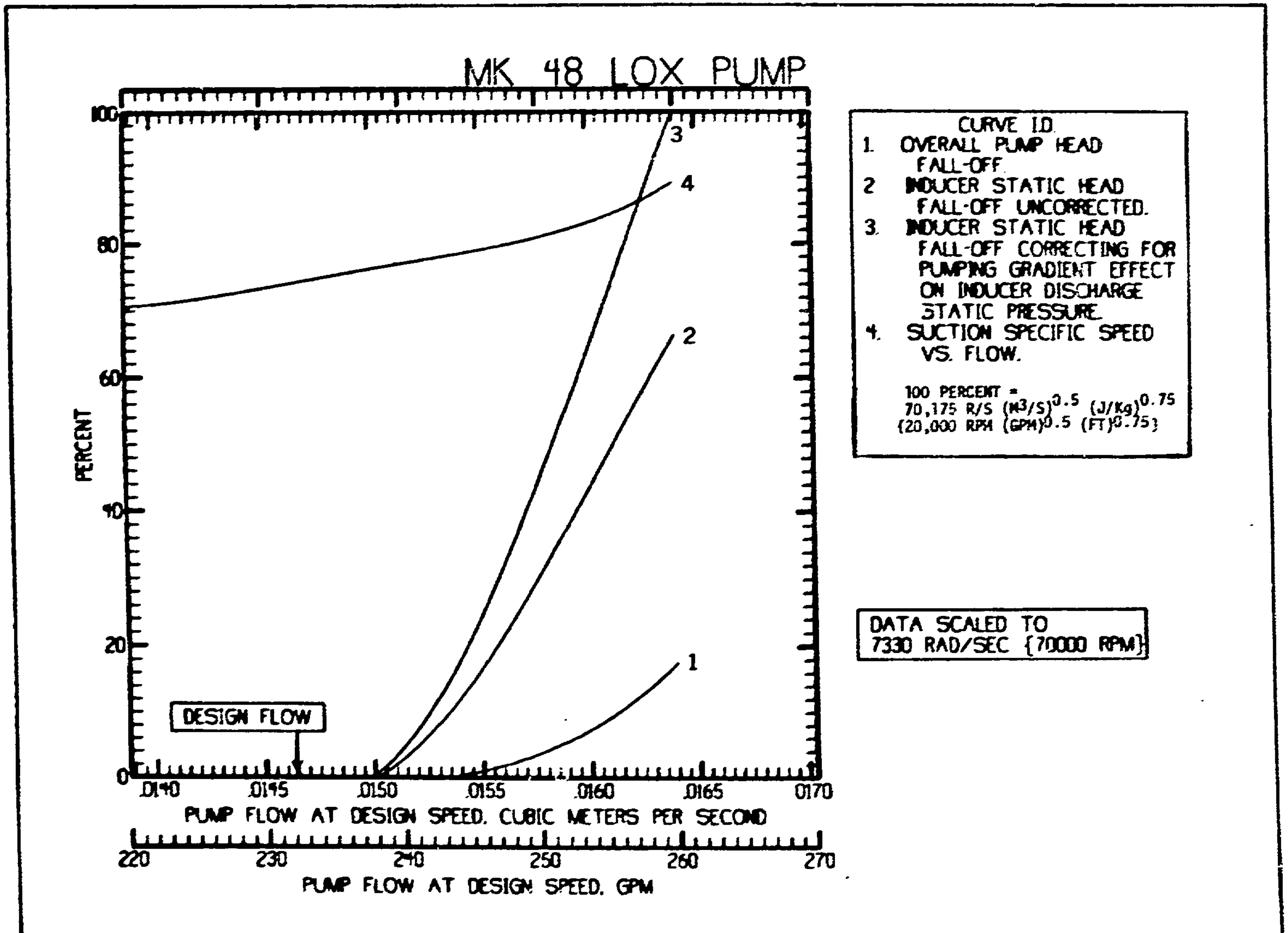

Figure 73. Head Falloff Due to Cavitation and Suction Specific Speed (Test 6, 1981)

The Mark 48 inducer is smaller (D_t = 1.65 in.) than previous designs and this could impact the suction performance because blockage due to fillets, boundary layers, etc. is much more severe percentage-wise. However, it is believed that a design exceeding 52,631 {(rad/s)$(m^3/s)^{1/2}/(J/Kg)^{3/4}$}{15000 (rpm)$(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$} suction specific speed is achievable in this size range.

There is one other potential explanation of the head falloff. During test 6, a portion of the design flow was recirculated to the eye of the impeller. This flow has experienced some temperature increase in passing through the pump, the balance piston, and the recirculation line. If this flow is vaporizing, creating a two-phase flow condition entering the eye of the impeller, it could impact both the pressure reading and the impeller cavitation characteristics. To attempt to verify one of these potential explanations as the cause of the problem, data from previous test series on the Mark 48 pump were examined, specifically data from the test series in 1977 and 1978. The 1978 test series never reached a suction specific speed as high as 52631{(rad/s)$(m^3/s)^{1/2}/(J/Kg)^{3/4}$} (15000 (rpm) $(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$), the maximum value being 47368 rad/s$(m^3/s)^{1/2}/(J/Kg)^{3/4}$ (13,500 (rpm)$(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$ at a flow below the design flow. Test 4 of the 1977 series reached 54035 (rad/s)$(m^3/s)^{1/2}/(J/Kg)^{3/4}${15400 (rpm)$(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$} suction specific speed but at a flow below the design flow, and it showed no indication of cavitation falloff. Test 5 of the 1977 test series was the one that experienced the LOX fire, but it did operate according to the data at high suction specific speed values (between 70175 and 84210 (rad/s) $(m^3/s)^{1/2}/(J/Kg)^{3/4}$ {20,000 and 24,000 (rpm)$(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$}. These data did indicate that head falloff was occurring but not as dramatically as for the current data. However, it is not clear what impact the fire incident had on the recorded data. Thus, examination of previous test data does not clarify the cause of the head falloff.

Balance Piston System Performance Evaluation

Balance Piston Performance. In 1979, the analytical model of the balance piston predicted balance piston operation to have large margins for flows at or below design flow but a margin of only 17% of the force range (13% with the high pressure orifice open) at a high flow coefficient (20% above design). These analyses are given in Table 17. To provide additional safety margin, it was decided to perform initial tests in the current series with an overboard bleed to help keep the sump pressure for the balance piston at a low value. The initial tests with the lower speed actually showed a much better axial thrust control using the measured pressures for impeller discharge, balance piston, and balance piston sump than had been predicted. However, it was also noted that the impeller discharge and inlet static pressures were much higher than had been used in the axial thrust model. The previous values used in the analytical model were based on pressure measurements from previous test series, but these measurements had been subject to error, particularly the impeller discharge pressure which read low due to leakage from the measurement transfer tube as it crossed flange interfaces.

TABLE 17. MARK 48 LOX PUMP PARAMETER STUDY SPIRAL GROOVE SEAL (70,000 RPM UNLESS NOTED) ENGLISH UNIT (SI UNITS)

CASE NO.	DESCRIPTION	BEARING, FLOW, LB/SEC (KG/SEC)	BEARING U/S PRESSURE, PSIA (N/CM^2)	BEARING U/S TEMPERATURE DEGREE, R (K)	BEARING U/S SPECIFIC WEIGHT, LB/FT^3 (KG/M^3)	BEARING ΔP, PSI (N/CM^3)	BALANCE PISTON RANGE, POUNDS (N)	BALANCE PISTON PERCENT POSITION, PERCENT	BALANCE PISTON PERCENT FORCE RANGE	FORCE ABOVE MINIMUM BALANCE PISTON FORCE, POUNDS (N)	BYPASS FLOW, LB/SEC (KG/SEC)	BYPASS DISCHARGE SPECIFIC WEIGHT, LB/FT^3 (KG/M^3)	BYPASS DISCHARGE TEMPERATURE DEGREES, R (K)
1	BASELINE (BALANCE PISTON K = 0.3, FRONT SHROUD K = 0.5 (A1)	0.78 (0.35)	493 (340)	208.0 (115.6)	63.3 (1014)	39.9 (27.5)	9931 (44173)	30.5 (30.5)	45.4 (45.4)	4507 (20047)	3.30 (1.50)	63.2 (1012)	207.8 (115.4)
2	BALANCE PISTON K = 0.1 (7A)	0.80 (0.36)	513 (354)	207.7 (115.4)	63.4 (1016)	41.2 (28.4)	10950 (48706)	30.8 (30.8)	45.5 (45.5)	4977 (22138)	3.51 (1.59)	63.3 (1014)	207.5 (115.3)
3	BALANCE PISTON K = 0.1, FRONT SHROUD K = 0.1 (8A)	0.81 (0.37)	522 (360)	207.5 (115.3)	63.4 (1016)	41.8 (28.8)	10950 (48706)	32.8 (32.8)	49.6 (49.6)	5436 (24179)	3.61 (1.64)	63.3 (1014)	207.4 (115.2)
4	BALANCE PISTON K = 0.2, FRONT SHROUD K = 0.1 (6A)	0.81 (0.37)	515 (355)	207.6 (115.3)	63.4 (1016)	41.3 (28.5)	10568 (47006)	32.7 (32.7)	49.8 (49.8)	5260 (23396)	3.53 (1.60)	63.3 (1014)	207.5 (115.3)
5	BALANCE PISTON K = 0.3, FRONT SHROUD K = 0.1 (3A)	0.79 (0.36)	502 (346)	207.8 (115.4)	63.3 (1014)	40.5 (27.9)	9931 (44173)	32.7 (32.7)	50.0 (50.0)	4965 (22084)	3.40 (1.54)	63.2 (1012)	207.7 (115.4)
6	BALANCE PISTON K = 0.1, FRONT SHROUD K = 0.2 (9A)	0.81 (0.37)	521 (359)	207.6 (115.3)	63.4 (1016)	41.7 (28.8)	10950 (48706)	32.5 (32.5)	49.1 (49.1)	5377 (23917)	3.59 (1.63)	63.3 (1014)	207.4 (115.2)
7	BALANCE PISTON K = 0.2, FRONT SHROUD K = 0.2 (5A)	0.80 (0.36)	514 (354)	207.7 (115.4)	63.4 (1016)	41.2 (28.4)	10568 (47006)	32.5 (32.5)	49.2 (49.2)	5202 (23138)	3.52 (1.60)	63.3 (1014)	207.5 (115.3)
8	BALANCE PISTON K = 0.3, FRONT SHROUD K = 0.2 (2A)	0.79 (0.36)	501 (345)	207.8 (115.4)	63.3 (1014)	40.4 (27.9)	931 (44173)	32.5 (32.5)	49.4 (49.4)	4908 (21831)	3.39 (1.54)	63.2 (1012)	207.7 (115.4)
9	SUMP PRESSURE = 450 PSIA (12A)	0.65 (0.29)	391 (270)	208.0 (115.6)	63.1 (1011)	32.9 (22.7)	10435 (46415)	31.6 (31.6)	48.0 (48.0)	5004 (22257)	3.58 (1.62)	63.0 (1009)	207.8 (115.4)
10	SUMP PRESSURE = 750 PSIA (11A)	1.03 (0.47)	757 (522)	207.9 (115.5)	63.8 (1022)	53.4 (36.8)	8673 (38578)	27.2 (27.2)	37.7 (37.7)	3078 (13691)	2.66 (1.21)	63.8 (1022)	207.7 (115.4)
11	30,000 RPM, 120% Q/N, BALANCE PISTON K = 0.3 (10A)	0.41 (0.19)	139 (96)	182.8 (101.6)	67.7 (1084)	9.5 (6.6)	1035 (4603)	18.0 (18.0)	18.0 (18.0)	187 (832)	0.61 (0.28)	67.7 (1084)	182.8 (101.6)
12	INCREASE BALANCE PISTON HEATING (4X) (15A)	0.72 (0.33)	506 (349)	221.6 (123.1)	60.3 (966)	36.7 (25.3)	10165 (45214)	30.2 (30.2)	46.6 (46.6)	4737 (21070)	3.31 (1.50)	60.2 (964)	221.3 (122.9)
13	INCREASED BALANCE PISTON HEATING (2X) (16A)	0.76 (0.34)	497 (343)	212.6 (118.1)	62.3 (998)	39.0 (26.9)	9993 (44449)	30.4 (30.4)	45.7 (45.7)	4567 (20314)	3.31 (1.50)	62.2 (996)	212.4 (118.0)
14	T_1 INCREASE 10 R (C4)	0.74 (0.34)	500 (345)	216.8 (120.4)	61.4 (984)	37.9 (26.1)	9963 (44315)	30.6 (30.6)	45.6 (45.6)	4543 (20207)	3.30 (1.50)	61.3 (982)	216.4 (120.3)
15	INCREASED LABYRINTH CLOSURE 50% (C8)	1.11 (0.50)	467 (322)	208.0 (115.6)	63.2 (1012)	58.1 (40.1)	9933 (44182)	30.7 (30.7)	45.1 (45.1)	4483 (19940)	3.01 (1.37)	63.2 (1012)	207.8 (115.4)
16	1% HEAD LOSS, CAVITATION (C10)	0.75 (0.34)	466 (321)	207.3 (115.2)	63.4 (1015)	33.4 (26.5)	10660 (47416)	29.3 (29.3)	42.6 (42.6)	3693 (16426)	3.00 (1.36)	63.4 (1016)	207.1 (115.1)
17	Q/N = 0.7 DESIGN (C14)	0.91 (0.41)	618 (426)	209.3 (116.3)	63.2 (1012)	46.7 (32.2)	11974 (53260)	33.4 (33.4)	51.4 (51.4)	6154 (27373)	3.75 (1.70)	63.4 (1016)	209.1 (116.2)
18	Q/N = 120% DESIGN (C16)	0.48 (0.22)	295 (203)	206.2 (114.6)	63.3 (1014)	24.3 (16.8)	6365 (28311)	27.0 (27.0)	38.4 (38.4)	2442 (10862)	2.61 (1.18)	63.3 (1014)	206.0 (114.4)

Using the pressures as measured in the current test effort in the analytical model resulted in excellent agreement with the test data and a prediction of comfortable margins for axial thrust control at all flows at a speed of 3141 rad/s (30,000 rpm).

During the initial tests in this series, there was evidence that the overboard drain line was choking causing a high back pressure for the balance piston sump. Modifications were made to the overboard drain line to decrease the line resistance by enlarging the flow control orifice while retaining the flow measurement orifice. This was done to ensure that test 6, which ran to higher speeds, was performed with the flow from the balance piston free to flow either overboard or recirculate into the eye of the impeller. A schematic of this flow path is shown in Fig. 74. The measured parameters include the balance piston sump pressure, inducer discharge pressure, overboard flow ($\dot{\omega}_3$), and bearing flow ($\dot{\omega}_2$). These data together with the analytical model of Ref. 2 are sufficient to calculate the resistance and flow through the recirculation line ($\dot{\omega}_4$) which also permits calibration of the balance piston flow ($\dot{\omega}_1$).

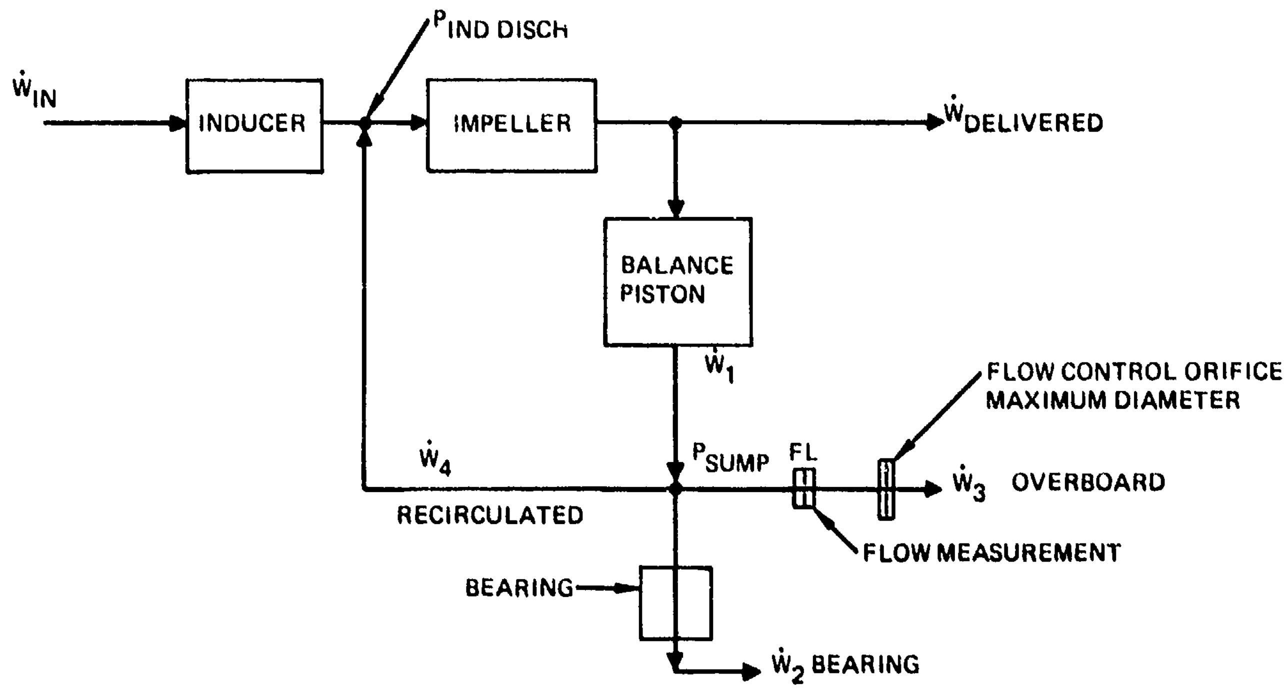

Figure 74. Flow Schematic Representative of Test 6

The model does not include a separate flow path for both overboard flow and recirculation flow. Therefore, the procedure used was as follows:

1. Permit the overboard flow ($\dot{\omega}_3$) and the bearing flow ($\dot{\omega}_2$) to both exit through the bearing flowpath by empirically decreasing the resistance in the analytical model until the calculated flow agrees with the sum of the test flows

2. Adjust the resistance in the recirculation line until the correct balance piston sump pressure occurs simultaneously with the correct flow through the bearing

Since there are two measured values being matched (sump pressure and $\dot{\omega}_2$ plus $\dot{\omega}_3$) and two resistances being adjusted, a unique solution can be obtained at each flow. This procedure was adopted for three data points from test 6, and an average resistance for the recirculation line was calculated. Table 18 shows the resulting values of the analytical model compared with the test data.

Having empirically anchored the analytical model, and particularly the recirculation line resistance, the model can be analyzed eliminating the overboard dump to simulate the mode of operation with recirculation of all of flow except that going through the bearing. For this calculation the resistance of flow passing through the bearing and overboard was returned to its original design value because this resistance was verified to be accurate by the data. The results of this analysis are shown in Table 19, along with the predicted balance piston axial thrust results.

Figure 75 to 77 show the axial thrust force curve for the three operating points of Tables 18 and 19. The figures each contain two curves; the solid curve representing the mode of operation as used on Test 6, and the dashed curve showing the recirculation-only mode. The point where the axial thrust is balanced is shown on each curve, and both the table data and the curves show a very satisfactory operation of the balance piston over the full range of flow tested.

In fact, there is no indication that the balance piston ever approached its limits of axial thrust range during the test, nor would it with a recirculation-only mode. Figure 78 shows the primary pressure parameters that reflect the behavior of the balance piston, and even during the portion of the test when large pressure falloff was experienced due to cavitation, the pressures all responded in a relative manner that indicates only a small shift in the balance piston. To verify this the balance piston parameter Γ was calculated where:

$$\Gamma = (P_{BP-1} - P_{SUMP})/(P_{IMP} - P_{SUMP})$$

where P_{BP-1} is the number 1 balance piston pressure, P_{SUMP} is the sump pressure, and P_{IMP} is the impeller discharge static pressure. If Γ approaches zero, the high pressure orifice is approaching a closed position. Similarly, if Γ approaches a value of one, the low pressure orifice is approaching closed. The most desirable value would be Γ approximately equal to 0.5. During test 6, including the cavitating part of the operation, Γ only varied from a value of 0.40 to 0.365 from one extreme of flow to the other. This is strong evidence that the balance piston was fully operational and able to handle all of the imposed loads with margin to spare throughout the test. Evaluation of the bearings after test indicated no large axial loads had occurred on the bearings during turbopump operation.

TABLE 18. TEST 006 BALANCE PISTON FLOW CALCULATIONS
ENGLISH UNITS (S.I. UNITS)

DATA SLICE NO.	PERCENT DESIGN FLOW	SUMP PRESSURE, PSIA (N/CM^2)	OVBD FLOW, $\dot{\omega}_3$ LB/SEC (KG/SEC)	BEARING FLOW, $\dot{\omega}_2$ LB/SEC (KG/SEC)	$\dot{\omega}_2 + \dot{\omega}_3$, LB/SEC (KG/SEC)	SUMP PRESSURE, PSIA (N/CM^2)	BALANCE PISTON FLOW, $\dot{\omega}_1$ LB/SEC (KG/SEC)	$\dot{\omega}_2 + \dot{\omega}_3$ LB/SEC (KG/SEC)	RECIRCULATION FLOW, $\dot{\omega}_4$ LB/SEC (KG/SEC)
32	82 (82)	940 (648)	3.588 (1.628)	0.713 (0.323)	4.3 (1.951)	971 (670)	4.47 (2.028)	4.3 (1.950)	0.17 (0.077)
8	96 (96)	760 (524)	3.04 (1.379)	0.741 (0.336)	3.78 (1.715)	768 (529)	4.46 (2.023)	3.76 (1.706)	0.70 (0.318)
16	108 (108)	420 (290)	1.82 (0.826)	0.600 (0.272)	2.42 (1.098)	418 (288)	4.07 (1.846)	2.34 (1.061)	1.73 (0.785)

TABLE 19. PREDICTED BALANCE PISTON FLOW AND AXIAL
THRUST CONTROL RECIRCULATION MODE OF OPERATION
ENGLISH UNITS (S.I. UNITS)

PERCENT DESIGN, Q/N	SPEED, RPM	SUMP PRESSURE, PSIA (N/CM^2)	SUMP PRESSURE, PSIA (N/CM^2)	BEARING FLOW, LB/SEC (KG/SEC)	RECIRCULATION FLOW, LB/SEC (KG/SEC)	BALANCE PISTON PERFORMANCE		
						FLOW, LB/SEC (KG/SEC)	HIGH PRESSURE ORIFICE OPEN, %	FORCE RANGE, %
82	69,160 (69,160)	1531 (1056)	169 (117)	1.50 (0.680)	2.86 (1.297)	4.36 (1.977)	24.2 (24.2)	39.2 (39.2)
96	67,870 (67.870)	904 (623)	140 (97)	1.10 (0.499)	3.17 (1.438)	4.27 (1.937)	28.5 (28.5)	40.5 (40.5)
108	67,430 (67.430)	646 (445)	117 (81)	0.87 (0.395)	2.89 (1.311)	3.76 (1.706)	27.6 (27.6)	44.8 (44.8)

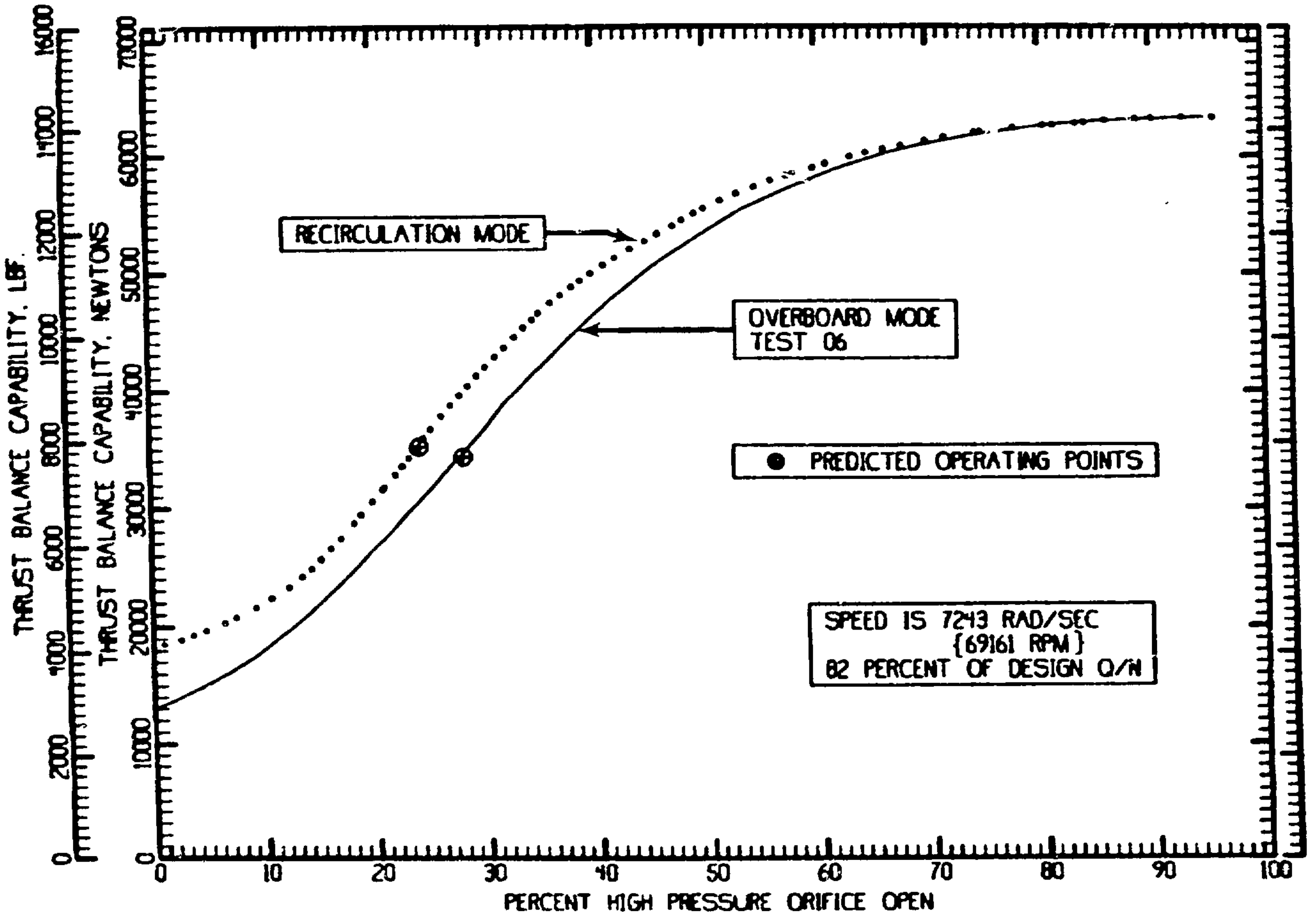

Figure 75. Pump Balance Piston Performance at Low Flow (During Test 6, 1981)

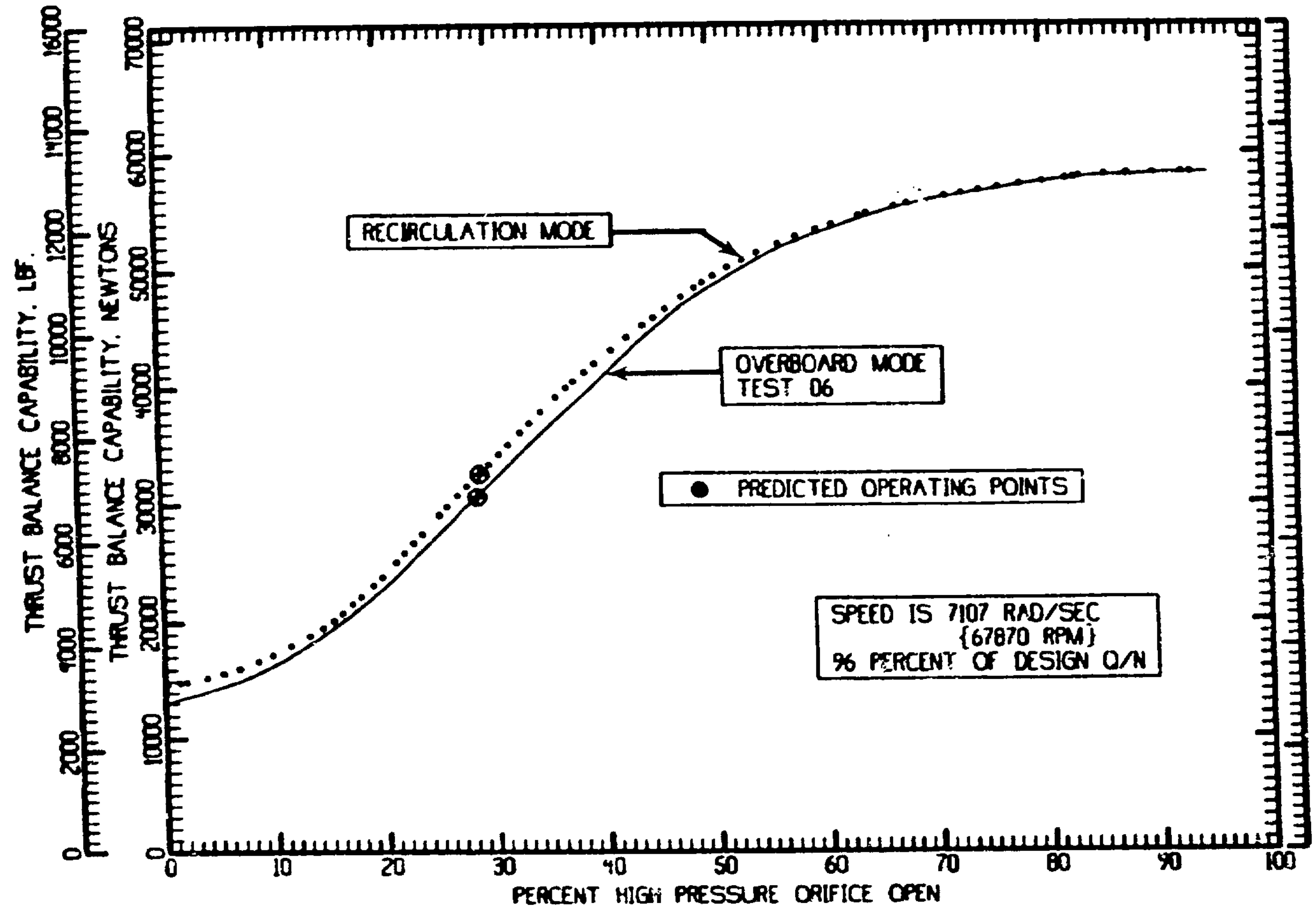

Figure 76. Balance Piston Performance Near Design Flow (During Test 6, 1981)

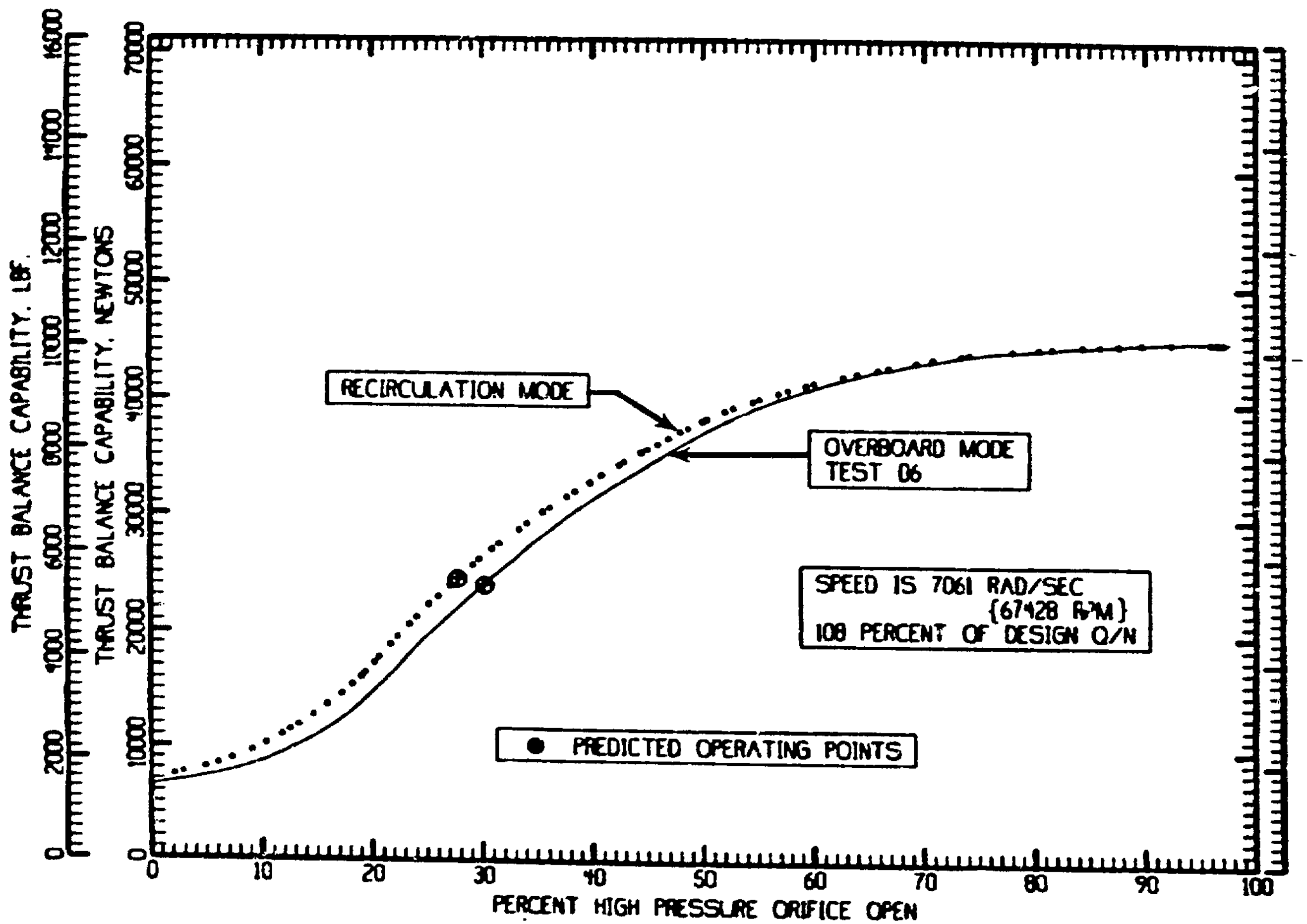

Figure 77. Balance Piston Performance at High Flow (During Test 6, 1981)

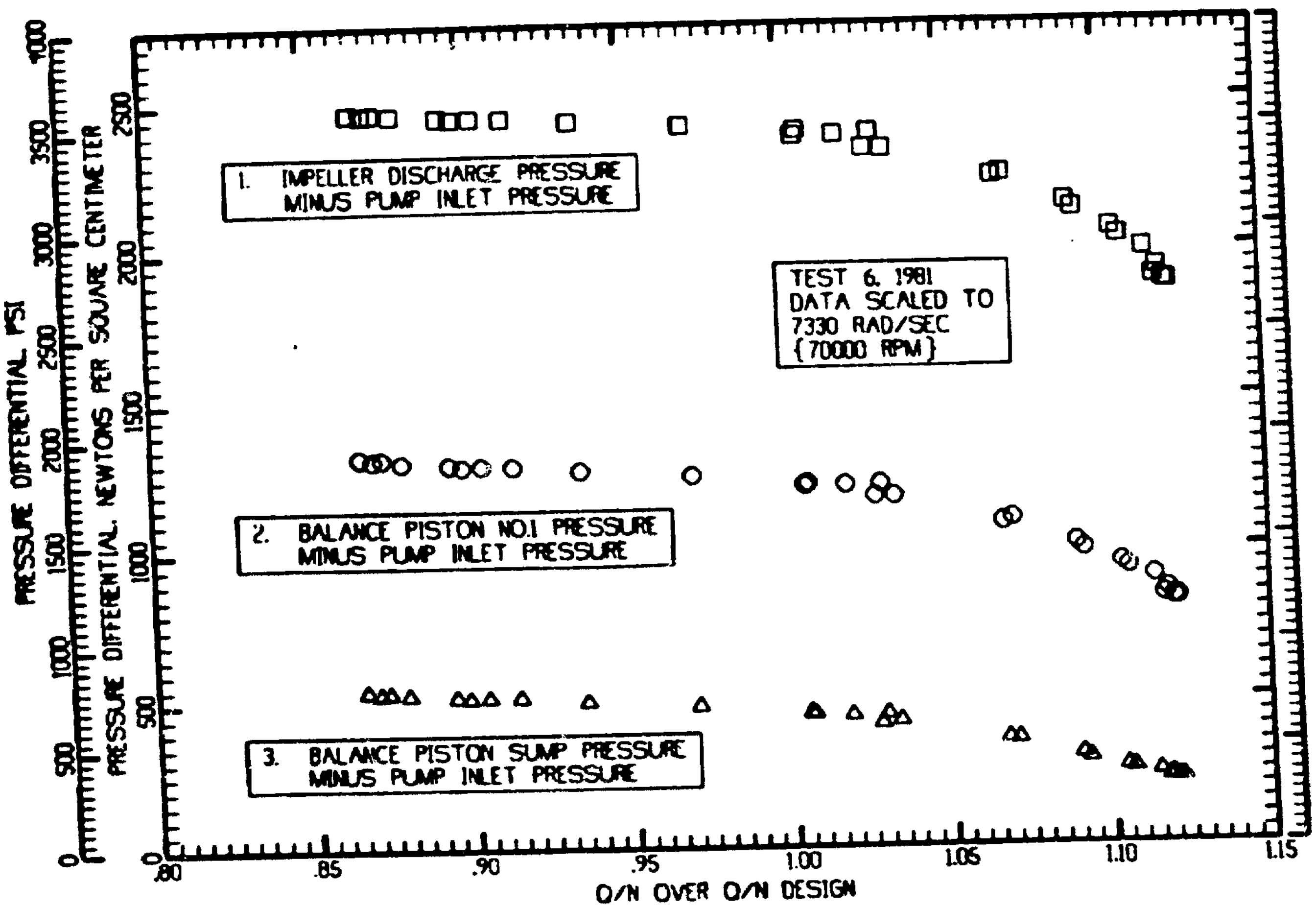

Figure 78. Balance Piston Pressure Differentials (Test 6, 1981)

Dynamic Seals Performance

Labyrinth Seals. The condition of the labyrinth seals on the impeller front shroud and slinger indicated satisfactory operation with slight wear-in showing on the silver plated lands. Pressure measurements across the impeller front wear ring were compared to determine the range of seal pressure drop. A correlation of test 6 data given in Table 20 show at speeds near 7120 rad/s (68,000 rpm) the pressure drop across the seal is as would be expected and the impeller front shroud labyrinth seal is operating satisfactorily.

The labyrinth seal on the slinger consists of a two land stepped static component with three labyrinth grooves for each land on the rotating slinger. The static clearances are shown in Fig. 43. The data from test 6 (Table 20) indicates a large pressure drop across the seal. The pressure drop data accounts for the radial pressure gradient from the slinger seal to the slinger sump pressure measurement assuming a radial pressure gradient as measured and reported in Ref.2. These measured pressure gradients were found to have very low pumping effectiveness at high speed with a K slinger pumping coefficient K of 0.05 at 6912 rad/s (66,000 rpm) and a K of 0.17 at 3141 rad/s (30,000 rpm).

As a result, the pressure drop across the labyrinth seal is very high which leaves a much lower pressure in the seal cavity. As a result it is possible that the slinger height could be reduced considerably. This would reduce the pumping losses of the rotating slinger. There is some heating associated with the slinger disc friction. The temperature measurements between bearing coolant flow, slinger sump temperature and balance piston flow temperature show a higher temperature by 1.11 K (2 R) for the balance piston flow. The accuracy of the thermocouple readings is well below what the isenthalpic temperature change and disc pumping would be, so a comparison cannot be made except to note that the temperature rise for the isenthalpic pressure drop across the labyrinth seal is 0.94 K (1.7 R) or very nearly the measured temperature difference.

The flow rate was estimated through the bearings and slinger labyrinth by combining the overboard bearing flow with the measured primary LOX seal flow of test series 3 and 4, which runs very nearly a constant 0.077 Kg/s (0.170 lb/s) at all speeds and cavity pressures measured. The net flow rate through the bearings is of the order of 2.2% of the pump flowrate.

Floating Ring Seals. The performance of the floating ring seals has shown good consistency throughout the several test series. The seal packages consist of three seals, having three drains and one helium purge supply section. The helium purge supply pressure has been maintained on test series 4 and 5 at 152 N/cm^2 (220 psia) at all test conditions at near ambient supply temperatures of 300 to 311 K (540 to 560 R). The primary LOX seal drain temperatures in test series 5 are considerably higher than on test series 6 (Table 21). This would indicate relatively less cold LOX leakage with more warm helium gas in the mixture probably caused by the reduced slinger sump pressures. The secondary hot gas seal drain shows little change between the two test series. The primary hot gas seal drain gas temperatures are affected by the amount of chill on the turbine bearing package for each test but the pressure levels are only slightly higher as are the measured flowrates for 3141 rad/s (30,000 rpm).

TABLE 20. TEST 016-006 LABYRINTH SEAL PERFORMANCE, S.I. UNITS (ENGLISH UNITS)

SLICE NUMBER	ROTATING SPEED, RAD/S (RPM)	NOMINAL FLOW, %	IMPELLER FRONT SHROUD PRESSURE, N/CM^2 (PSIA)	INDUCER DISCHARGE PRESSURE, N/CM^2 (PSIA)	LABYRINTH PRESSURE DROP, N/CM^2 (PSIA)	BEARING DOWNSTREAM PRESSURE, N/CM^2 (PSIA)	SLINGER SUMP PRESSURE, N/CM^2 (PSIA)	SLINGER PRESSURE GRADIENT, N/CM^2 (PSI)	LABYRINTH BEARING FLOW, KG/SEC* (LB/SEC)	LABYRINTH PRESSURE DROP, N/CM^2** (PSI)
2	3085 (29462)	101.5 (101.5)	519 (752)	210 (304)	309 (448)	266 (386)	35 (51)	32 (47)	0.288 (0.634)	199 (288)
6	7136 (68144)	102.8 (102.8)	2093 (3036)	537 (779)	1556 (2257)	723 (1048)	92 (134)	15 (22)	0.390 (0.854)	616 (892)
8	7107 (67870)	100.6 (100.6)	2067 (3001)	535 (776)	1534 (2225)	716 (1038)	98 (142)	15 (22)	0.413 (0.911)	603 (874)
16	7061 (67428)	112.1 (112.1)	1571 (2279)	214 (311)	1357 (1968)	455 (660)	76 (110)	15 (21)	0.349 (0.770)	364 (529)
22	7125 (68034)	100.5 (100.5)	2071 (3003)	550 (798)	1521 (2205)	725 (1051)	94 (136)	15 (22)	0.359 (0.792)	616 (893)
32	7242 (69161)	86.6 (86.6)	2251 (3265)	675 (979)	1576 (2286)	849 (1231)	108 (153)	16 (23)	0.400 (0.883)	725 (1051)

*ASSUMES 0.170 LB/SEC (0.077 KG/SEC) FLOW THROUGH PRIMARY LOX SEAL
**ASSUMES SLINGER PRESSURE GRADIENT REPORTED FOR TEST SERIES NO. 3

TABLE 21. DYNAMIC SEAL PERFORMANCE
ENGLISH UNITS (S.I. UNITS)

TEST NO.	SPEED, RPM (RAD/S)	PRIMARY LOX SEAL DRAIN PRESSURE, PSIA (N/CM2)	PRIMARY LOX SEAL DRAIN TEMPERATURE, R (K)	INTERMEDIATE SEAL PURGE SUPPLY PRESSURE, PSIA (N/CM2)	INTERMEDIATE SEAL PURGE SUPPLY TEMPERATURE, R (K)	SECONDARY HOT-GAS SEAL DRAIN PRESSURE, PSIA (N/CM2)	SECONDARY HOT-GAS SEAL DRAIN TEMPERATURE, R (K)	PRIMARY HOT-GAS SEAL DRAIN PRESSURE, PSIA (N/CM2)	PRIMARY HOT-GAS SEAL DRAIN TEMPERATURE, F (K)	FLOW, LB/SEC (KG/SEC)
1981										
003	30,000 (3141)	14.6 (10.1)	350 TO 307 (194 TO 171)	225 (155)	540 (300)	17 TO 18 (11.7 TO 12.4)	434 TO 281 (241 TO 156)	17 TO 16 (11.7 TO 11.0)	333 TO 185 (185 TO 103)	0.052 (0.024)
004	32,500 (3403)	14.5 (10.0)	389 TO 365 (216 TO 202)	218 (150)	548 (304)	18 TO 19 (12.4 TO 13.1)	401 TO 312 (223 TO 173)	18 TO 17 (12.4 TO 11.7)	372 TO 227 (207 TO 126)	0.052 (0.024)
005	28,500 (2985)	14.4 (9.9)	399 TO 380 (222 TO 211)	222 (153)	545 (303)	18 TO 19 (12.4 TO 13.1)	411 TO 322 (228 TO 179)	18 TO 17 (12.4 TO 11.7)	348 TO 244 (193 TO 136)	0.052 (0.024)
006	30,000 (3141)	14.4 (9.9)	264 TO 303 (147 TO 168)	216 (149)	557 (309)	18 TO 19 (12.4 TO 13.1)	390 TO 309 (217 TO 172)	19 (13.1)	345 TO 220 (192 TO 122)	0.063 (0.029)
006	68,000 (7121)	14.5 (10.0)	316 TO 394 (176 TO 219)	219 (151)	559 (311)	30 TO 39 (20 TO 27)	412 TO 422 (229 TO 234)	26 TO 29 (18 TO 20)	391 TO 401 (217 TO 217)	0.076 TO 0.083 (0.034 TO 0.038)
1978										
006	29,800 (3121	15.5 (10.7)	152 TO 174 (84 TO 97)	214 (148)	551 (306)	16.5 (11.4)	462 (257)	14.8 (10.2)	274 (152)	0.030 (0.014)
010	31,000 (3246)	24.7 (17.0)	157 (87)	217 (150)	559 (311)	16 TO 21 (11 TO 14.5)	418 TO 280 (232 TO 156)	14.7 (10.1)	213 TO 216 (118 TO 120)	0.035 (0.016)
012	30,000 (3141)	40.0 (27.6)	157 TO 164 (87 TO 91)	227 (157)	554 (307)	20 (13.8)	363 TO 318 (202 TO 177)	15.0 (10.3)	356 TO 257 (198 TO 143)	0.033 (0.015)
012	69,000 (7226)	41.0 (28.3)	164 TO 170 (91 TO 94)	230 (159)	555 (306)	20 TO 32 (14 TO 22)	355 TO 435 (197 TO 242)	15.4 (10.6)	257 TO 425 (143 TO 236)	0.089 TO 0.103 (0.040 TO 0.047)

Dynamic Performance

The dynamic data from tests 2 through 6 were processed and analyzed to determine what the dynamic characteristics of the turobpump were. The pump instrumentation consisted of radial accelerometers located on the volute inlet and turbine housing flange, and a pump axial accelerometer located on the volute inlet face. Two radial proximeter transducers were located at the turbine bearing instrumentation cap to measure shaft position and one axial proximeter transducer at the end of the shaft. All these data were recorded on FM tape for future processing. The data processing was done at the analog facility in the Rocketdyne Engineering Development Laboratory.

Maximum axial and radial acceleration levels measured for each of the four 3141 rad/s (30,000 rpm) tests were less than 1 g rms. All peak acceleration levels referred to are taken from Amplitude Mean Squared (AMS) traces filtered with a 0 to 2000 Hz low pass filter or a 200 to 2000 Hz band-pass filter. At the beginning of test 6 operation at 7121 rad/s (68,000 rpm), all of the accelerometer measurements were overdriven on FM tape. Using the best data retrieval methods available, the accelerometers show maximum amplitudes on the order of 7 G's rms. These levels are roughly twice the maximum accelerations observed on a 1978 test (series 4) that was also conducted at 7121 rad/s (68,000 rpm).

Turbine end rubbing was indicated on every test by 2X and 3X synchronous speed frequencies. After test 6, the rotor experienced high torque. No explanation for this increased interference was found in the data. It is assumed that the higher speeds of test 6 aggravated the rubbing condition that had been noted since the first test of the series. Test 6 ramp down rate was not significantly different below 3141 rad/s (30,000 rpm) than that seen on previous tests. Similarly, its ramp down from 7121 rad/s (68,000 rpm) compares closely to the 1978 test mentioned above.

Spectrum data (isoplots) from tests 2 and 3 show anomalous frequencies at 3.2X and 3.6X speed. These frequencies do not appear on any later tests. They could be related to a ball spin frequency which is calculated to occur at 3.1X speed.

Two other anomalous frequencies, one at 1500 Hz and the other ranging from 2700 to 3100 Hz, appear in the data. During each test the frequencies remain constant, independent of rotor speed, and on some isoplots they appear before the test was begun. Consequently, they are believed to be unrelated to rotating irregularities and are most probably acoustic frequencies or noise.

A final anomalous frequency was seen on test 5. It is subsynchronous and because it appears most strongly on axial amplitude spectra, it is believed to be related to balance piston vibration.

Bently displacement data on all of the tests in this series were of dubious value. Time histories (Statos records) and isoplots were characteristically garbled with noise frequencies. In most instances spot face amplitudes could not be distinguished from rotor translational amplitudes. Peak displacement values were obtained by subtacting amplitudes attributable to noise from nominal amplitudes.

Radial and axial displacements for the 3141 rad/s (30,000 rpm) tests were on the order of 0.762×10^{-2}mm (3.0×10^{-4} inch) peak to peak, while the displacements seen at 7121 rad/s (68,000 rpm) were on the order of 1.524×10^{-2}mm (6.0×10^{-4} inch) peak to peak.

The conclusions reached for test series 5 dynamic analysis were that observed acceleration and displacement levels were consistently low. The operating speeds of 7121 rad/s (68,000 rpm) and 3141 rad/s (30,000 rpm) exceeded the 20% safety envelope around the rotors observed critical speed of 5655 rad/s (54,000 rpm).

Except for the Mark 48-0 turbine-end rubbing, none of the anomalies identified in the test data are deemed to be serious. Some improvement should be channeled into improving the readability of the Bently traces. Perhaps a different spotface or spotface-probe configuration should be employed because of the extremely small shaft diameter of the Mark 48-0.

Mechanical Performance

The condition of the component parts on disassembly were generally in excellent condition. The inspection revealed three areas where damage to the turbopump had been sustained during the testing. These areas were:

1. Turbine tip rubbing
2. Inducer tip rubbing
3. Distress of the chrome plating on the rotor shaft at the turbine seal

An evaluation of the specific hardware, causes for the condition and recommended solutions follow.

Turbine Tip Rubbing. It has been previously stated that the high torque exhibited on the rotor during posttest torque checks indicated the rotor torque to be 903 to 1130 N/cm (80 to 100 in.-lb). Attempts to free the rotor by turning only resulted in larger torque values. A combination of blowing ambient GN_2 through the turbine while heating the turbine housing provided no reduction of the torque. As the rotor turned, it would at some points break loose for an arc of as much as 0.785 radius (45 degrees) but with added rotation would seize. A push-pull check was made at one point where the shaft rotated freely within the arc described. Measurements indicated an axial shaft travel of approximately 0.254 mm (0.010 inch) for only slight axial load. This indicates the rotor was operating within the acceptable axial travel band width of the balance piston. Disassembly was accomplished by pulling the bearing support housing off the turbopump. The support housing contains the turbine tip seal. The interference causing the high rotor torque was caused by the rubbing of the rotor tip and the galling of the copper plating on the seal diameter adjacent to the stator vanes. This is clearly shown by the condition of the copper plating in Fig. 79. The rotor also shows evidence of rubbing and some collection of copper on the blade tips in Fig. 80.

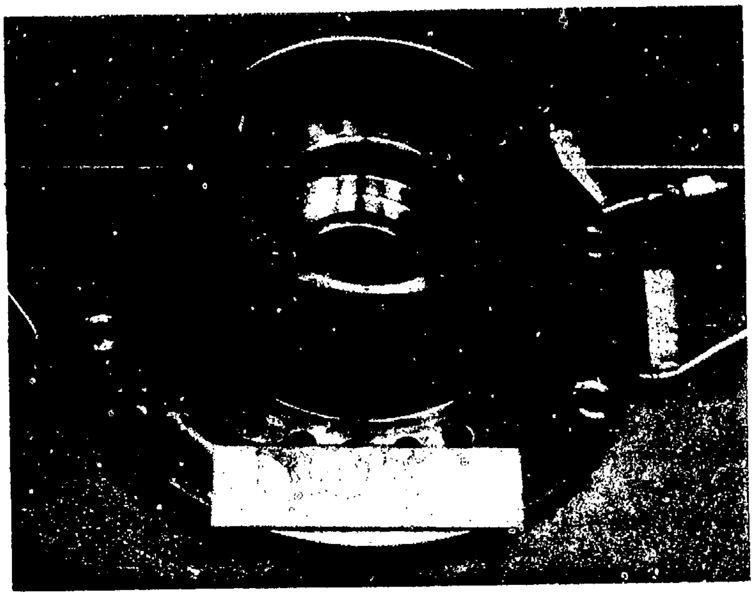

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Figure 79. Rubbing at Turbine Tip Seal

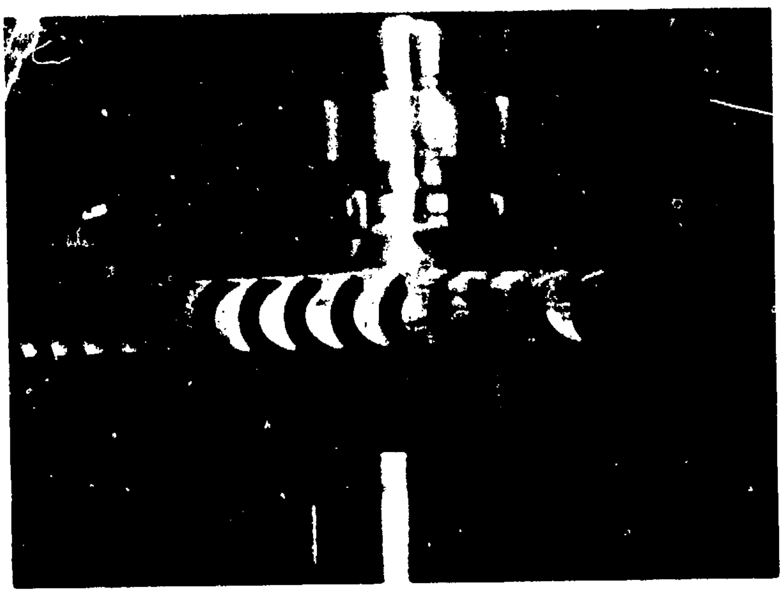

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Figure 80. Mark 48-0 Turbine Tip Rubbing

It will be necessary to strip and replate the copper before the support housing is useable. No other damage is apparent. The rotor blade tips will require cleanup by hand to remove the copper accumulation. The blade tip itself shows very little wear.

The cause for the rubbing condition was investigated and found to be due to the close tip clearances used in the build and the operating changes involved. The drawing stackup showed the radial clearance at assembly to be 0.051 to 0.102 mm (0.002 to 0.004 inch) as is given in Fig. 81. The actual measured radial clearance at assembly was 0.127 mm (0.005 in.). The clearance increases due to the effects of chilldown if housing and rotor temperatures remain the same temperature. When the turbine wheel speeds up, the wheel growth decreases the clearance and if the ambient GH_2 gas drive warms the components further, the clearance decreases further. At this point, the rubbing is highly likely. If the system was driven with hot gas at 922 K (1200 F), the housing growth would provide more than adequate clearance. It is recommended that with GH_2 drive, the turbine tip clearance be increased to avoid the rubbing condition.

Inducer Tip Rubbing. The disassembly revealed some slight rubbing of the inducer blade tip with the inlet wall. The rubbing traces are shown in Fig. 82. The duct surrounding the inducer tip is silver plated to a depth of 0.254 mm (0.010 inch). The measurements of the inlet duct indicate the depth of the rubbing is of the order of 0.051 mm (0.002 inch) maximum over a circumferential arc of 1.57 radius (90 degrees). This slight rubbing has been reported on previous builds. The radial tip clearance at assembly was measured at 0.174 mm (0.0069 inch) with an inducer tip runout of 0.0102 mm (0.0004 inch). It is recommended that no inducer tip radial clearances tighter than 0.203 mm (0.008 inch) be run.

Shaft Distress at Turbine Seal. Examination of the shaft-rotor on the sealing surfaces reveals characteristic carbon tracks on the turbine end seal and primary LOX seal. The tracking of the primary LOX seal is shown at midspan on the shaft in Fig. 83. This condition is normal and not considered a problem. The turbine seal area which is nearest the rotor wheel on the pump side of the shaft showed serious distress in the chrome plating. This is easily recognized in Fig. 83. The seal used here uses two floating rings made of Amcermet. These rings are shown with the seal package in Fig. 84. The ring nearest the pump (left side in Fig. 84) lost its press fit and came loose from the retainer while the one nearest the rotor did not and is shown with its retainer ring. It is hypothesized that as the Amcermet operates at close clearances near the chrome, heat is generated. This heat causes expansion of the Amcermet and yielding of the retainer ring until the Amcermet ring press fit is lost. At this point the seal ring can wear on both the outside and inside diameter of the seal ring. The evidence of high heat in the chrome has been verified by hardness tests on the shaft both on and adjacent to the seal damaged area. The tests reveal high Rockwell C hardness adjacent to the distressed area but below scale hardness on the distressed area. Although the hardness test is not completely accurate for thin chrome plating, it does reveal that temperatures as high as 1033 K (1400 F) may have developed in order to soften the chrome plating in the distressed area.

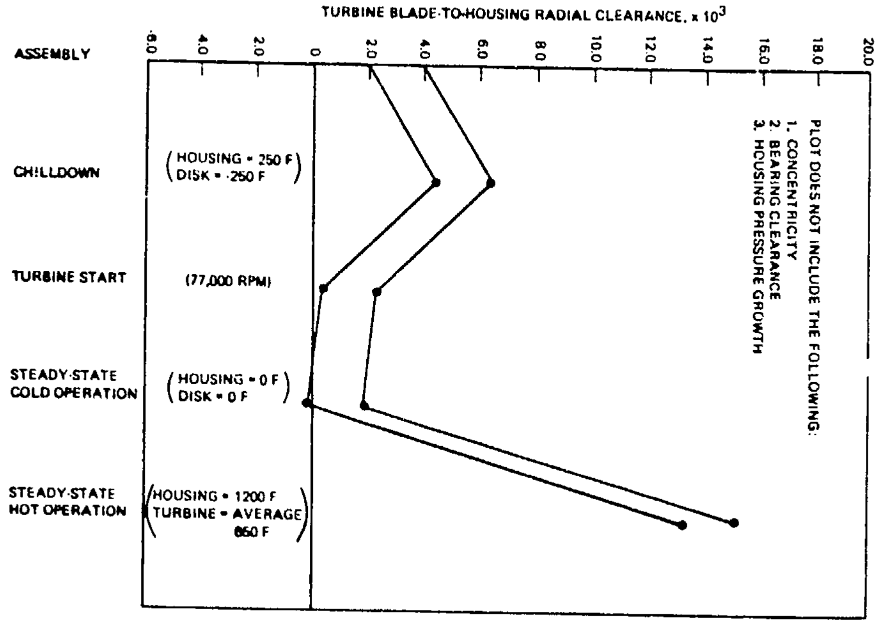
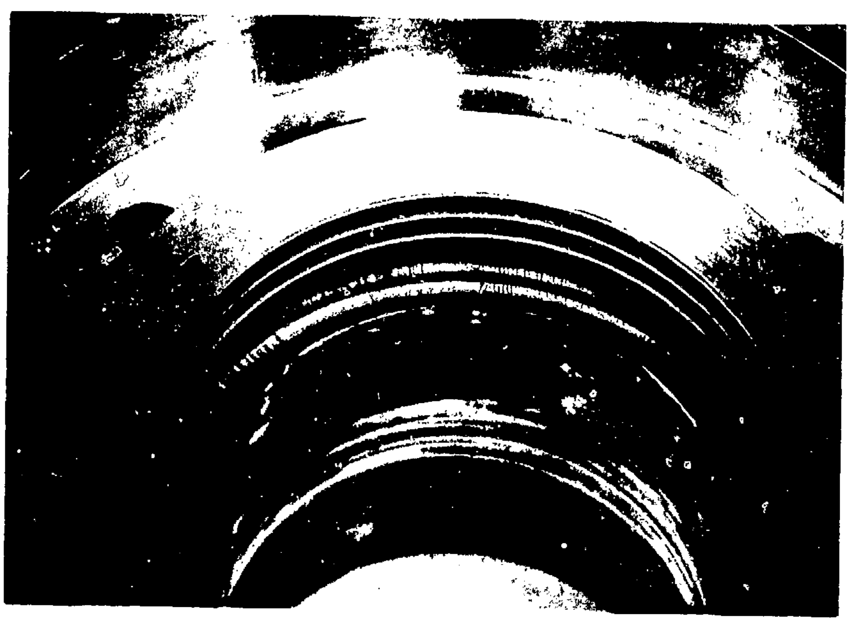
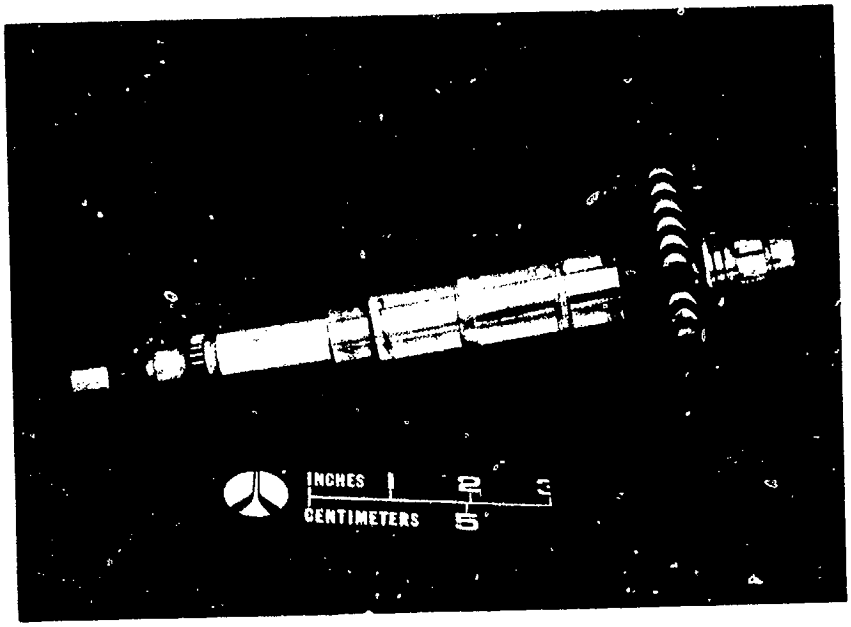


Figure 81. Mark 48-0 Turbine Blade Tip Clearance



1SM55-5/28/81-C1K

Figure 82. Mark 48-0 Inducer Tip Rubbing on Inlet



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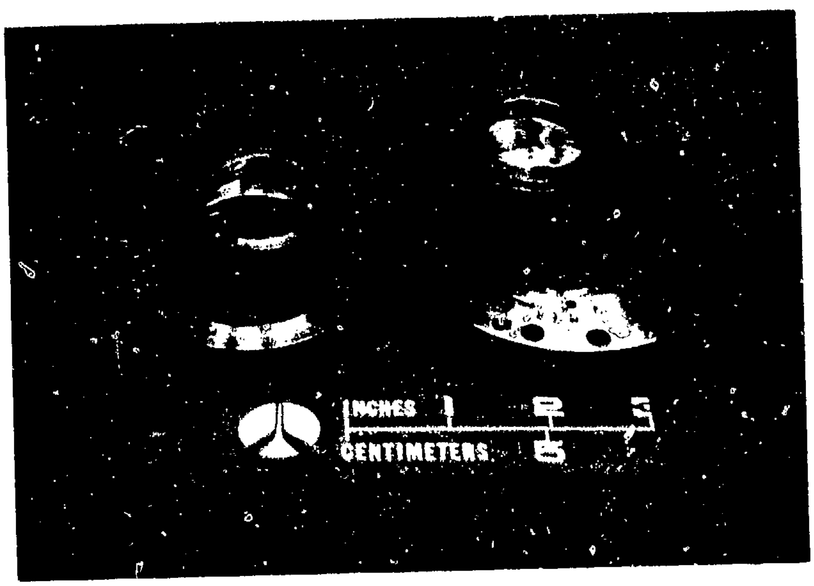
1SM55-5/28/81-C1D

Figure 83. Mark 48-0 Rotor Condition After Test Series 5



1SM55-5/28/81-C1G

Figure 84. Mark 48-0 Turbine Seal Damage

Test data on hard chrome plating indicate that when chrome plating is subjected to temperatures above 672 K (750 F) the hardness is reduced considerably.

Several small segments of the chrome plating are missing in the distressed area. The shaft does not reveal any permanent damage but the chrome will need to be stripped and replated before it can be acceptable for use. It is recommended that on subsequent builds the radial clearance on this seal ring be increased to avoid the problem. The condition seems to be caused by lack of film cooling existing across this seal segment since the one closest to the turbine wheel with more pressure drop across it seems to be undamaged with only slight rub markings. The problem could also be corrected on the testing with GH_2 turbine gas drive if the Amcermet seals were replaced with carbon seal rings.

Bearing Analysis. The bearings were analyzed after disassembly of the turbopump. During disassembly, the bearings were damaged by the static axial overload required to separate the pump components. The bearings were examined after six starts during which they accumulated a total of 580 seconds operating time. The pump was run at 524 rad/s (5000 rpm) for 326 seconds, 3141 rad/s (30,000 rpm) for 166 seconds and 7121 rad/s (68,000 rpm) for 35 seconds. The balance of the time was at transient speeds. The conclusions drawn from the bearing examination were:

1. The bearings would have continued to operate

2. The coolant for the turbine bearing set showed evidence of particulate contamination

3. All bearings were damaged by static axial overload during disassembly

4. The turbine end bearings were subjected to synchronous radial load

The ball surface was mostly roughened, accompanied with a dull band. Some balls show Brinnel marks and some have shallow spalls. One ball had a short crease.

The general condition of the bearings was not bad enough to preclude continued service, although the deterioration was evident and the rate would be expected to accelerate.

The high contact angle indicates that the inner race press fits may not be as tight as intended. The press fit on these bearings at ambient condition was measured at 0.0229 to 0.0254 mm (0.0009 to 0.0010 inch) tight.

The No. 3 bearing had experienced a radial synchronous load, as the inner raceway eccentric load path indicates. This could be due to a residual rotor imbalance of the turbine wheel. It is difficult to explain the lesser indications of synchronous radial loading in the No. 4 bearing, which is adjacent to the No. 3. A hypothetical combination of:

(1) Axial hang up of the No. 3 and 4 bearing cartridge,

(2) A shaft motion toward the No. 4 bearing, or

(3) A looser fit between the outer race of the No. 4 bearing and the cartridge

could be responsible. Another contributing factor would be due to an anomaly in shaft alignment; any out-of-squareness of the shoulder where the rotor end is attached will magnify the runout at No. 3,4 bearing location. It was also noticed that about 20% of the No. 3 bearing OD was unsupported. Any combination of these factors might make the No. 4 bearing radially softer so that it experienced a lesser radial load.

The No. 1 and 4 bearings have Brinnel marks high on the shoulders, but Nos. 2 and 3 at the low angle shoulders. This will result during dismantling in which Nos. 1 and 2 outer rings were pulled out with the cartridge, leaving the No. 2 inner ring still on the rotor. Similarly, the force required to pull the No. 4 bearing inner race was applied through the bearing, brinnelling it. The No. 3 race was damaged as the balls were pulled over the low shoulder.

A localized fretting on the OD of the No. 4 bearing suggests a fixed radial load or misalignment of the bearing mounting bore.

It is recommended that the turbine bearing coolant system be reviewed for contamination and corrected. The shaft and bearing inner race fits should be reviewed to determine if they are too loose at operating conditions.

SUMMARY OF RESULTS

The objectives of the program have generally been completed with the conclusion of this test program. The specific objective of obtaining characterization of the primary LOX seal leakage flows and baseline pump performance data was achieved. The results indicate that the head-flow performance was as predicted at design flow for test series 4. In the subsequent test series (5) using newly fabricated component parts, the head rise averages 6% higher than measured on test series 4. No satisfactory explanation has been found for this difference except the newly fabricated impellers had some dimensional discrepancies of thin blades and shrouds which could contribute to the condition.

On test series 4, test 9, a noncavitating suction performance capability of 84210 (rad/s) $(m^3/s)^{1/2}/(J/Kg)^{3/4}$ [24,000 (rpm) $(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$] was demonstrated at a flow of 105% of design flow at a test speed of approximately 6964 rad/s (66,500 rpm). It was predicted at that time that the suction performance capability of the pump could be as high as 112,280 (rad/s) $(m^3/s)^{1/2}/(J/Kg)^{3/4}$ [32,000 (rpm) $(gpm)^{1/2}/(ft\text{-}lbf/lbm)^{3/4}$]. During test 6 of test series 5 with the newly fabricated components a cavitating suction specific speed of only 52,631 (rad/s) $(m^3/s)^{1/2}/(J/Kg)^{3/4}$ [15,000 (rpm) (gpm)/$(ft\text{-}lbf/lbm)^{3/4}$] was obtained at a flow rate of 103% of nominal and a speed of 7225 rad/s (69,000 rpm). A potential explanation of the poor suction performance exhibited is that recirculation of the balance piston flow back to the impeller eye may be the cause but examination of the limited data available does not clarify the cause. The efficiency of the pump was found to be the same as found in previous testing. The peak efficiency is 68% with the efficiency at the design flow at 67%. The originally predicted peak efficiency for this pump design was 70%.

The data from tests on the balance piston were correlated with the balance piston computer model to account for overboard balance piston flow. The results indicate the rotor operates in a range of 39.2 to 44.8% of the net force range of the balance piston over a respective flow range of 82 to 108% of nominal flow at near design speed [7121 rad/s (68,000 rpm)]. The balance piston exhibits a force range of 50262, 44925 and 39142 Newtons (11,300, 10,100 and 8800 lbs) force at flows of 82, 96 and 108% of design. This force range and piston position exhibits a very comfortable operating margin and therefore can be expected to perform reliably over the complete operating spectrum required.

The test program was curtailed due to high rotor torque at the conclusion of test 6. The high torque was traced to the rubbing of the turbine tip and the galling of the copper plating used as the tip sealing surface over the shroudless turbine blades. The cause was traced to reduced clearance during operation of the turbopump with an ambient drive gas such as gaseous hydrogen at 306 K (550 R) in place of the LOX/LH_2 combustion products operating at 1041 K (1874 R) inlet temperature. The result is a radial tip clearance increase of 0.356 mm (0.014 inch) when operating with hot drive gases. It is recommended that the tip clearance at the turbine be increased to avoid rubbing when using ambient gaseous hydrogen as the drive fluid.

In general the mechanical performance of the turbopump was satisfactory with exception of the first test build where a failure resulting in fire damage occurred. The problem was traced to the balance piston range and axial thrust control capability which was indicated to be marginal. The results of the last test program, when correlated with computer modeling to account for the internal recirculation of balance piston flow, indicate very adequate axial thrust margin capability for the turbopump.

REFERENCES

1. Csomor, A. and R. Sutton, Interim Report - Small, High-Pressure Liquid Oxygen Turbopump, NASA CR-135211, Rocketdyne Report, RI/RD76-178, Rocketdyne Division of Rockwell International, July 1977.

2. Csomor, A, Final Report - Small High-Pressure Liquid Oxygen Turbopump, NASA CR-159509, Rocketdyne Report, RI/RD78-278, Rocketdyne Division of Rockwell International, October 1978.

3. Burcham, R. E. and J. L. Boynton, Final Report - Small High-Speed Self-Acting Shaft Seals for Liquid Rocket Engines, NASA CR-135167, Rocketdyne Report, RI/RD77-195, Rocketdyne Division of Rockwell International, July 1977.

4. Young, W. E. and H. F. Dul, Investigation of Pressure Prediction Methods for Low-Flow Radial Impellers, Draft, PWA FR-1716, 13 January 1966.

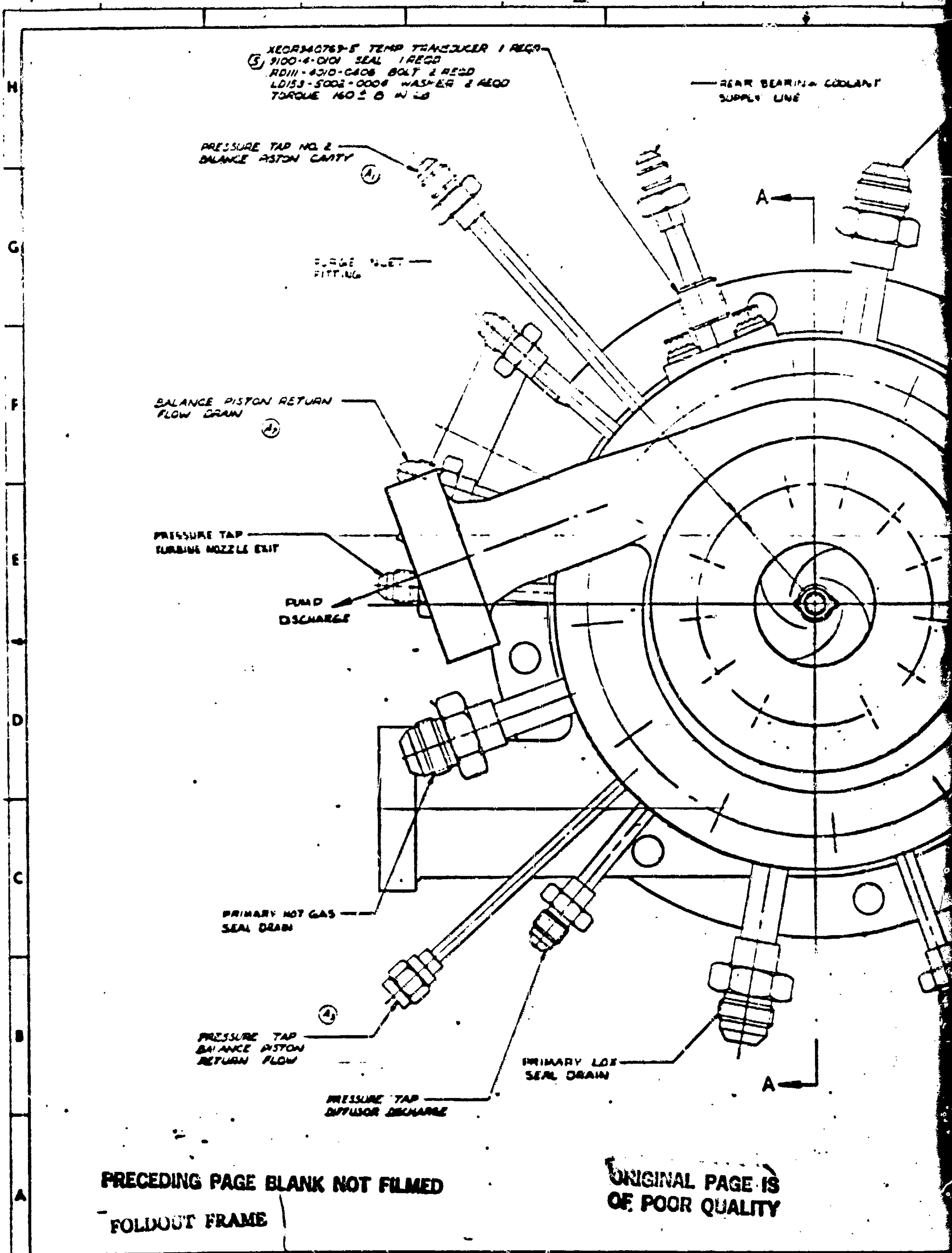
APPENDIX A

MARK 48-OXIDIZER TURBOPUMP ASSEMBLIES

RS009820E - Original Configuration
Test Series No. 4

9R0012300 - Turbopump Incorporating
Spiral Groove Liftoff Seal

9R0014079 - Test Configuration
Test Series No. 5



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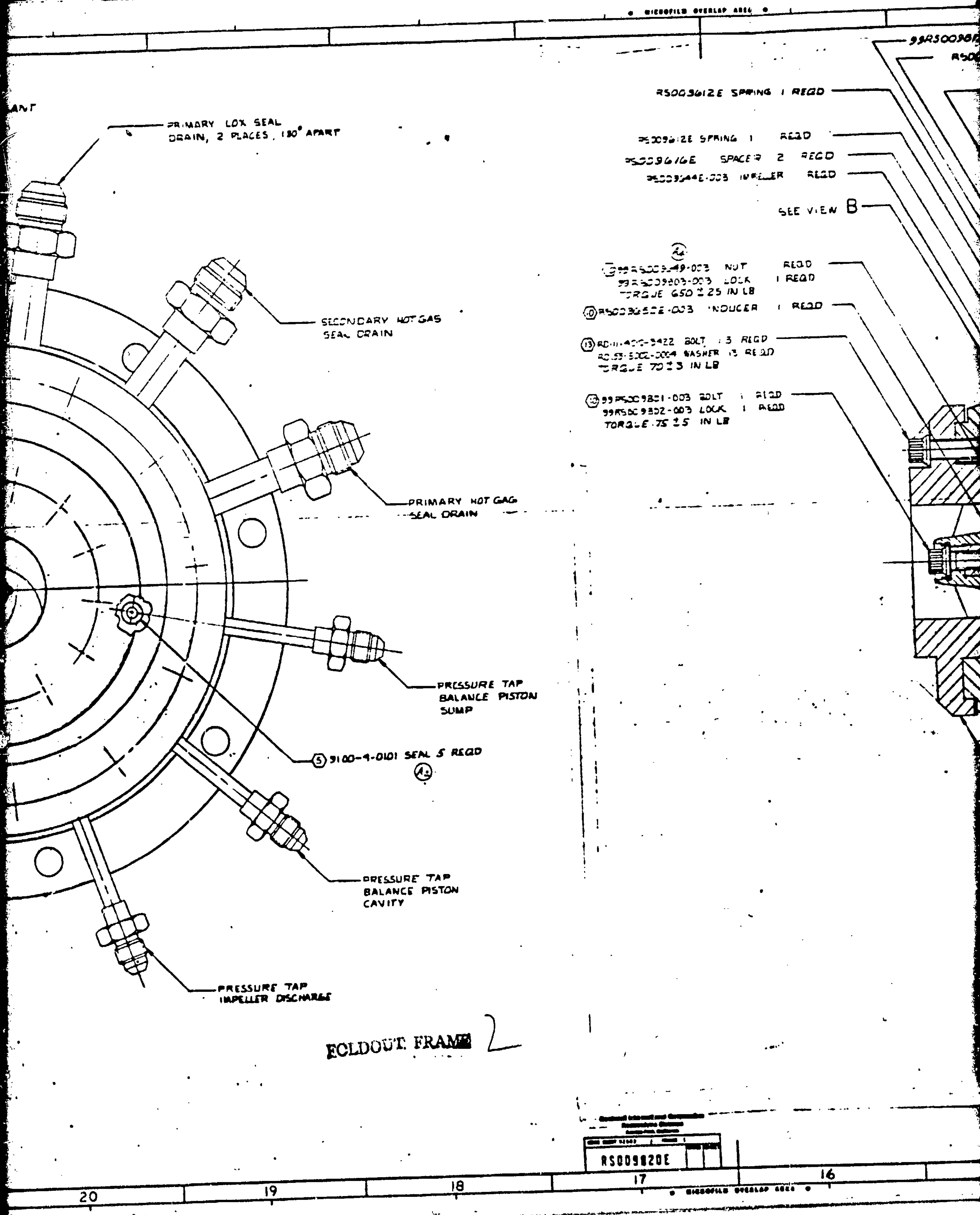

RS009612E SPRING 1 REQD
RS009616E SPACER 2 REQD
SEE VIEW B
NUT REQD
LOCK 1 REQD
TORQUE 650 ± 25 IN LB
INDUCER 1 REQD
BOLT 13 REQD
WASHER 13 REQD
TORQUE 70 ± 5 IN LB
99RS009801-003 BOLT 1 REQD
LOCK 1 REQD
TORQUE 75 ± 5 IN LB
PRIMARY LOX SEAL DRAIN, 2 PLACES, 180° APART
SECONDARY HOT GAS SEAL DRAIN
PRIMARY HOT GAS SEAL DRAIN
PRESSURE TAP BALANCE PISTON SUMP
9100-4-0101 SEAL 5 REQD
PRESSURE TAP BALANCE PISTON CAVITY
PRESSURE TAP IMPELLER DISCHARGE
FOLDOUT FRAME 2
RS009820E
20
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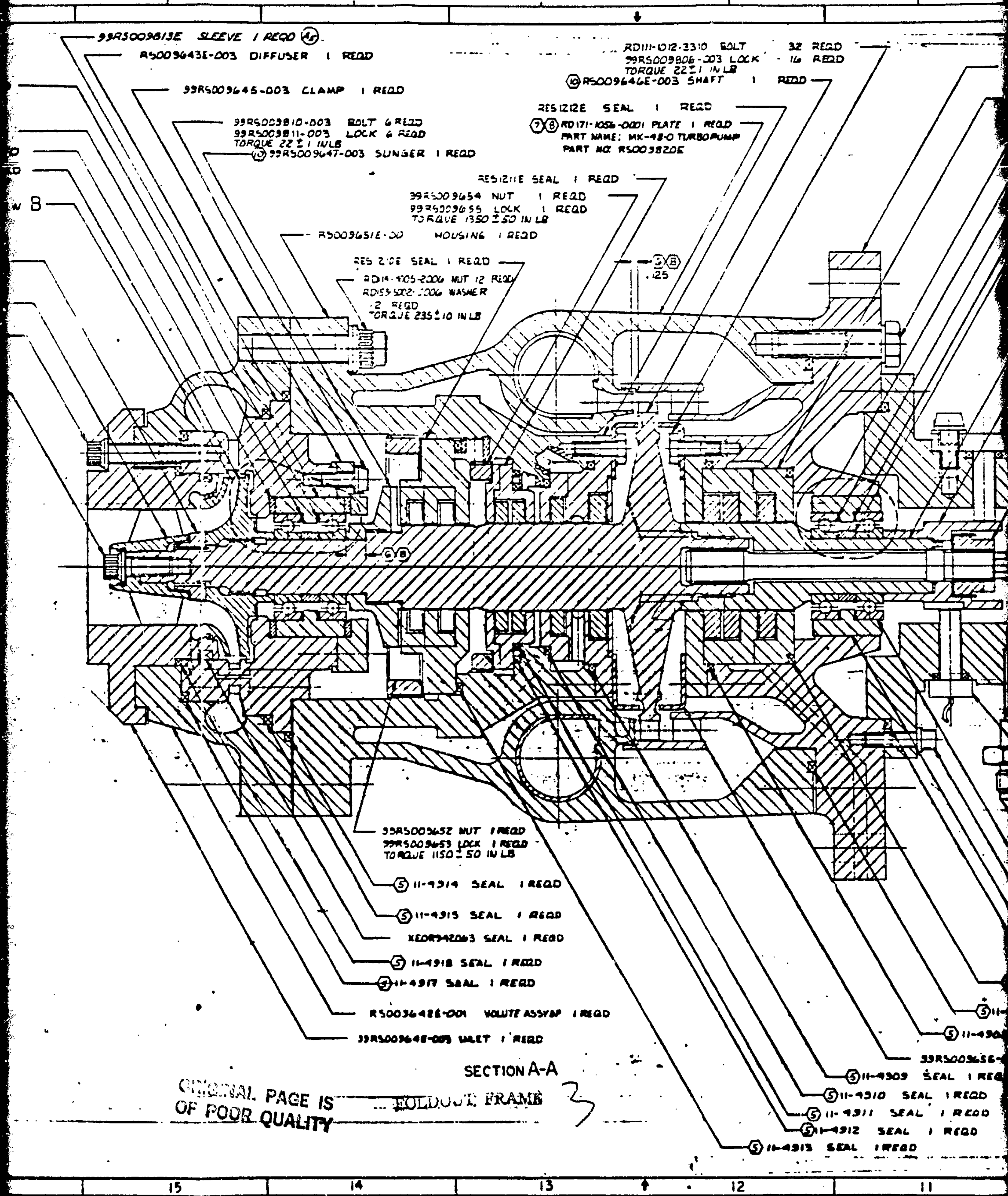
16



SECTION A-A

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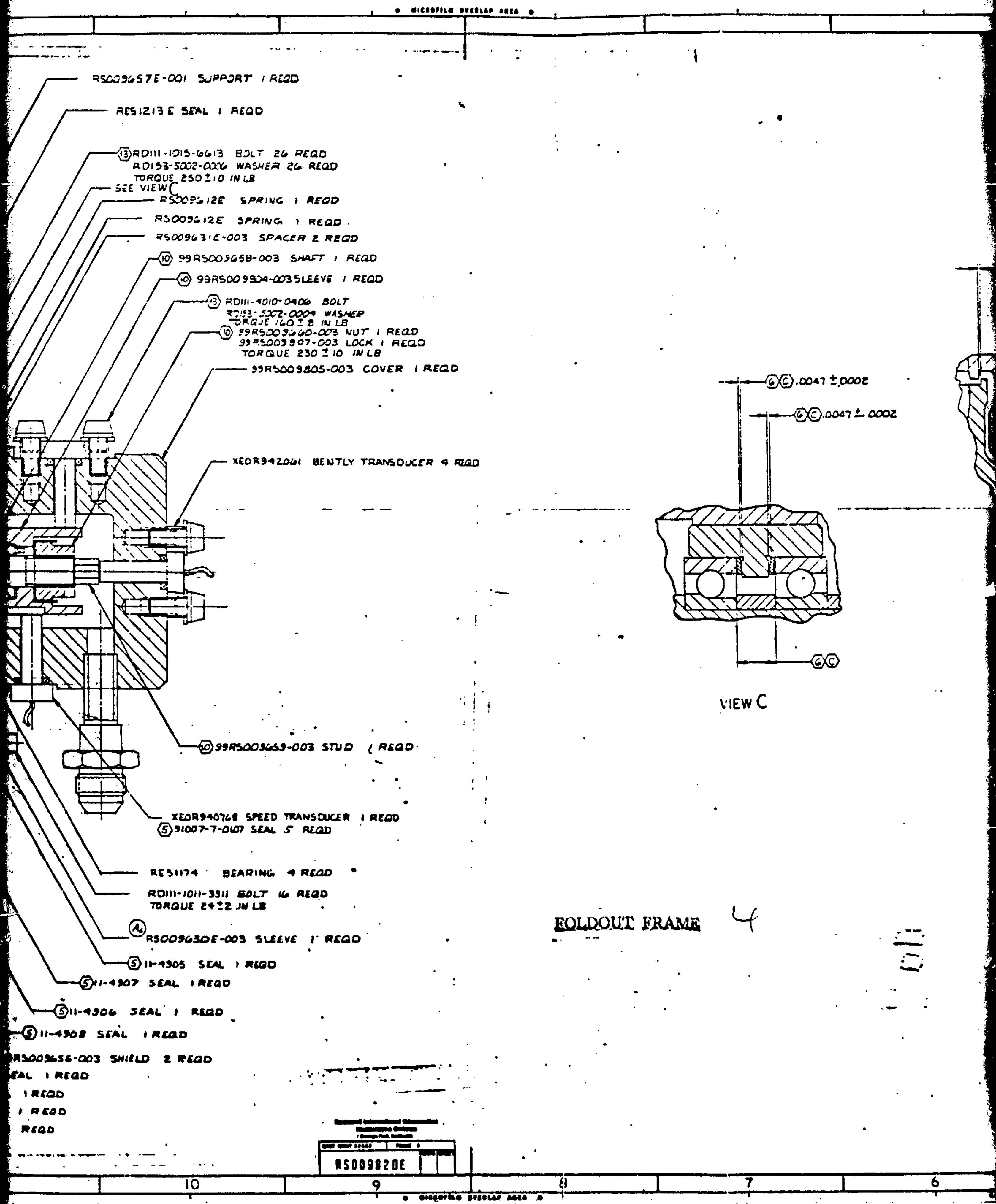

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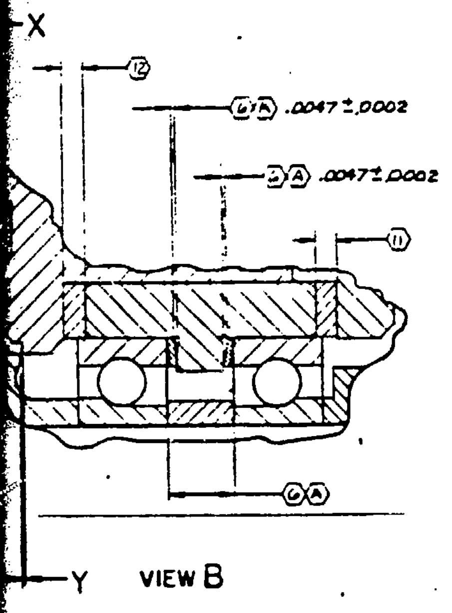
REVISIONS

SYM	DESCRIPTION
A	1. ADDED [illegible] - PRESSURE TAP [illegible] BALANCE PISTON CAVITY
	2. [illegible] SEAL 5 REQD WAS [illegible] SEAL 4 REQD
	3. ADDED [illegible] - PRESSURE TAP [illegible] BALANCE PISTON RETURN FLOW
	4. [illegible] NUT 1 REQD WAS [illegible] NUT 1 REQD
	5. ADDED [illegible] SLEEVE [illegible]
	6. [illegible] SLEEVE 1 REQD WAS [illegible] SLEEVE 2 REQD
	7. BALANCE PISTON RETURN [illegible] WAS PRESSURE TAP BALANCE PISTON RETURN FLOW
	EFFECT — EXPERIMENTAL



VIEW B

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FOR INFORMATION

13. LOCKWIRE BOLTS PER [illegible].
12. MACHINE SPACER THICKNESS PER DETAIL DRAWING TO OBTAIN AT LIQUID NITROGEN TEMPERATURE A FORCE OF [illegible] LB ON THE ROTOR WHEN CLEARANCE X IS ZERO.
11. MACHINE SPACER THICKNESS PER DETAIL DRAWING TO OBTAIN AT LIQUID NITROGEN TEMPERATURE A FORCE OF [illegible] LB ON THE ROTOR WHEN CLEARANCE Y IS ZERO.
10. BALANCE ROTOR ASSEMBLY TO WITHIN [illegible] GRAM INCHES.
9. MATCH MARK ALL ROTOR ASSEMBLY COMPONENTS PER [illegible] BY ELECTRO-[illegible] ETCH. [illegible] COMPONENTS OF THE ROTOR ASSEMBLY [illegible] FITTINGS [illegible]
8. APPLY PER [illegible].
7. [illegible] PER [illegible].
6. MACHINE SPACER PER DETAIL DRAWING TO OBTAIN MATCH CODED DIMENSION.
5. [illegible] DIVISION, [illegible] INC, NORTH HOLLYWOOD, CAL.
4. INSTALL PROTECTIVE COVERS OVER ALL EXPOSED FLANGES, TUBE FITTINGS & PORTS.
3. LEAK CHECK TURBOPUMP PER DETAILED ASSEMBLY INSTRUCTIONS.
2. INSTALL THREADED FASTENERS PER [illegible].
1. CLEAN ALL PARTS PRIOR TO PUMP ASSEMBLY PER [illegible]. ALL INTERNAL SURFACES TO BE MAINTAINED LOX CLEAN.

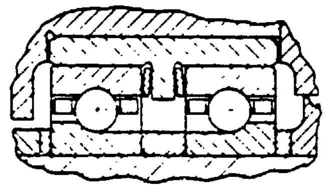
143

NONE	NONE

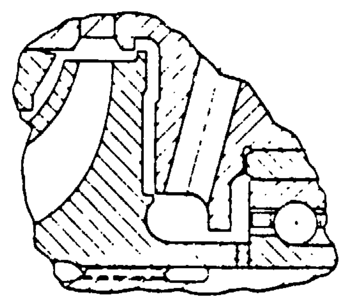
TURBOPUMP ASSY - OXIDIZER

J | 02602 | RS009E[illegible]

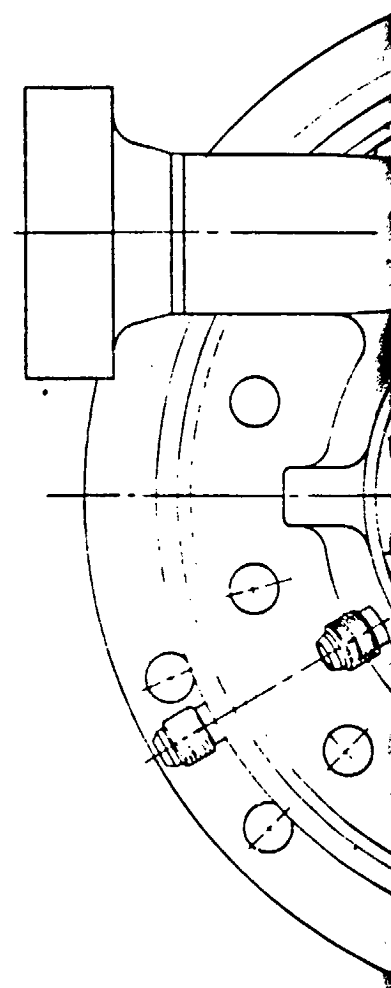
MK-48-O



VIEW D [15H]
SCALE $\frac{4}{1}$



VIEW E [15G]
SCALE $\frac{4}{1}$



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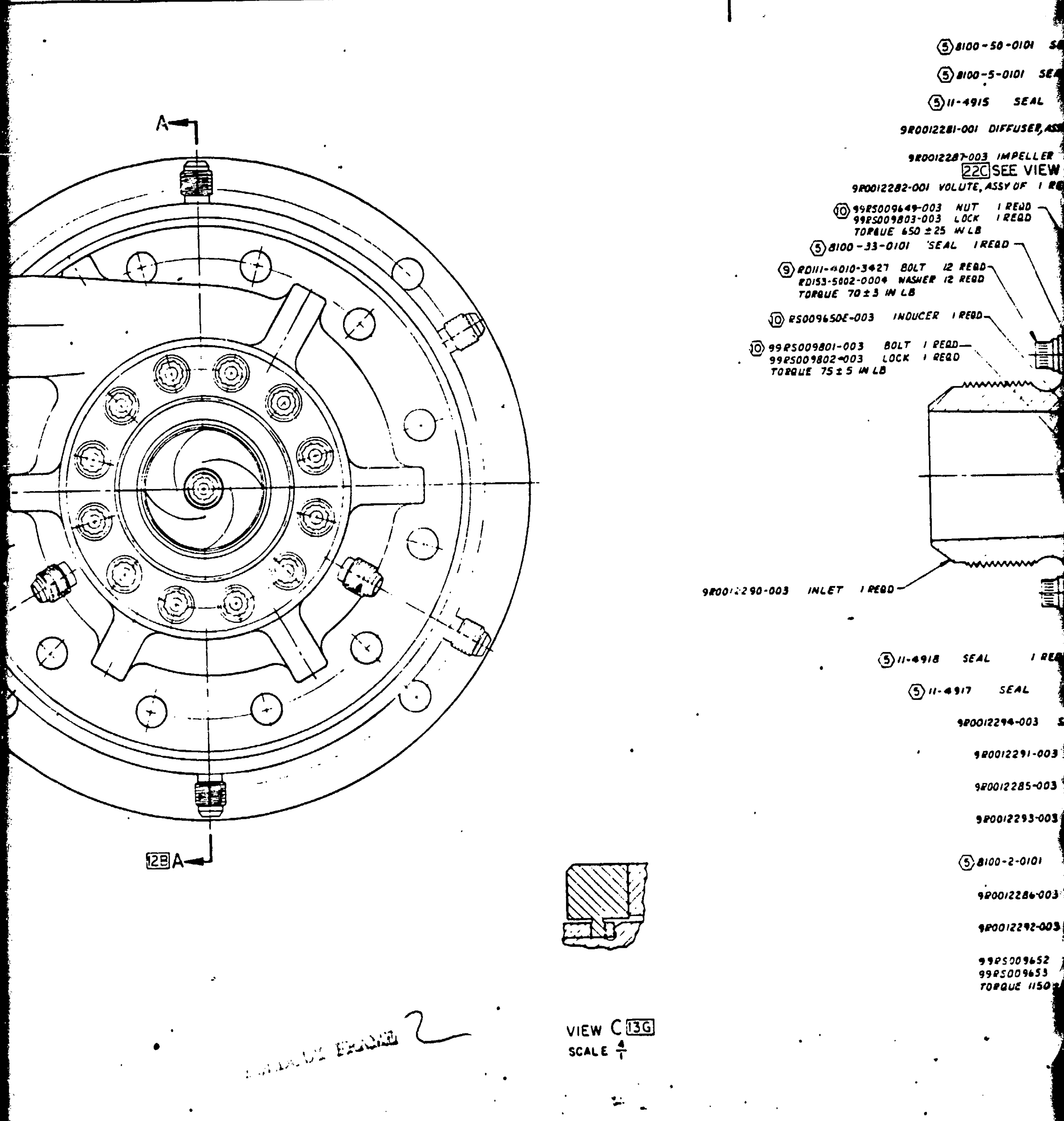
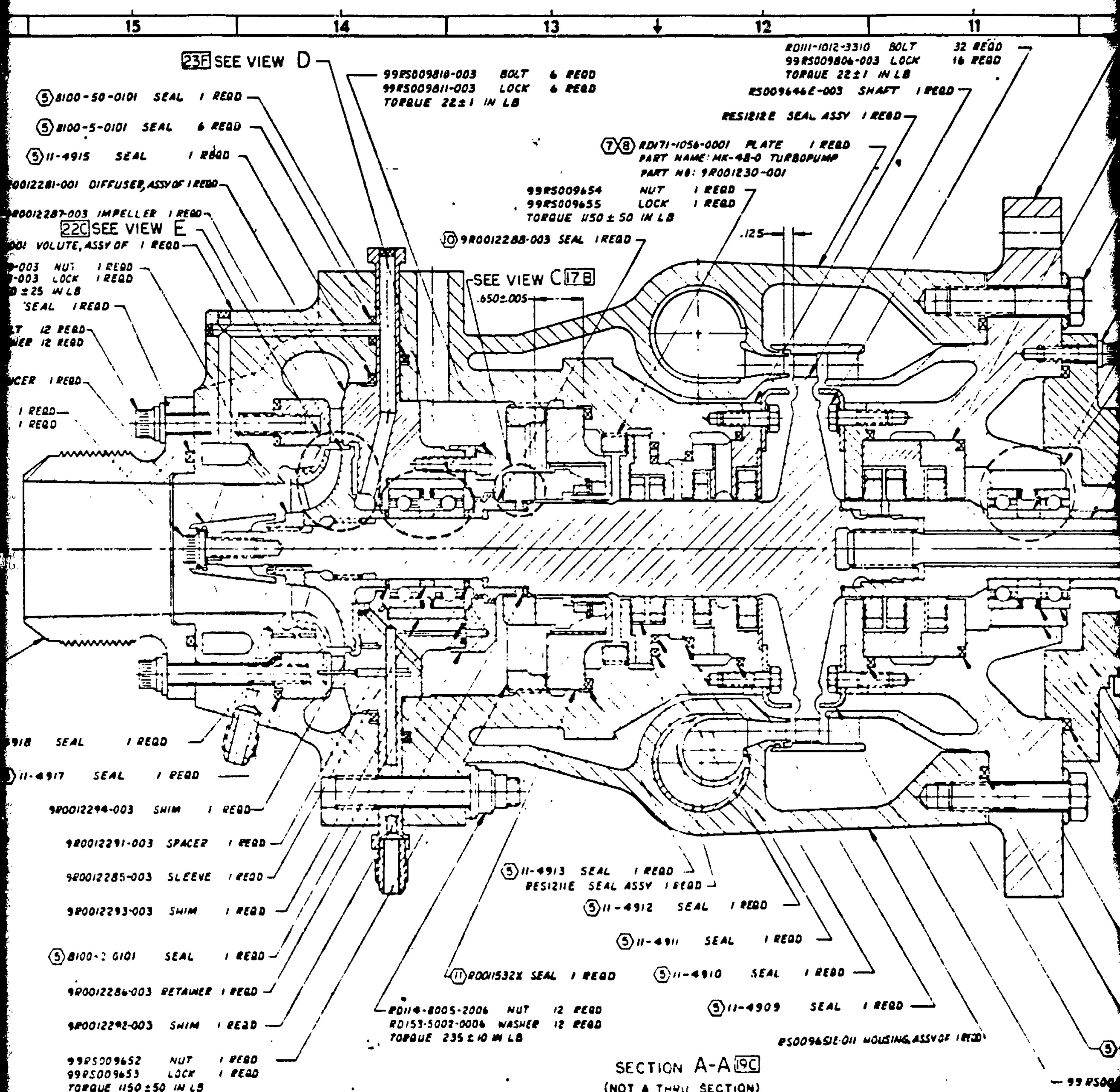


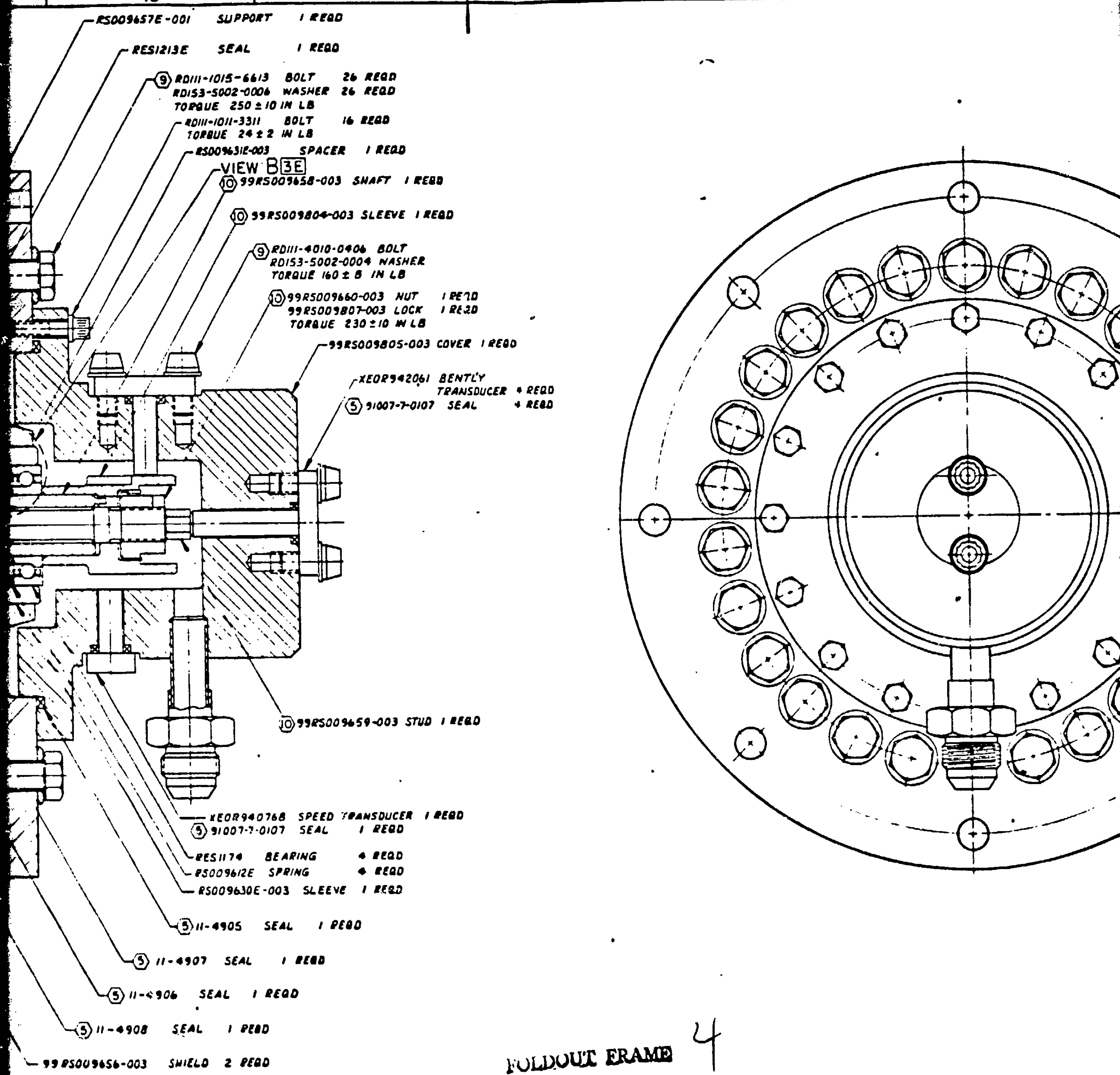
Rockwell International Corporation
Rocketdyne Division
Canoga Park, California

9RC012300			



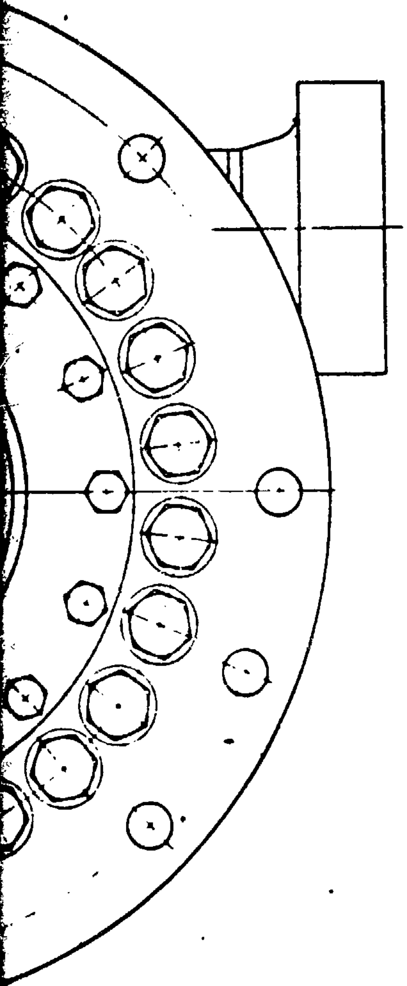
SECTION A-A 19C
(NOT A THRU SECTION)

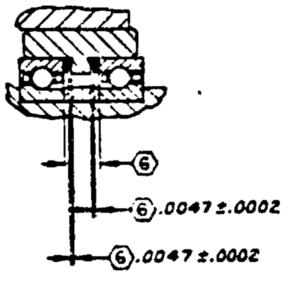
FOLDOUT FRAME 3



FOLDOUT FRAME 4

9R0012300





VIEW B 9G

FOLDOUT FRAME 5

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(11) MATING RING TO BE INCLUDED IN (10).
(10) BALANCE ROTOR ASSEMBLY TO WITHIN .02 GRAM INCHES. MATCH MARK ALL ROTOR ASSEMBLY COMPONENTS PER RA0104-008 BY ELECTRO CHEM ETCH. CODED PARTS ARE COMPONENTS OF THE ROTOR ASSEMBLY. ALIGN MATCHMARKS.
(9) LOCKWIRE BOLTS PER RA0101-002.
(8) APPLY PER RA0106-010.
(7) IDENTIFY PER RA0104-008.
(6) MACHINE SPACER PER DETAIL DRAWING TO OBTAIN MATCH CODED DIMENSION.
(5) HYDRODYNE DIVISION FPI INC NORTH HOLLYWOOD, CA.
4. INSTALL PROTECTIVE COVERS OVER ALL EXPOSED FLANGES, TUBE FITTINGS AND PORTS
3. LEAK CHECK TURBOPUMP PER DETAILED ASSY INSTRUCTIONS
2. INSTALL THREADED FASTENERS PER RA0101-002.
1. CLEAN ALL PARTS PRIOR TO PUMP ASSY PER RA0110-004. ALL INTERNAL SURFACES TO BE MAINTAINED LOX CLEAN.

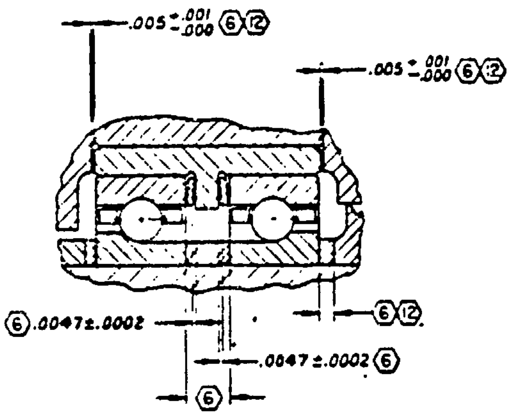
145

NONE	TURBOPUMP ASSY, OXIDIZER
NONE	J 02602 9R0012300

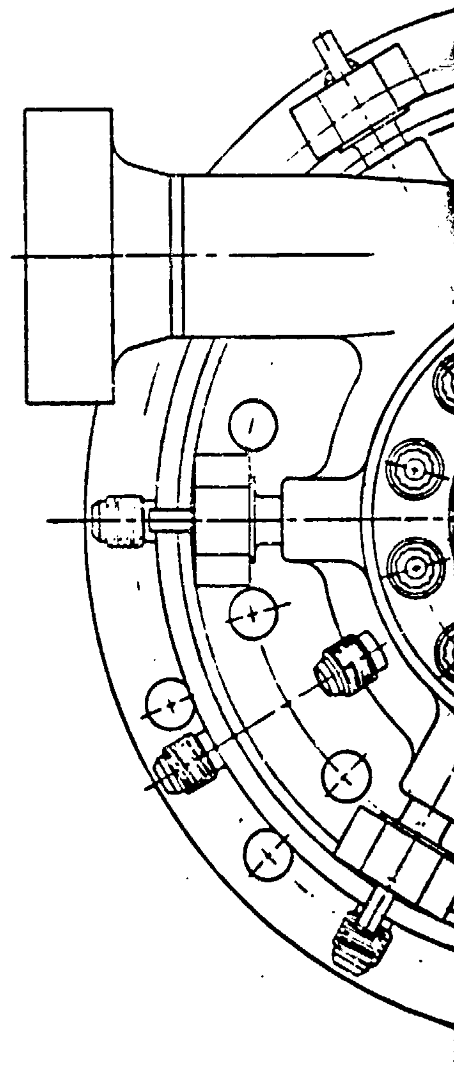
9R0012300

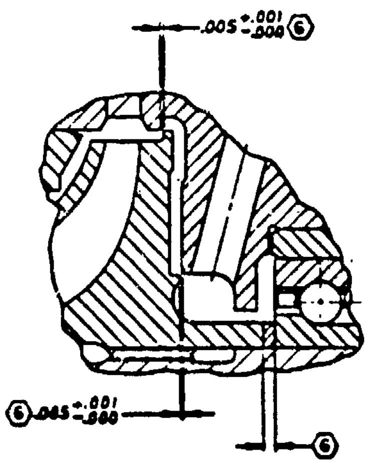
24 23 22 21 20

H G F E D C B A



VIEW D 15H
SCALE 4/1





VIEW E 15G
SCALE 4/1

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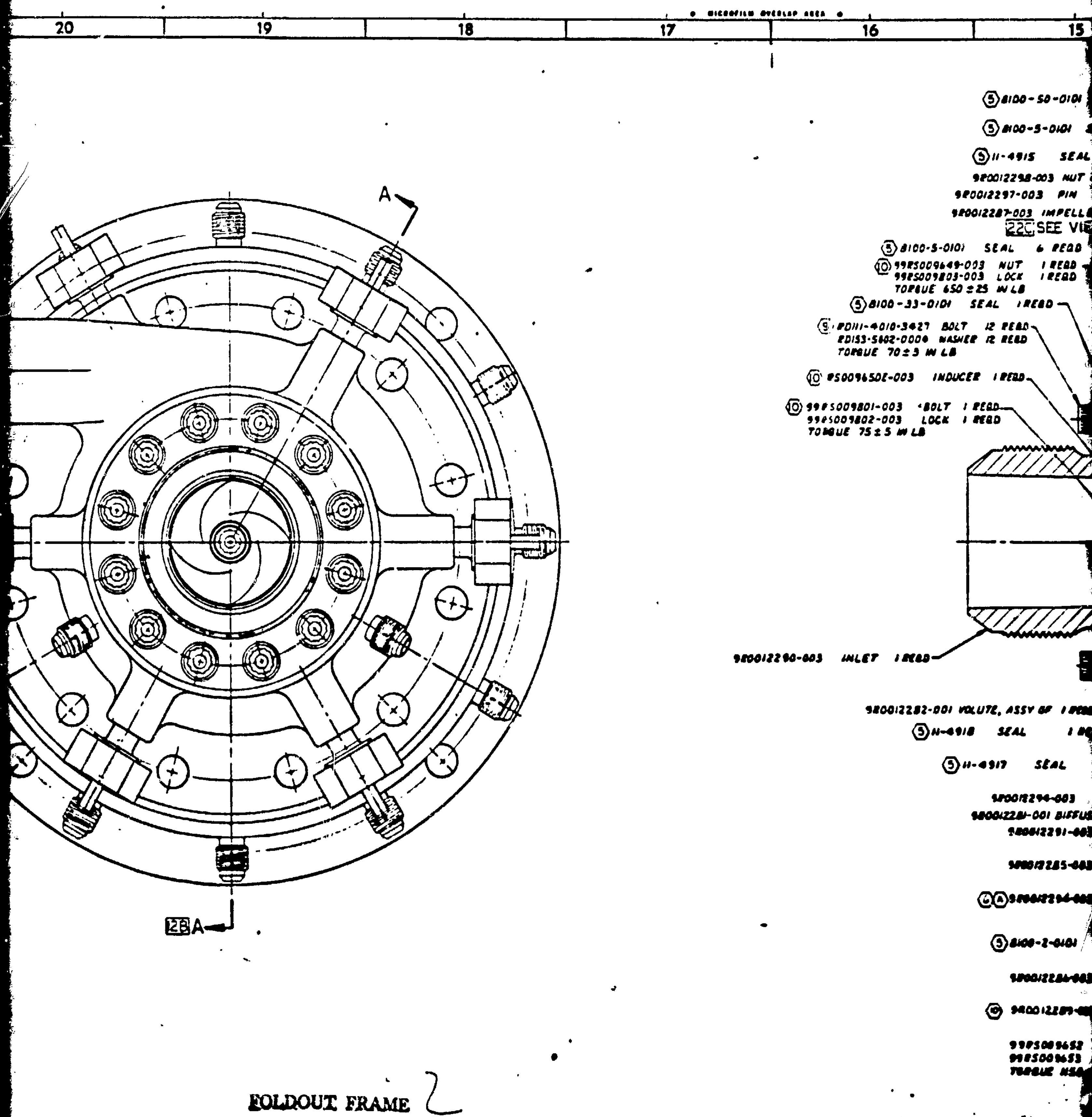

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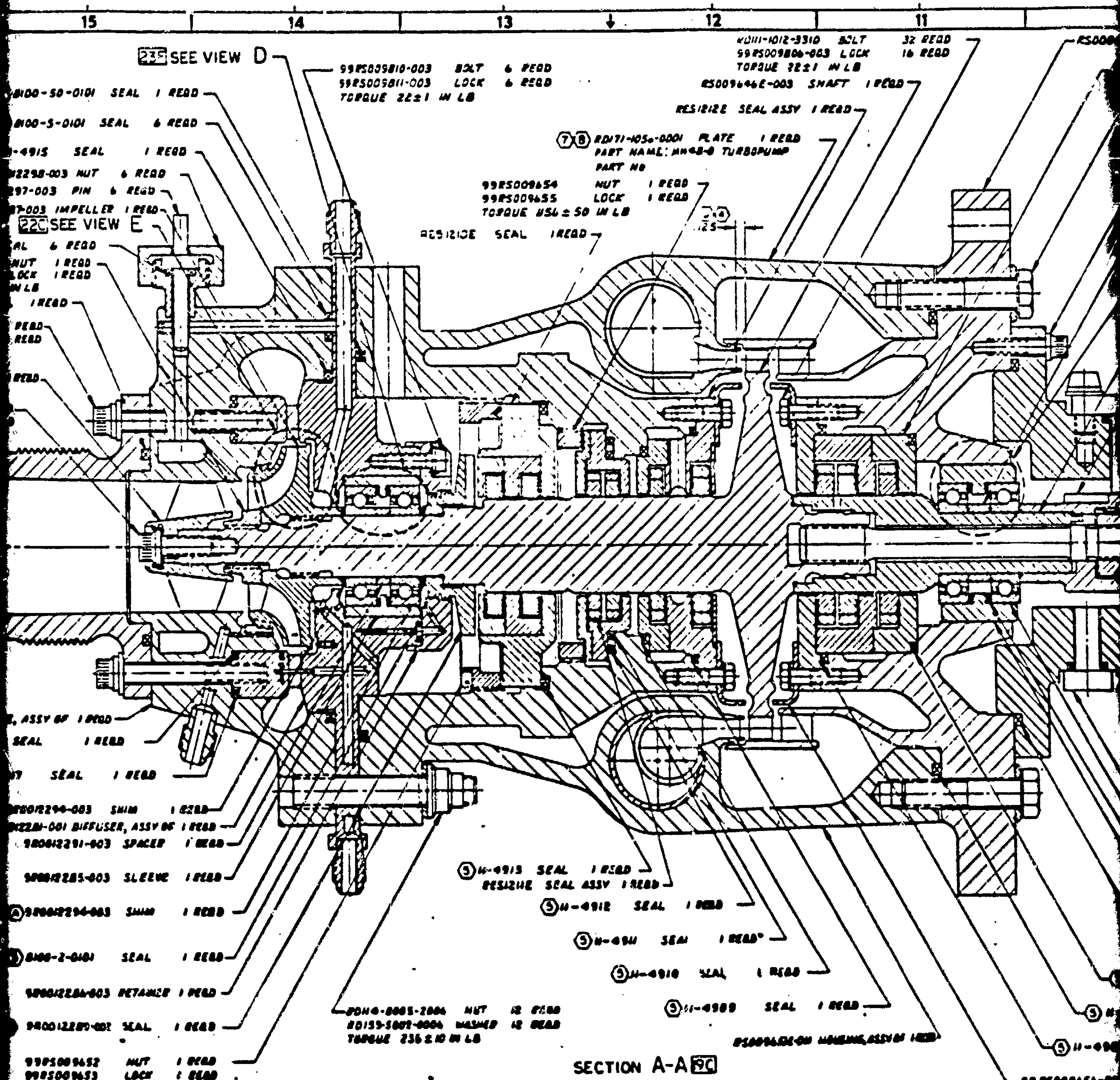

SECTION A-A 9C
(NOT A THRU SECTION)

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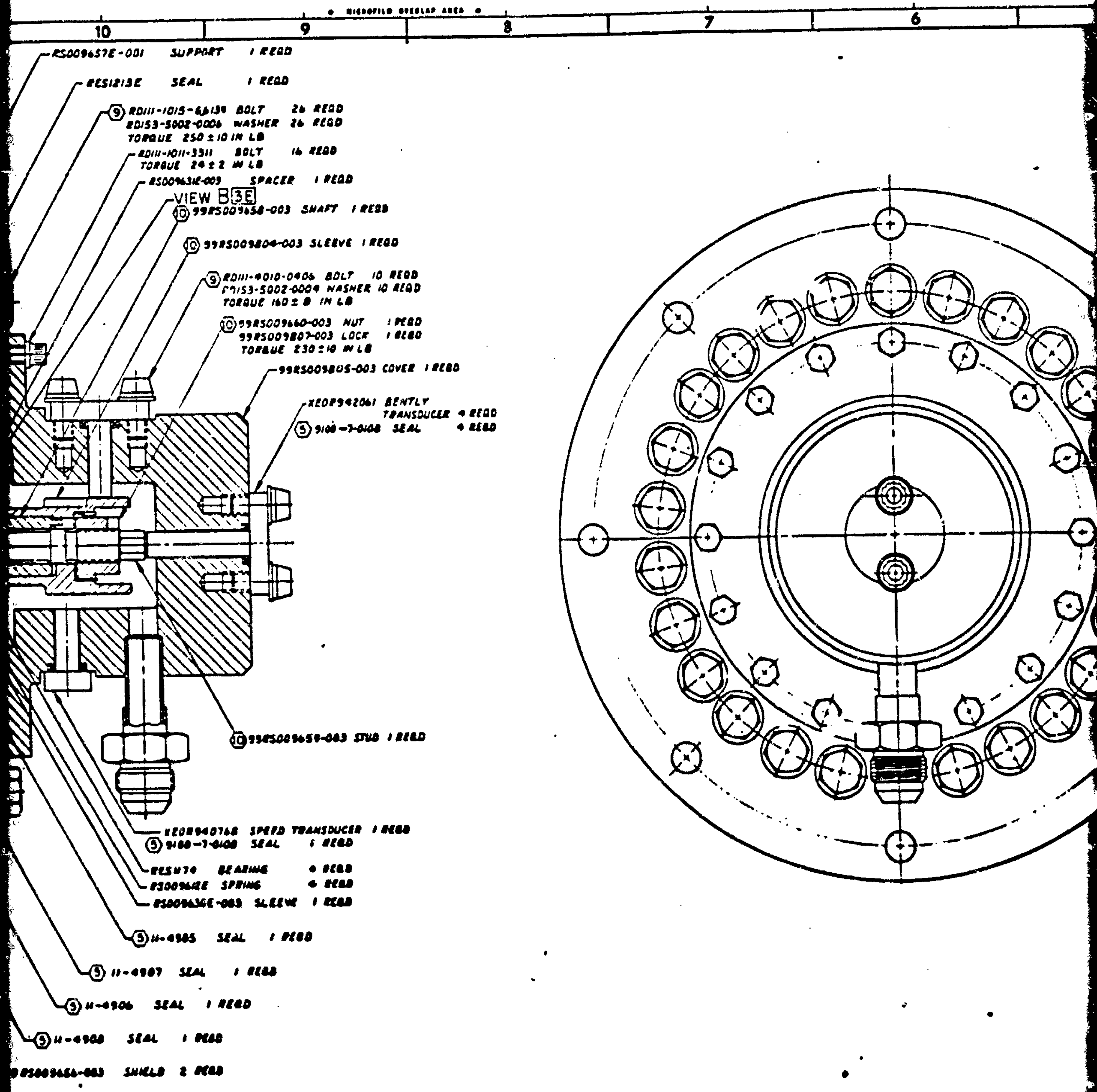
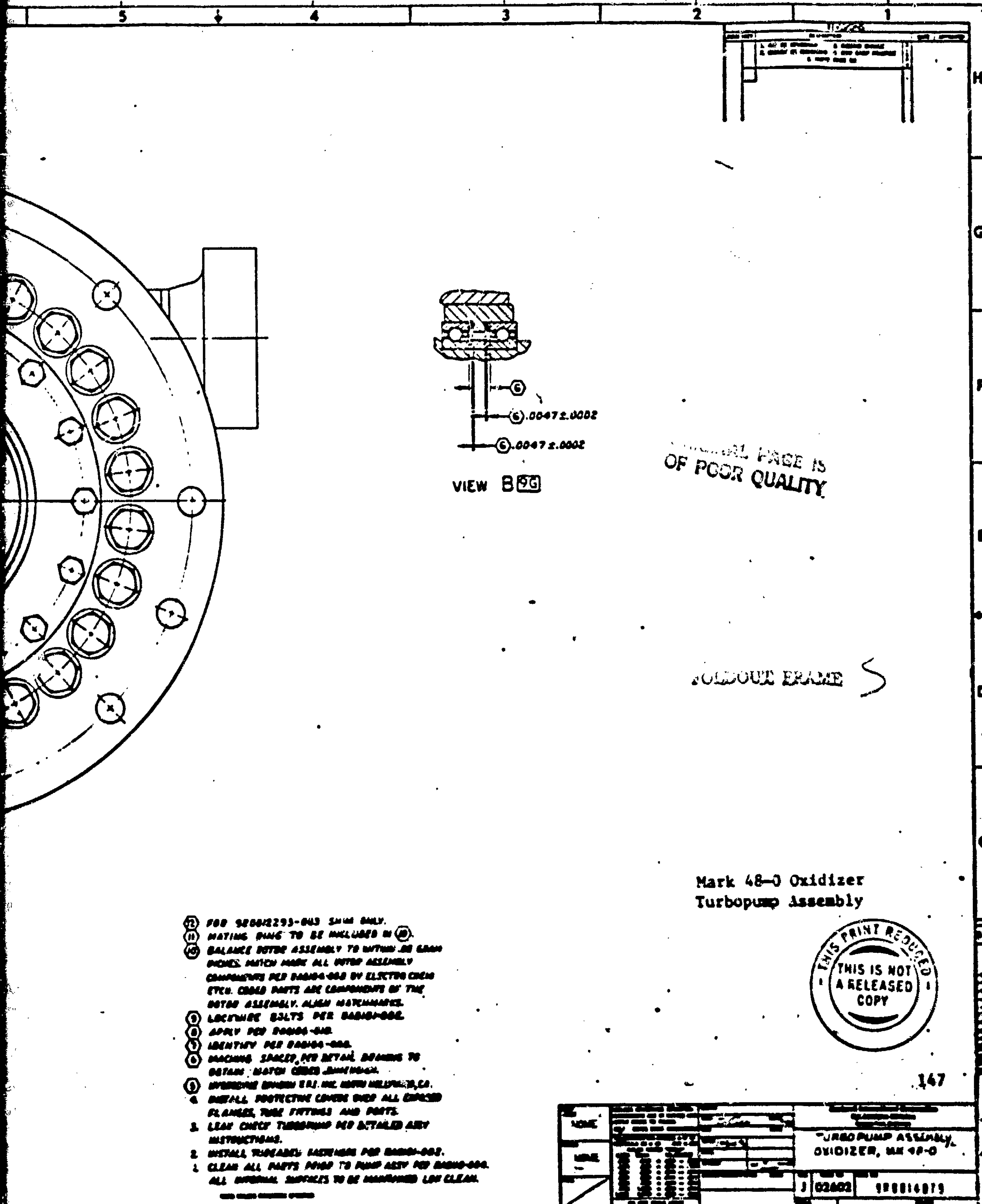
FOLDOUT FRAME 3



FOLDOUT FRAME 4

998014973



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Mark 48-O Oxidizer
Turbopump Assembly

APPENDIX B

MARK 48-OXIDIZER TURBOPUMP OCTOBER 1978 TEST DATA

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MK LIQUID CXYGEN TURBCFUMP ASSEMBLY

RUN NUMBER 9		PROCESSING DATE	1J-J6-7ъ
TEST CATE 10-05-78		TEST CURATION, SEC	55.0J

COMMENTS . . .

NPSH TEST AT NOMINAL CON AND BALANCE PISTON FLUID ROUTED OVERBOARD.
USED GASFLO FOR TLRB FLOW.

AMBIENT PRESSURE		13.8CUC
LO2 VENTLRI (GG)		
P/N V160248-SGR	UPSTREAM CIAMETER	0.957C
S/N 8871	THROAT CIAMETER	0.248C
	THRCAT CD	0.9850
GH2 VENTURI (TURB)		
P/N VP0312CC-SGR	UPSTREAM DIAMETER	2.300C
S/N 9731	THRCAT DIAMETER	1.3C85
	THRCAT CD	0.9873
LH2 VENTURI (GG)		
P/N V320471-SGR	UPSTREAM CIAMETER	1.689C
S/N 8873	THRCAT CIAMETER	C.471C
	THRCAT CC	0.9765
LOX VENTURI (PUMP DISCH)		
P/N V321059-SGR	UPSTREAM DIAMETER	1.669C
S/N 8877	THROAT CIAMETER	1.0590
	THRCAT CD	0.982C
	BAL PIST CVBD CONT ORIFICE	0.2420
	BAL PIST CVBC CRIFICE	0.2210
	LCX SEAL CRAIN ORIFICE	C.875C
	TURBINE EFFECTIVE AREA	0.2319
	TURBINE EXHAUST ORIFICE	0.6600
	PRIMARY H.C. CRAIN ORIFICE	0.255C
	SEC. H.G. CRAIN ORIFICE	0.6000
	REAR BRG CCCLANT ORIFICE	0.1800
	INTERMECIATE SEAL PURGE CRIFICE	0.126C

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MK48-0
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

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GASEOUS HYDROGEN TURBINE DRIVE PARAMETERS

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	VENTURI U/S PR (PSIA)	VENTURI U/S TEMP (DEG R)	VENTURI DELTA PR (PSID)	SPIN VALVE POSN	SPIN VALVE U/S PR (PSIA)	SPIN VALVE DELTA P (PSID)	TURB GH2 FLOW (LB/SEC)	SPEED (RPM)
1	46.029	46.545	4231.3	544.0	0.48	3.600	4224.6	3635.020	0.90669	29905.
2	55.020	55.536	4123.8	544.3	0.53	4.000	4118.3	3502.628	0.93311	30609.
3	62.032	62.547	4040.0	544.5	0.55	4.108	4034.9	3418.790	0.93452	30662.
4	67.023	67.538	3865.5	544.8	15.45	35.288	3822.6	624.913	4.26224	67067.
5	70.033	70.549	3747.1	543.4	15.91	39.130	3707.2	503.975	4.26920	67324.
6	73.003	73.560	3632.1	542.1	16.22	43.475	3590.4	398.917	4.26069	67257.
7	76.014	76.529	3521.1	540.8	16.53	48.817	3480.0	307.096	4.24364	67114.
8	77.004	77.560	3484.7	540.4	16.61	50.909	3443.1	278.873	4.23586	67164.
9	78.035	78.550	3448.9	540.0	16.67	53.190	3407.6	252.305	4.22286	67159.
10	79.025	79.540	3413.4	539.6	16.76	55.595	3371.6	223.612	4.21548	67037.
11	80.015	80.530	3379.2	539.2	16.79	58.149	3338.1	200.581	4.20440	66961.
12	81.004	81.561	3344.0	538.7	16.79	61.086	3304.0	181.867	4.18534	66812.
13	82.035	82.551	3309.7	538.2	16.78	64.257	3268.0	162.921	4.16477	66641.
14	83.025	83.541	3276.2	537.8	16.79	67.719	3236.3	144.559	4.15077	66570.
15	84.015	84.531	3242.9	537.3	16.78	71.526	3202.9	129.908	4.12880	66579.
16	85.005	85.562	3209.7	536.8	16.71	75.759	3170.1	117.623	4.10467	66472.
17	86.036	86.552	3176.9	536.4	16.64	80.390	3137.1	103.318	4.08151	66310.
18	87.026	87.542	3173.4	536.4	0.74	-2.171	2568.6	2295.548	0.76643	27512.

[illegible] MK4[illegible]

LIQUID OXYGEN TURBOPUMP ASSEMBLY

[illegible] NUMBER [illegible] 9
[illegible] DATE [illegible]10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

T U R B I N E   P A R A M E T E R S

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	SPEED (RPM)	TURB INLET STAT PR (PSIA)	TURB INLET TOT PR (PSIA)	TURB INLET TOT TEMP (DEG R)	TURB NOZZ D/S PR (PSIA)	TURB EXH STAT PR (PSIA)	TURB EXH TOT PR (PSIA)	TURB EXH TOT TEMP (DEG R)	TURB DSCH ORIFICE DELTA P (PSID)
1	46.029	46.545	29905.	585.7	581.1	556.8	392.2	392.0	403.7	431.5	382.6
2	55.020	55.536	30609.	613.4	607.9	558.2	410.4	409.2	419.8	441.0	398.9
3	62.032	62.547	30662.	614.6	608.2	558.3	411.0	409.7	421.5	443.3	400.5
4	67.023	67.538	67067.	3171.8	3145.9	547.8	1941.4	1957.2	1985.9	480.9	1941.7
5	70.033	70.545	67324.	3179.1	3151.3	546.5	1941.6	1959.0	1988.1	479.4	1943.5
6	73.003	73.560	67257.	3165.4	3139.1	545.1	1933.9	1952.6	1981.1	477.8	1936.5
7	76.014	76.529	67114.	3147.2	3120.1	543.0	1922.4	1940.7	1970.3	476.3	1925.6
8	77.004	77.560	67164.	3138.3	3113.8	542.4	1917.8	1936.4	1965.6	475.8	1920.9
9	78.035	78.550	67159.	3126.4	3104.3	542.0	1911.9	1930.5	1958.7	475.3	1914.1
10	79.025	79.540	67037.	3120.6	3097.2	541.4	1907.8	1926.2	1954.4	474.9	1910.0
11	80.015	80.530	66961.	3110.5	3087.5	540.9	1902.2	1920.3	1948.6	474.5	1904.2
12	81.004	81.561	66812.	3098.6	3071.4	540.6	1893.0	1910.7	1939.3	474.2	1895.1
13	82.035	82.551	66641.	3080.6	3055.3	540.0	1883.1	1900.9	1928.9	473.7	1884.9
14	83.025	83.541	66570.	3065.3	3042.2	539.8	1875.4	1892.9	1921.2	473.1	1877.5
15	84.015	84.531	66579.	3047.4	3024.0	539.2	1864.0	1881.3	1909.7	472.4	1866.4
16	85.005	85.562	66472.	3029.7	3003.8	538.9	1851.8	1868.9	1897.2	471.6	1854.0
17	86.036	86.552	66310.	3009.3	2984.8	538.6	1840.2	1857.1	1885.5	471.1	1842.4
18	87.026	87.542	27512.	212.8	939.6	467.9	159.5	159.7	316.3	367.7	293.6

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MK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

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T U R B I N E P A R A M E T E R S (CONTINUED)

TIME SLICE NO	SPEED RPM	FLOW (LB/SEC)	PR RATIO (T-T)	BHP (CALIB) (HP)	BHP (DELTA T) (HP)	TORQUE (FT-LB)	U/C (T-S)	EFF (T-S)	TURB NOZ IN TOT P (PSIA)
1	29905.	0.9067	1.4528	97.1	572.3	17.04	0.1951	38.35	569.4
2	30635.	0.9331	1.4560	102.0	550.4	17.49	0.1988	38.83	595.8
3	30662.	0.9345	1.4549	102.2	541.4	17.49	0.1993	38.89	596.1
4	67067.	4.2622	1.5752	755.7	1469.9	59.15	0.3942	51.55	3083.0
5	67324.	4.2692	1.5765	756.4	1478.4	58.98	0.3958	51.53	3088.3
6	67257.	4.2607	1.5755	752.2	1479.5	58.71	0.3961	51.52	3076.3
7	67114.	4.2436	1.5756	746.6	1460.4	58.41	0.3959	51.53	3057.7
8	67164.	4.2359	1.5759	744.8	1458.6	58.22	0.3963	51.52	3051.5
9	67159.	4.2229	1.5759	741.9	1454.5	58.00	0.3964	51.52	3042.2
10	67037.	4.2155	1.5758	740.0	1449.6	57.95	0.3959	51.53	3035.3
11	66961.	4.2044	1.5757	737.3	1441.6	57.81	0.3957	51.53	3025.8
12	66812.	4.1853	1.5753	733.4	1436.2	57.63	0.3950	51.54	3010.0
13	66641.	4.1648	1.5751	728.9	1426.7	57.43	0.3942	51.55	2994.2
14	66570.	4.1508	1.5750	726.0	1429.2	57.26	0.3940	51.56	2981.4
15	66575.	4.1288	1.5753	721.7	1426.7	56.91	0.3941	51.55	2963.5
16	66472.	4.1047	1.5752	717.0	1427.9	56.63	0.3937	51.56	2943.8
17	66310.	4.0815	1.5751	712.5	1424.2	56.41	0.3928	51.57	2925.1
18	27512.	0.7664	5.7679	168.5	400.8	32.15	0.0978	23.40	920.9

LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER [illegible] · PROCESSING DATE 10-06-78
TEST DATE 10-05-78 · TEST DURATION, SEC 56.00

TURBINE PARAMETERS (CONTINUED)

TIME SLICE NO.	SPEED RPM	AVAIL. ENERGY(T-S) (BTU/LB)	GAMMA	CP (BTU/LBM-R)	SPEED PARA-METER	FLOW PARA-METER	TORQUE PARA-METER	TURB WHEEL EXH PRESS PSIA
[illegible]	[illegible]	157.31	1.3905	3.5585	215.[illegible]	4.4873	0.0275	393.7
[illegible]	[illegible]	158.97	1.3908	3.5585	219.9	4.4189	0.0269	409.7
[illegible]	[illegible]	158.65	1.3908	3.5584	220.2	4.4243	0.0269	410.6
[illegible]	[illegible]	243.05	1.3998	3.6456	486.4	3.8642	0.0176	1996.3
[illegible]	[illegible]	[illegible]	1.3997	3.6473	488.8	3.8594	0.0175	1996.8
[illegible]	[illegible]	[illegible]	1.3997	3.6487	488.9	3.8617	0.0175	1989.2
[illegible]	[illegible]	[illegible]	1.3996	3.6508	488.9	3.8621	0.0175	1977.8
[illegible]	[illegible]	[illegible]	1.3996	3.6513	489.5	3.8610	0.0175	1972.7
[illegible]	[illegible]	[illegible]	1.3996	3.6517	489.6	3.8593	0.0175	1966.1
[illegible]	[illegible]	[illegible]	1.3996	3.6522	489.0	3.8594	0.0175	1961.9
[illegible]	[illegible]	[illegible]	1.3995	3.6526	488.7	3.8594	0.0175	1956.4
[illegible]	[illegible]	[illegible]	1.3995	3.6525	487.7	3.8612	0.0176	1947.1
[illegible]	[illegible]	[illegible]	1.3995	3.6528	486.7	3.8602	0.0176	1936.9
[illegible]	[illegible]	[illegible]	[illegible]	3.6528	486.3	3.8626	0.0176	1929.1
[illegible]	[illegible]	[illegible]	[illegible]	3.6531	486.6	3.8636	0.0176	1917.2
[illegible]	[illegible]	[illegible]	[illegible]	3.6530	486.0	3.8658	0.0177	1904.5
[illegible]	[illegible]	[illegible]	[illegible]	3.6530	485.0	3.8673	0.0177	1892.9
[illegible]	[illegible]	[illegible]	[illegible]	3.6882	215.9	2.1501	0.0320	157.6

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MK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

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SEAL AND BEARING DATA

TIME SLICE NO	PRIM LOX SEAL DR PR (PSIA)	PRIM LOX SEAL DR TEMP (DEG R)	T/S PURGE PR (PSIA)	T/S PURGE TEMP (DEG R)	PRIM HG SEAL ORIF U/S PR (PSIA)	PRIM HG SEAL ORIF U/S TEMP (DEG R)	PRIM HG SEAL DR FLOW (LB/SEC)	SEC HG SEAL DR PR (PSIA)	SEC HG SEAL DR TEMP (DEG R)	SEC HG SEAL ORIF U/S PR (PSIA)	SEC HG SEAL ORIF U/S TEMP (DEG R)
1	16.68	148.87	221.32	557.95	15.07	232.88	0.0360	20.8	314.44	14.24	358.40
2	16.49	148.23	219.13	557.29	14.98	239.10	0.0343	20.9	308.52	14.23	330.72
3	16.30	148.16	217.53	557.95	14.92	241.73	0.0333	20.9	309.07	14.21	325.35
4	18.81	154.45	220.86	558.28	34.77	394.75	0.0992	29.9	418.04	14.65	384.60
5	18.57	160.09	221.75	558.24	36.81	422.15	0.1017	31.4	434.64	14.69	412.78
6	18.62	162.71	221.79	558.14	36.86	430.08	0.1010	30.7	439.26	14.67	426.70
7	18.68	164.55	221.61	558.18	36.41	433.43	0.0994	30.0	442.40	14.62	434.53
8	18.70	165.15	221.56	558.14	36.19	434.40	0.0987	29.8	443.38	14.63	436.37
9	18.69	166.13	221.50	557.97	36.00	435.48	0.0981	29.7	444.03	14.64	438.10
10	18.70	167.28	221.30	557.95	35.81	436.29	0.0974	29.8	444.76	14.64	439.46
11	18.70	167.68	221.15	557.95	35.60	437.13	0.0968	29.7	445.66	14.64	440.79
12	18.69	168.05	221.01	557.95	35.38	437.99	0.0961	29.5	446.17	14.61	442.02
13	18.68	168.60	220.96	557.95	35.15	438.39	0.0954	29.2	446.65	14.59	443.03
14	18.68	169.33	220.89	557.95	34.93	438.82	0.0948	29.1	447.20	14.58	443.89
15	18.68	169.88	220.86	557.95	34.64	438.83	0.0940	28.8	447.23	14.56	444.74
16	18.68	170.61	220.76	557.95	34.33	438.81	0.0932	28.7	447.20	14.59	445.13
17	18.66	171.17	220.86	557.95	33.94	438.62	0.0921	28.7	446.88	14.56	445.73
18	17.10	174.65	213.67	557.95	14.77	436.43	0.0232	17.0	445.60	13.92	446.09

LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 9
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	SEC FG SEAL DR FLOW (LB/SEC)	RR BRG COOLANT SUPPL.PR (PSIA)	RR BRG COOLANT SUPPL.TEMP (DEG R)	RR BRG DRAIN PR (PSIA)	RR BRG DRAIN TEMP (DEG R)	RR BRG COOL.ORIF U/S PR (PSIA)	RR BRG COOL.ORIF U/S TEMP (DEG R)	RR BRG COOLANT FLOW (LB/SEC)
1	0.0	3508.3	81.13	205.2	84.35	13.8	460.00	0.0
2	0.0	3509.2	83.25	206.8	84.35	13.8	460.00	0.0
3	0.0	3510.6	85.50	206.1	84.39	13.8	460.00	0.0
4	0.0	3525.7	87.81	197.0	91.61	13.8	460.00	0.0
5	0.0	3528.1	88.63	198.6	92.76	13.8	460.00	0.0
6	0.0	3528.8	89.75	199.4	93.75	13.8	460.00	0.0
7	0.0	3461.6	90.94	197.8	93.46	13.8	460.00	0.0
8	0.0	3432.3	91.13	195.7	93.18	13.8	460.00	0.0
9	0.0	3396.6	92.19	195.9	94.17	13.8	460.00	0.0
10	0.0	3362.6	92.06	194.9	93.34	13.8	460.00	0.0
11	0.0	3329.2	92.44	194.4	93.99	13.8	460.00	0.0
12	0.0	3294.4	93.00	192.9	93.99	13.8	460.00	0.0
13	0.0	3260.3	92.81	191.4	92.73	13.8	460.00	0.0
14	0.0	3227.5	92.56	189.0	91.55	13.8	460.00	0.0
15	0.0	3195.1	91.13	187.1	90.66	13.8	460.00	0.0
16	0.0	3162.4	90.19	184.8	89.30	13.8	460.00	0.0
17	0.0	3130.2	88.63	182.4	87.93	13.8	460.00	0.0
18	0.0	1683.9	91.19	119.2	79.40	13.8	460.00	0.0

ORIGINAL PAGE IS OF POOR QUALITY

PK4

LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	LOX SEAL DRAIN ORIF L/S PRESS PSIA	LOX SEAL DRAIN ORIF U/S TEMP DEG R	LOX SEAL DRAIN FLOWRATE (LB/SEC)
1	14.2	530.56	0.065
2	14.1	531.57	0.059
3	14.1	532.10	0.055
4	14.6	531.35	0.100
5	14.6	530.91	0.097
6	14.6	530.80	0.097
7	14.6	530.80	0.097
8	14.6	530.78	0.097
9	14.6	530.78	0.097
10	14.6	530.78	0.097
11	14.6	530.77	0.097
12	14.6	530.76	0.096
13	14.6	530.78	0.096
14	14.6	530.80	0.096
15	14.6	530.80	0.096
16	14.6	530.79	0.096
17	14.5	530.80	0.095
18	14.3	530.83	0.080

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OF POOR QUALITY

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 9
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

PUMP PRESSURES

TIME SLICE NO	SUPPLY TANK PR (PSIA)	PUMP INLET PR (PSIA)	IMPELLER DISCH PR (PSIA)	DIFFUSER DISCH PR (PSIA)	PUMP DISCH PR (PSIA)	BAL PIST CAV PR #1 (PSIA)	BAL PIST SUMP PR (PSIA)	BAL PIST RETURN PR (PSIA)	IMPELLER FRONT SHROUD PR (PSIA)
1	263.9	246.5	562.0	834.9	962.0	747.5	352.4	279.2	778.9
2	263.7	245.3	561.6	859.9	999.1	772.1	366.3	290.4	804.7
3	263.4	244.7	553.8	860.6	1000.6	768.4	366.1	291.0	806.1
4	259.9	160.0	1733.9	2656.9	4040.3	1990.2	1258.4	1044.5	2940.5
5	260.5	160.1	1723.8	2556.3	4064.1	1960.1	1282.7	1053.4	2957.5
6	260.6	160.3	1719.8	2546.2	4059.0	1946.0	1291.7	1054.9	2954.6
7	260.5	160.9	1716.1	2503.3	4044.4	1931.4	1299.0	1053.2	2944.7
8	244.7	146.6	1705.4	2456.8	4035.2	1923.2	1290.4	1045.6	2932.1
9	226.1	127.6	1682.1	2477.5	4003.2	1905.4	1272.7	1030.7	2899.9
10	214.3	116.2	1669.1	2465.3	3978.8	1890.5	1264.0	1023.2	2878.4
11	206.3	108.0	1660.1	2451.1	3957.1	1877.1	1257.1	1016.3	2860.3
12	200.3	103.0	1637.1	2445.5	3927.9	1874.0	1238.0	1006.6	2833.9
13	196.0	99.2	1623.7	2437.9	3699.5	1853.3	1228.2	999.6	2811.1
14	192.9	97.1	1624.2	2433.7	3887.0	1846.4	1220.9	996.2	2801.4
15	190.5	94.0	1625.0	2430.7	3881.5	1826.5	1217.4	992.9	2797.3
16	188.7	93.0	1622.1	2402.0	3864.3	1825.9	1210.9	987.5	2786.0
17	187.3	92.1	1607.9	2406.2	3844.5	1798.5	1206.1	981.2	2772.5
18	186.6	181.1	579.8	781.1	989.8	646.9	456.1	352.4	879.2

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S

100

TIME SLICE NO	SPEED RPM	INDUCER DISCH PRESS PSIA	PUMP BRG D/S PRESS PSIA	BAL PIST RECIRC TEMP DEG R (Bad)	PUMP BRG DELTA P PSID
1	29505.	274.1	285.5	445.19	75.48
2	30609.	276.5	295.5	445.09	76.41
3	30662.	276.0	296.8	445.16	75.26
4	67067.	418.8	998.9	444.89	266.70
5	67324.	413.5	1044.1	445.29	246.46
6	67257.	416.4	1081.2	445.15	217.88
7	67114.	414.5	1078.1	445.16	226.91
8	67164.	391.4	1075.5	445.08	220.79
9	67155.	352.3	1066.1	445.07	212.92
10	67037.	330.0	1056.1	445.11	213.76
11	66961.	313.6	1036.3	445.10	224.09
12	66812.	299.9	1061.9	445.16	181.76
13	66641.	290.7	1048.4	445.10	185.51
14	66570.	285.9	1042.2	444.73	184.09
15	66579.	279.7	1037.7	445.12	185.33
16	66412.	278.4	1037.0	445.08	179.59
17	66310.	278.5	1031.1	445.14	180.15
18	27512.	257.2	468.6	445.15	-10.07

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MK4.
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-16-78
TEST DURATION, SEC 56.00

P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S (CONTINUED)

TIME SLICE NO	BAL PIST OVBC PRESS PSIA	BAL PIST CVBD TEMP DEG R	BAL PIST OVBC DELTA P PSI	BAL PIST FLOW LB/SEC	BAL PIST FLOW TEMP RISE DEG R
1	265.0	191.2	61.68	1.614	279.62
2	274.7	192.1	63.72	1.636	279.47
3	275.5	192.2	63.60	1.637	279.43
4	927.3	252.3	210.79	2.685	266.48
5	935.4	253.3	211.21	2.681	266.47
6	936.9	253.4	211.11	2.680	266.00
7	936.0	253.3	210.14	2.674	266.00
8	928.8	253.6	208.36	2.659	266.00
9	916.4	254.3	204.88	2.631	266.00
10	905.6	254.3	203.24	2.619	266.00
11	904.0	254.3	201.65	2.608	266.00
12	894.8	254.2	199.63	2.594	266.00
13	889.3	254.3	198.30	2.587	266.00
14	886.1	254.0	197.92	2.584	266.00
15	883.6	254.0	197.07	2.578	266.00
16	878.4	253.9	196.09	2.572	266.00
17	873.3	253.7	194.93	2.565	266.00
18	3[illegible].4	235.4	42.31	1.232	266.00

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PK48
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

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PUMP PRESSURES AND TEMPERATURES

TIME SLICE NO	PUMP INLET TEMP (DEG R)	PUMP DISCH TEMP (DEG R)	BAL PIST RETURN TEMP (DEG R)	PUMP DISCH VENT U/S TEMP (DEG R)	PUMP DISCH VENT U/S PR (PSIA)	PUMP DISCH VENT DELTA PR (PSI)	HP (TEMP)
1	175.58	180.38	460.00	180.44	938.4	16.61	96.89
2	175.51	180.53	460.00	180.55	975.2	16.69	101.90
3	175.50	180.56	460.00	180.59	976.7	16.70	102.59
4	175.58	193.52	460.00	193.48	3976.0	51.28	741.81
5	175.58	193.52	460.00	193.48	3998.0	51.35	744.58
6	175.58	194.00	460.00	194.00	3992.7	50.93	751.26
7	175.58	194.00	460.00	194.00	3977.4	50.37	745.88
8	175.57	194.00	460.00	194.00	3968.6	50.13	744.50
9	175.78	194.00	460.00	194.00	3937.6	49.64	734.12
10	175.64	194.00	460.00	194.00	3913.4	49.17	732.50
11	175.57	194.00	460.00	194.00	3893.1	48.99	731.35
12	175.53	194.00	460.00	194.00	3863.5	48.39	725.61
13	175.48	194.00	460.00	194.00	3835.8	48.23	722.83
14	175.43	194.00	460.00	194.00	3822.8	47.72	719.77
15	175.43	194.00	460.00	194.00	3817.6	47.67	718.97
16	175.41	194.00	460.00	194.00	3801.1	47.70	718.05
17	175.41	194.00	460.00	194.00	3781.7	47.39	714.08
18	175.57	194.00	460.00	194.00	984.9	9.31	207.21

MK4.

LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 9
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

CALCULATED PUMP PARAMETERS

TIME SLICE NO	TEST SPEED (RPM)	PUMP FLOW GPM	PUMP FLOW (LB/SEC)	HEAD FT	PRESS RISE (PSI)	FLUID HP (HP)	TURB HP (HP)	EFF (%)	ISEN EFF (%)	SPECIFIC SPEED
1	29905.	136.95	21.0664	1525.8	715.5	58.4	97.07	60.24	60.32	1433.
2	30609.	137.24	21.1206	1605.4	753.8	61.6	102.00	60.46	60.50	1414.
3	30662.	137.29	21.1264	1609.9	755.9	61.8	102.16	60.55	60.28	1414.
4	67067.	239.26	37.3178	8139.5	3880.3	552.3	755.68	73.11	74.45	1211.
5	67324.	239.35	37.3492	8187.3	3904.0	556.0	756.38	73.53	74.67	1210.
6	67257.	238.55	37.1767	8179.7	3898.7	552.9	752.15	73.54	73.60	1208.
7	67114.	237.26	36.9683	8148.0	3883.5	547.7	746.64	73.38	73.43	1205.
8	67164.	236.71	36.8788	8159.3	3888.6	547.1	744.82	73.48	73.49	1204.
9	67155.	235.58	36.6664	8136.5	3875.6	542.8	741.92	73.18	73.93	1203.
10	67037.	234.50	36.5069	8109.2	3862.6	538.3	740.00	72.77	73.49	1201.
11	66561.	234.12	36.4390	8081.9	3849.1	535.4	737.27	72.65	73.21	1202.
12	66812.	232.71	36.2365	8031.9	3824.9	528.7	733.38	72.12	72.87	1201.
13	66641.	232.30	36.1255	7981.7	3800.3	524.3	728.94	71.96	72.54	1203.
14	66570.	231.17	35.9412	7959.5	3790.0	520.2	726.03	71.68	72.28	1201.
15	66579.	231.05	35.9260	7954.8	3787.5	519.6	721.67	72.03	72.27	1201.
16	66472.	231.14	35.9320	7922.2	3771.4	517.6	716.99	72.21	72.08	1203.
17	66310.	230.43	35.8124	7883.2	3752.4	513.3	712.53	72.07	71.88	1203.
18	27512.	104.43	15.9240	1735.3	808.7	49.0	168.46	29.09	23.63	1046.

MK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.0

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C A L C U L A T E D   P U M P   P A R A M E T E R S

TIME SLICE NO	TEST SPEED (RPM)	NPSH (FT)	SUCTION SPECIFIC SPEED	INLET FLOW COEFF	HEAD COEFF	PUMP DELTA T (DEG R)	(Q/N) OVER (Q/N)DES
1	29505.	456.37	3544.27	0.11639	0.44340	.80	1.3817
2	30605.	453.80	3647.05	0.11397	0.44534	5.02	1.3529
3	30662.	452.53	3661.76	0.11381	0.44502	5.06	1.3510
4	67067.	286.55	14879.37	0.09067	0.47030	17.94	1.0764
5	67324.	287.17	14931.57	0.09038	0.46946	17.95	1.0729
6	67257.	287.31	14677.75	0.09015	0.46996	18.42	1.0702
7	67114.	288.52	14767.26	0.08985	0.47012	18.42	1.0666
8	67164.	258.59	16024.47	0.08958	0.47007	18.43	1.0634
9	67159.	219.09	16101.22	0.08916	0.46884	18.22	1.0584
10	67037.	195.04	19669.50	0.08891	0.46897	18.36	1.0555
11	66961.	177.90	21033.14	0.08887	0.46845	18.43	1.0549
12	66812.	167.31	21909.00	0.08853	0.46763	18.47	1.0509
13	66641.	159.38	22643.14	0.08860	0.46710	18.52	1.0518
14	66570.	154.72	23071.96	0.08826	0.46673	18.57	1.0478
15	66575.	148.27	23817.31	0.08820	0.46638	18.57	1.0471
16	66472.	146.15	24042.92	0.08838	0.46597	18.59	1.0492
17	66310.	144.37	24167.09	0.08833	0.46595	18.59	1.0485
18	27512.	318.33	3730.57	0.09647	0.59562	18.43	1.1452

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MK4.

LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-76
TEST DURATION, SEC 56.00

SCALED TC TARGET SPEED = 70000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (W/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	320.56	49.31591	8359.97	3920.27	1242.61	2500.52
2	313.67	48.30138	8396.44	3942.30	1218.80	2373.40
3	313.44	48.23078	8390.55	3939.65	1220.71	2358.54
4	249.72	38.55010	8867.10	4227.21	843.47	312.60
5	248.91	38.83394	8851.16	4220.56	836.96	310.45
6	248.28	38.69317	8860.63	4223.21	846.99	311.44
7	247.46	38.55780	8863.71	4224.69	846.29	313.86
8	246.71	38.43582	8862.83	4223.91	842.83	280.89
9	245.55	38.24070	8839.55	4210.46	831.30	238.02
10	244.87	38.12266	8841.98	4211.63	834.00	212.67
11	244.74	38.09280	8832.15	4206.45	835.51	194.42
12	243.82	37.93428	8816.77	4198.70	834.53	183.66
13	244.01	37.95075	8806.74	4193.09	837.74	175.86
14	243.08	37.79518	8810.79	4190.53	836.85	171.07
15	242.92	37.77177	8793.22	4186.67	835.58	163.90
16	243.40	37.83886	8785.37	4182.28	838.54	162.07
17	243.25	37.80555	8785.13	4181.65	840.06	160.89
18	265.69	39.45791	11233.68	5234.86	3413.82	2060.72

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LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

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SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	320.56	49.31591	8359.97	3920.27	1242.61	2500.52
2	313.87	48.30138	8396.44	3942.30	1218.80	2373.40
3	313.44	48.23078	8390.55	3939.65	1220.71	2358.54
4	249.72	38.95010	8867.10	4227.21	843.47	312.60
5	248.91	38.83394	8851.16	4220.56	836.96	310.45
6	248.28	38.65317	8860.63	4223.21	846.99	311.44
7	247.46	38.55780	8863.71	4224.69	846.29	313.86
8	246.71	38.43582	8862.83	4223.91	842.83	280.89
9	245.55	38.24070	8839.55	4210.46	831.30	238.02
10	244.87	38.12266	8841.98	4211.63	834.00	212.67
11	244.74	38.09280	8832.15	4206.45	835.51	194.42
12	243.82	37.93428	8816.77	4198.70	834.53	183.66
13	244.01	37.95075	8806.74	4193.09	837.74	175.86
14	243.08	37.79918	8800.79	4190.53	836.85	171.07
15	242.92	37.77177	8793.22	4186.67	835.58	163.90
16	243.40	37.83886	8785.37	4182.28	838.54	162.07
17	243.25	37.80555	8785.13	4181.65	840.06	160.89
18	265.65	35.45791	11233.68	5234.86	3413.82	2060.72

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 9
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

SCALED TC TARGET SPEED = 70000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	151.00	696.39
2	163.26	728.03
3	163.24	729.75
4	281.93	1507.09
5	273.97	1630.06
6	277.37	1638.78
7	275.90	1676.48
8	265.96	1671.01
9	244.15	1657.49
10	233.16	1650.22
11	224.71	1645.80
12	216.12	1627.24
13	211.31	1612.71
14	208.77	1606.90
15	205.30	1603.63
16	205.65	1621.61
17	207.70	1602.87
18	492.47	1351.20

PK4.
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 5
TEST DATE 10-05-78

PROCESSING DATE 10-06-78
TEST DURATION, SEC 56.00

168

SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	151.00	656.39
2	163.26	728.03
3	163.24	725.75
4	281.93	1507.09
5	273.97	1630.06
6	237.37	1638.78
7	215.90	1676.48
8	265.96	1671.01
9	244.15	1657.49
10	233.16	1650.22
11	224.71	1645.80
12	216.12	1627.24
13	211.31	1612.71
14	238.77	1606.50
15	205.30	1603.63
16	205.65	1621.61
17	207.73	1632.87
18	452.47	1351.20

MK48-II
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

COMMENTS . . .

OBJECTIVE SUCTION PERFORMANCE WITH B.P. FLUID RECIRCULATED TO IMP. INLET

AMBIENT PRESSURE		13.8000
LO2 VENTURI (GG) P/N V160248-SGR S/N 8871	UPSTREAM DIAMETER	0.9570
	THROAT DIAMETER	0.2480
	THROAT CD	0.9850
GH2 VENTURI (TURB) P/N VP031200-SGR S/N 9731	UPSTREAM DIAMETER	2.3000
	THROAT DIAMETER	1.3085
	THROAT CD	0.9873
LH2 VENTURI (GG) P/N V320471-SGR S/N 8873	UPSTREAM DIAMETER	1.6890
	THROAT DIAMETER	0.4710
	THROAT CD	0.9765
LOX VENTURI (PUMP DISCH) P/N V321059-SGR S/N 8877	UPSTREAM DIAMETER	1.6890
	THROAT DIAMETER	1.0590
	THROAT CD	0.9820
	BAL PIST RECIRC ORIFICE	0.2600
	LOX SEAL DRAIN ORIFICE	0.5000
	TURBINE EFFECTIVE AREA	0.2319
	TURBINE EXHAUST ORIFICE	0.6600
	PRIMARY H.G. DRAIN ORIFICE	0.6550
	SEC. H.G. DRAIN ORIFICE	0.6000
	REAR BRG COOLANT ORIFICE	0.1800
	INTERMEDIATE SEAL PURGE ORIFICE	0.1260

ORIGINAL PAGE IS OF POOR QUALITY

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MK4
LIQUID OXYGEN TURBOPUMP SSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

GASEOUS HYDROGEN TURBINE DRIVE PARAMETERS

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	VENTURI U/S PR (PSIA)	VENTURI U/S TEMP (DEG R)	VENTURI DELTA PR (PSID)	SPIN VALVE POSN	SPIN VALVE U/S PR (PSIA)	SPIN VALVE DELTA P. (PSID)	TURB GH2 FLOW (LB/SEC)	SPEED (RPM)
1	42.028	42.131	4071.0	541.7	14.91	32.018	4031.3	813.290	3.95587	69160.
2	42.152	42.255	4067.1	541.7	14.90	32.136	4027.7	808.541	3.95248	69203.
3	42.276	42.337	4062.1	541.7	14.94	32.218	4024.9	801.970	3.95655	69246.
4	42.358	42.461	4058.6	541.6	14.97	32.304	4019.8	798.369	3.95856	69250.
5	42.482	42.544	4054.8	541.7	14.91	32.394	4015.4	796.021	3.94937	69252.
6	42.564	42.626	4051.7	541.6	15.04	32.471	4011.7	788.842	3.96532	69263.
7	42.647	42.750	4048.3	541.6	15.03	32.575	4009.9	787.046	3.96207	69301.
8	42.771	42.832	4044.5	541.6	14.99	32.647	4007.4	784.466	3.95558	69340.
9	42.853	42.956	4040.4	541.6	15.05	32.724	4001.9	778.678	3.96158	69324.
10	42.977	43.039	4035.5	541.6	15.10	32.823	3996.9	773.596	3.96732	69340.
11	43.059	43.121	4033.8	541.6	15.14	32.885	3997.3	772.195	3.97188	69340.
12	43.142	43.245	4030.1	541.5	15.04	32.959	3993.1	768.767	3.95690	69175.
13	43.265	43.327	4026.9	541.5	15.14	33.023	3986.5	762.291	3.96911	68847.
14	43.348	43.451	4022.0	541.5	15.11	33.143	3982.3	759.443	3.96254	67894.
15	43.472	43.534	4019.3	541.5	15.23	33.214	3978.7	752.811	3.97672	68226.
16	43.554	43.657	4015.1	541.4	15.13	33.281	3976.5	753.319	3.96245	68171.
17	43.678	43.740	4011.3	541.4	15.23	33.390	3972.7	748.924	3.97400	68226.
18	43.760	43.822	4007.6	541.4	15.22	33.436	3968.0	742.473	3.97157	68337.
19	43.843	43.946	4005.0	541.4	15.23	33.526	3964.4	738.883	3.97105	68410.
20	43.967	44.028	4000.7	541.4	15.24	33.590	3960.6	731.592	3.97182	68390.
21	44.049	44.152	3997.0	541.4	15.28	33.689	3958.5	731.600	3.97427	68316.
22	44.173	44.235	3993.1	541.4	15.23	33.751	3954.5	725.967	3.96712	68308.
23	44.255	44.358	3989.4	541.4	15.26	33.853	3950.0	724.810	3.96867	68238.
24	44.379	44.441	3986.2	541.4	15.28	33.896	3944.7	717.943	3.97013	68214.
25	44.462	44.523	3982.7	541.4	15.32	33.973	3942.7	715.923	3.97415	68173.
26	44.544	44.647	3978.8	541.3	15.35	34.057	3938.8	712.141	3.97667	68124.
27	44.668	44.730	3974.8	541.3	15.28	34.165	3933.3	706.932	3.96635	68202.
28	44.750	44.853	3971.7	541.2	15.36	34.226	3930.7	702.613	3.97540	68277.
29	44.874	44.936	3967.5	541.2	15.37	34.333	3927.6	701.209	3.97455	68208.
30	44.956	45.060	3963.9	541.2	15.33	34.384	3923.8	697.394	3.96746	68230.

ORIGINAL PAGE IS
OF POOR QUALITY

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.0(

TURBINE PARAMETERS

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	SPEED (RPM)	TURB INLET STAT PR (PSIA)	TURB INLET TOT PR (PSIA)	TURB INLET TOT TEMP (DEG R)	TURB NOZZ D/S PR (PSIA)	TURB EXH STAT PR (PSIA)	TURB EXH TOT PR (PSIA)	TURB EXH TOT TEMP (DEG R)	TURB DSC ORIFICE DELTA P (PSID)
1	42.028	42.131	69160.	3180.6	3155.9	509.6	1942.3	1963.5	1991.1	477.8	1951.3
2	42.152	42.255	69203.	3183.3	3157.0	509.7	1942.7	1963.9	1991.4	477.8	1951.5
3	42.276	42.337	69246.	3189.5	3159.4	509.6	1943.4	1965.0	1992.8	477.8	1952.9
4	42.358	42.461	69250.	3187.4	3160.0	509.8	1943.2	1965.7	1992.7	477.8	1952.8
5	42.482	42.544	69252.	3182.6	3156.4	509.8	1942.1	1963.7	1990.8	477.8	1951.0
6	42.564	42.626	69263.	3199.7	3161.1	509.8	1944.1	1965.7	1992.5	477.8	1952.6
7	42.647	42.750	69301.	3192.4	3160.6	509.8	1943.7	1966.2	1993.2	477.8	1953.2
8	42.771	42.832	69340.	3190.1	3161.8	509.8	1944.5	1966.8	1993.2	477.8	1953.2
9	42.853	42.956	69324.	3200.1	3161.3	509.9	1943.9	1965.7	1992.7	477.9	1952.8
10	42.977	43.039	69340.	3201.1	3161.8	509.8	1944.5	1966.4	1992.8	477.7	1952.8
11	43.059	43.121	69340.	3201.1	3163.8	509.8	1945.1	1967.4	1994.5	477.5	1954.5
12	43.142	43.245	69175.	3198.8	3163.1	509.8	1945.2	1967.5	1994.3	477.7	1954.3
13	43.265	43.327	68847.	3201.1	3162.4	509.8	1946.2	1967.8	1994.5	477.7	1954.5
14	43.348	43.451	67894.	3194.7	3161.1	509.8	1954.8	1970.3	1997.6	477.8	1957.6
15	43.472	43.534	68226.	3197.6	3164.8	509.8	1956.4	1972.5	1999.9	478.3	1959.6
16	43.554	43.657	68171.	3194.7	3161.1	509.7	1954.1	1970.3	1997.9	478.8	1957.9
17	43.678	43.740	68226.	3195.6	3163.1	509.7	1955.0	1971.2	1999.2	479.0	1958.9
18	43.760	43.822	68337.	3201.1	3163.8	509.7	1956.0	1971.9	1999.2	479.1	1959.1
19	43.843	43.946	68410.	3201.1	3164.9	509.6	1955.9	1972.3	2000.1	478.9	1960.0
20	43.967	44.028	68390.	3195.6	3166.5	509.6	1957.4	1972.9	2000.6	478.7	1960.4
21	44.049	44.152	68316.	3201.1	3166.3	509.6	1956.8	1973.0	2000.3	478.8	1960.1
22	44.173	44.235	68308.	3201.1	3166.1	509.6	1956.7	1973.6	2000.6	478.8	1960.3
23	44.255	44.358	68238.	3201.1	3163.8	509.6	1955.9	1971.2	1999.7	478.7	1959.6
24	44.379	44.441	68214.	3190.1	3164.1	509.5	1956.7	1972.5	1999.9	478.8	1959.6
25	44.462	44.523	68173.	3197.6	3166.5	509.4	1956.7	1973.2	2000.6	478.8	1960.3
26	44.544	44.647	68124.	3201.1	3166.0	509.4	1956.8	1973.0	2000.6	479.0	1960.3
27	44.668	44.730	68202.	3195.6	3164.8	509.4	1956.4	1972.5	2000.6	478.9	1960.3
28	44.750	44.853	68277.	3192.9	3165.8	509.4	1956.8	1973.5	2000.8	478.9	1960.5
29	44.874	44.936	68208.	3201.1	3166.5	509.4	1956.7	1972.9	2000.9	478.8	1960.7
30	44.956	45.060	68230.	3201.1	3164.0	509.4	1956.6	1972.8	2000.8	478.7	1960.7

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

TURBINE PARAMETERS (CONTINUED)

TIME SLICE NO	SPEED RPM	FLOW (LB/SEC)	PR RATIO (T-S)	BHP (CALIB) (HP)	BHP (DELTA T) (HP)	TORQUE (FT-LB)	U/C (T-S)	EFF (T-S)	TURB NOZ IN TOT P (PSIA)
1	69160.	3.9559	1.5752	652.7	658.3	49.55	0.4188	50.93	3092.8
2	69203.	3.9525	1.5754	652.3	660.1	49.49	0.4190	50.92	3093.9
3	69246.	3.9565	1.5756	653.0	659.7	49.51	0.4192	50.92	3096.2
4	69250.	3.9586	1.5754	653.2	662.7	49.52	0.4193	50.91	3096.8
5	69252.	3.9494	1.5752	651.6	660.7	49.40	0.4193	50.91	3093.2
6	69263.	3.9653	1.5759	654.9	664.6	49.64	0.4192	50.92	3097.9
7	69301.	3.9621	1.5753	653.7	663.3	49.52	0.4196	50.90	3097.4
8	69340.	3.9556	1.5755	652.6	661.9	49.41	0.4198	50.89	3098.5
9	69324.	3.9616	1.5760	654.4	663.1	49.56	0.4195	50.91	3098.1
10	69340.	3.9673	1.5757	654.8	665.0	49.58	0.4197	50.90	3098.5
11	69340.	3.9719	1.5759	655.8	671.9	49.65	0.4196	50.90	3100.5
12	69175.	3.9569	1.5755	653.4	665.7	49.59	0.4188	50.93	3099.8
13	68847.	3.9691	1.5750	655.8	667.7	50.01	0.4169	51.00	3099.2
14	67894.	3.9625	1.5723	654.5	663.3	50.61	0.4119	51.16	3097.9
15	68226.	3.9767	1.5723	656.1	655.6	50.49	0.4139	51.10	3101.5
16	68171.	3.9624	1.5723	653.6	640.7	50.34	0.4136	51.11	3097.9
17	68226.	3.9749	1.5726	655.7	639.3	50.46	0.4139	51.10	3099.8
18	68337.	3.9716	1.5724	654.9	636.5	50.31	0.4146	51.08	3100.5
19	68410.	3.9711	1.5726	654.7	638.1	50.25	0.4150	51.06	3101.6
20	68390.	3.9718	1.5729	655.2	642.7	50.30	0.4148	51.07	3103.2
21	68316.	3.9743	1.5727	655.6	641.1	50.38	0.4144	51.08	3102.9
22	68308.	3.9671	1.5722	653.9	639.6	50.24	0.4145	51.08	3102.8
23	68238.	3.9687	1.5729	655.0	641.0	50.39	0.4139	51.10	3100.5
24	68214.	3.9701	1.5720	654.3	637.7	50.36	0.4140	51.09	3100.8
25	68173.	3.9741	1.5726	655.6	636.0	50.49	0.4136	51.11	3103.2
26	68124.	3.9767	1.5726	656.1	633.5	50.56	0.4133	51.12	3102.7
27	68202.	3.9663	1.5723	654.0	633.5	50.34	0.4139	51.10	3101.5
28	68277.	3.9754	1.5721	655.1	634.9	50.37	0.4144	51.08	3102.5
29	68208.	3.9745	1.5729	655.9	637.2	50.48	0.4137	51.10	3103.2
30	68230.	3.9675	1.5718	653.5	637.7	50.28	0.4142	51.09	3100.7

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-73
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T U R B I N E   P A R A M E T E R S (CONTINUED)

TIME SLICE NO	SPEED RPM	AVAIL. ENERGY(T-S) (BTU/LB)	GAMMA	CP (BTU/LBM-R)	SPEED PARA-METER	FLOW PARA-METER	TORQUE PARA-METER	TURB WHEEL EXH PRESS PSIA
1	69160.	228.94	1.3985	3.6990	520.0	3.4484	0.0147	2000.6
2	69203.	229.03	1.3985	3.6989	520.3	3.4445	0.0147	2000.2
3	69246.	229.09	1.3985	3.6990	520.6	3.4452	0.0147	2001.0
4	69250.	229.05	1.3985	3.6989	520.6	3.4467	0.0147	2001.1
5	69252.	229.02	1.3985	3.6987	520.6	3.4428	0.0147	1999.6
6	69263.	229.24	1.3985	3.6988	520.7	3.4516	0.0147	2001.0
7	69301.	229.06	1.3985	3.6988	521.0	3.4492	0.0147	2001.1
8	69340.	229.08	1.3985	3.6989	521.3	3.4422	0.0146	2001.3
9	69324.	229.31	1.3986	3.6987	521.1	3.4484	0.0147	2001.3
10	69340.	229.16	1.3985	3.6989	521.3	3.4524	0.0147	2001.7
11	69340.	229.25	1.3986	3.6989	521.2	3.4543	0.0147	2003.0
12	69175.	229.12	1.3986	3.6988	520.0	3.4421	0.0147	2002.2
13	68847.	228.95	1.3986	3.6988	517.5	3.4534	0.0148	2003.0
14	67894.	228.16	1.3986	3.6988	510.4	3.4492	0.0150	2008.6
15	68226.	228.17	1.3986	3.6989	512.9	3.4574	0.0149	2011.1
16	68171.	228.11	1.3985	3.6990	512.5	3.4486	0.0149	2007.6
17	68226.	228.20	1.3985	3.6990	512.9	3.4565	0.0149	2008.4
18	68337.	228.14	1.3985	3.6991	513.8	3.4537	0.0149	2009.5
19	68410.	228.18	1.3985	3.6992	514.3	3.4518	0.0149	2009.5
20	68390.	228.29	1.3986	3.6992	514.2	3.4508	0.0149	2010.8
21	68316.	228.22	1.3986	3.6992	513.6	3.4531	0.0149	2010.4
22	68308.	228.05	1.3985	3.6993	513.6	3.4468	0.0149	2010.5
23	68238.	228.26	1.3985	3.6993	513.1	3.4507	0.0149	2009.0
24	68214.	227.95	1.3985	3.6994	512.9	3.4513	0.0149	2010.1
25	68173.	228.12	1.3985	3.6996	512.7	3.4520	0.0149	2010.1
26	68124.	228.11	1.3985	3.6996	512.3	3.4547	0.0150	2010.6
27	68207.	228.03	1.3985	3.6995	512.9	3.4471	0.0149	2009.8
28	68277.	227.96	1.3985	3.6996	513.4	3.4538	0.0149	2010.1
29	68208.	228.20	1.3985	3.6996	512.9	3.4524	0.0149	2010.1
30	68230.	227.85	1.3985	3.6995	513.1	3.4489	0.0149	2009.9

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

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SEAL AND BEARING DATA

TIME SLICE NO	PRIM LOX SEAL DR PR (PSIA)	PRIM LOX SEAL DR TEMP (DEG R)	I/S PURGE PR (PSIA)	I/S PURGE TEMP (DEG R)	PRIM HG SEAL ORIF U/S PR (PSIA)	PRIM HG SEAL ORIF U/S TEMP (DEG R)	PRIM HG SEAL DR FLOW (LB/SEC)	SEC HG SEAL DR PR (PSIA)	SEC HG SEAL DR TEMP (DEG R)	SEC HG SEAL ORIF U/S PR (PSIA)	SEC HG SEAL ORIF U/S TEMP (DEG R)
1	43.00	168.39	230.90	554.90	35.45	406.32	0.0998	30.7	426.54	14.74	395.48
2	42.78	168.21	230.86	554.90	35.63	408.43	0.1000	30.8	427.61	14.76	397.15
3	42.59	168.18	230.78	554.90	35.74	410.14	0.1001	31.0	428.65	14.80	398.27
4	42.42	168.13	230.77	554.87	35.83	411.71	0.1002	31.0	429.51	14.80	399.50
5	42.23	168.18	230.76	554.90	35.88	413.23	0.1002	31.1	430.44	14.77	400.76
6	42.06	168.07	230.85	554.85	35.98	414.48	0.1003	31.1	431.05	14.81	401.72
7	41.86	167.84	230.83	554.81	36.10	415.91	0.1005	31.2	431.77	14.77	403.00
8	41.64	167.79	230.74	554.72	36.23	417.24	0.1007	31.2	432.41	14.82	404.08
9	41.44	167.84	230.88	554.78	36.26	418.54	0.1006	31.3	433.17	14.78	405.25
10	41.22	167.55	230.81	554.81	36.36	419.74	0.1008	31.3	433.82	14.71	406.37
11	41.03	167.55	230.61	554.64	36.40	420.68	0.1008	31.4	434.44	14.79	407.19
12	40.79	167.44	230.68	554.75	36.55	421.86	0.1010	31.5	435.05	14.85	408.29
13	40.74	167.55	229.79	554.68	36.76	422.98	0.1015	32.1	435.85	14.84	409.28
14	40.62	167.72	231.35	554.64	37.30	423.81	0.1029	32.0	436.68	14.83	410.27
15	39.87	167.22	231.19	554.64	37.25	424.29	0.1027	32.1	436.58	14.85	411.36
16	39.29	166.95	230.88	554.67	37.37	424.39	0.1030	31.7	436.15	14.79	412.08
17	38.73	167.22	230.81	554.64	37.33	424.60	0.1029	32.4	435.97	14.89	412.75
18	38.30	168.21	230.81	554.60	37.35	424.60	0.1029	32.3	435.54	14.87	413.38
19	37.69	169.21	230.72	554.58	37.39	424.72	0.1031	32.2	435.25	14.82	413.97
20	37.16	169.90	230.57	554.64	37.38	424.91	0.1030	32.7	435.11	14.90	414.70
21	36.57	170.00	230.41	554.61	37.25	425.09	0.1026	33.0	435.09	14.91	415.22
22	35.99	170.41	230.51	554.60	37.26	425.16	0.1026	32.9	434.99	14.91	415.95
23	35.45	171.08	230.47	554.58	37.29	425.43	0.1027	32.7	434.97	14.93	416.48
24	34.97	171.72	230.51	554.64	37.31	425.59	0.1027	32.4	435.29	14.85	417.21
25	34.60	172.36	230.47	554.64	37.28	425.84	0.1026	32.7	435.23	14.87	417.65
26	34.16	172.70	230.54	554.58	37.24	426.05	0.1025	32.9	435.38	14.89	418.19
27	33.75	173.01	230.47	554.60	37.27	426.33	0.1025	32.7	435.48	14.86	418.83
28	33.35	173.37	230.30	554.58	37.20	426.50	0.1023	33.1	435.56	14.92	419.27
29	32.99	173.51	230.37	554.60	37.11	426.71	0.1021	33.4	435.72	14.91	419.83
30	32.60	173.51	230.43	554.61	37.18	426.9[illegible]	0.1022	33.4	435.95	14.99	420.19

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MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION. SEC 25.00

S E A L A N D B E A R I N G D A T A (CONTINUED)

TIME SLICE NO	SEC HG SEAL DR FLOW (LB/SEC)	RR BRG COOLANT SUPPL.PR (PSIA)	RR BRG COOLANT SUPPL.TEMP (DEG R)	RR BRG DRAIN PR (PSIA)	RR BRG DRAIN TEMP (DEG R)	RR BRG COOL.ORIF U/S PR (PSIA)	RR BRG COOL.ORIF U/S TEMP (DEG R)	RR BRG COOLANT FLOW (LB/SEC)
1	0.0	3492.6	88.19	199.4	96.92	13.8	460.00	0.0
2	0.0	3492.4	88.38	200.2	97.22	13.8	460.00	0.0
3	0.0	3492.6	88.81	200.6	97.73	13.8	460.00	0.0
4	0.0	3492.6	89.13	200.8	98.17	13.8	460.00	0.0
5	0.0	3493.0	89.13	200.7	98.52	13.8	460.00	0.0
6	0.0	3493.3	89.00	200.7	98.44	13.8	460.00	0.0
7	0.0	3493.3	88.88	200.7	98.10	13.8	460.00	0.0
8	0.0	3493.6	88.50	200.6	97.85	13.8	460.00	0.0
9	0.0	3493.5	88.88	200.7	97.76	13.8	460.00	0.0
10	0.0	3493.3	89.31	200.8	97.97	13.8	460.00	0.0
11	0.0	3493.3	89.50	201.0	98.15	13.8	460.00	0.0
12	0.0	3494.0	89.31	201.0	98.61	13.8	460.00	0.0
13	0.0	3493.6	89.00	202.3	98.74	13.8	460.00	0.0
14	0.0	3493.1	88.88	203.0	99.47	13.8	460.00	0.0
15	0.0	3492.6	88.81	202.7	99.16	13.8	460.00	0.0
16	0.0	3492.6	89.25	202.9	99.51	13.8	460.00	0.0
17	0.0	3492.6	89.13	202.5	99.79	13.8	460.00	0.0
18	0.0	3492.6	89.00	202.4	99.66	13.8	460.00	0.0
19	0.0	3493.3	89.00	202.3	99.54	13.8	460.00	0.0
20	0.0	3492.6	89.00	201.9	99.27	13.8	460.00	0.0
21	0.0	3492.6	89.00	202.1	99.09	13.8	460.00	0.0
22	0.0	3493.3	89.31	202.3	99.33	13.8	460.00	0.0
23	0.0	3493.1	89.63	202.5	99.60	13.8	460.00	0.0
24	0.0	3493.0	89.63	202.3	100.00	13.8	460.00	0.0
25	0.0	3493.3	89.50	202.4	100.15	13.8	460.00	0.0
26	0.0	3493.7	89.63	202.2	100.11	13.8	460.00	0.0
27	0.0	3493.6	89.63	202.5	100.04	13.8	460.00	0.0
28	0.0	3494.0	90.00	202.3	100.21	13.8	460.00	0.0
29	0.0	3494.0	90.00	202.1	100.09	13.8	460.00	0.0
30	0.0	3494.0	89.75	202.2	99.93	13.8	460.00	0.0

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	LOX SEAL DRAIN ORIF U/S PRESS PSIA	LOX SEAL DRAIN ORIF U/S TEMP DEG R	LOX SEAL DRAIN FLOWRATE (LB/SEC)
1	39.0	501.01	0.175
2	38.9	501.01	0.174
3	38.7	501.09	0.174
4	38.6	501.25	0.173
5	38.4	501.44	0.173
6	38.3	501.57	0.173
7	38.1	501.69	0.172
8	38.0	501.93	0.171
9	37.8	502.10	0.171
10	37.6	502.28	0.170
11	37.4	502.33	0.170
12	37.2	502.40	0.169
13	37.0	502.55	0.168
14	36.9	502.70	0.168
15	36.6	502.81	0.167
16	36.2	503.02	0.165
17	35.8	503.08	0.164
18	35.4	503.21	0.163
19	34.9	503.31	0.161
20	34.3	503.39	0.159
21	33.8	503.61	0.157
22	33.3	503.65	0.155
23	32.8	503.73	0.153
24	32.3	503.92	0.151
25	32.0	504.01	0.150
26	31.5	504.05	0.148
27	31.1	504.14	0.147
28	30.7	504.29	0.145
29	30.3	504.45	0.143
30	30.0	504.64	0.142

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

ORIGINAL PAGE IS OF POOR QUALITY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

P U M P   P R E S S U R E S

TIME SLICE NO	SUPPLY TANK PR (PSIA)	PUMP INLET PR (PSIA)	IMPELLER DISCH PR (PSIA)	DIFFUSER DISCH PR (PSIA)	PUMP DISCH PR (PSIA)	BAL PIST CAV PR #1 (PSIA)	BAL PIST SUMP PR (PSIA)	BAL PIST RETURN PR (PSIA)	IMPELLER FRONT SHROUD PR (PSIA)
1	263.0	[illegible]	1948.0	2812.0	4294.6	2148.4	1508.4	1292.4	3123.3
2	263.1	180.4	1950.6	2812.4	4298.2	2148.2	1510.4	1294.2	3125.5
3	263.1	180.6	1952.0	2816.9	4301.2	2148.3	1511.9	1295.6	3129.2
4	263.1	179.6	1952.1	2820.7	4302.5	2146.8	1512.2	1294.7	3129.2
5	263.1	179.1	1952.7	2822.3	4305.3	2145.6	1512.9	1293.9	3129.8
6	263.1	179.8	1954.6	2822.3	4307.0	2145.9	1514.2	1295.9	3132.2
7	263.1	179.9	1956.4	2822.7	4307.9	2145.7	1515.6	1295.6	3132.1
8	263.2	180.2	1956.0	2826.3	4310.7	2145.6	1517.6	1295.9	3133.6
9	263.2	180.3	1959.8	2826.5	4312.4	2146.6	1519.9	1298.9	3136.2
19	263.1	180.6	1958.9	2824.3	4312.7	2146.6	1519.3	1298.6	3135.6
11	263.2	179.8	1959.9	2825.6	4315.4	2144.9	1519.6	1296.9	3137.3
12	263.1	180.9	1953.9	2818.7	4304.0	2131.6	1514.7	1291.7	3123.9
13	263.1	187.1	1949.4	2838.2	4282.3	2096.2	1508.5	1297.6	3118.3
14	263.2	183.5	1754.1	2763.3	4290.5	2017.2	1225.9	1033.8	3196.3
15	263.2	178.3	1666.7	2777.7	4350.6	2160.6	1150.3	984.9	3239.5
16	263.2	180.1	1666.4	2781.4	4357.5	2207.0	1151.7	988.2	3242.0
17	263.2	175.3	1663.1	2779.0	4362.1	2210.7	1150.3	985.9	3233.0
18	263.2	177.8	1668.7	2789.4	4380.1	2221.9	1155.3	995.7	3248.3
19	263.2	179.3	1674.7	2798.6	4394.3	2232.2	1162.1	998.5	3258.5
20	263.2	178.9	1672.0	2802.8	4396.3	2254.3	1164.8	1001.4	3257.2
21	263.2	179.5	1674.7	2783.8	4390.7	2274.0	1167.3	996.0	3257.9
22	263.2	177.9	1676.9	2779.7	4387.2	2277.0	1162.8	990.3	3265.4
23	263.3	178.4	1676.7	2777.8	4383.5	2280.4	1158.3	985.9	3271.5
24	263.3	177.6	1673.3	2772.0	4383.5	2287.0	1156.7	985.2	3280.0
25	263.3	179.5	1673.0	2776.4	4379.1	2285.3	1158.7	986.2	3276.6
26	263.3	178.8	1674.9	2774.0	4375.1	2289.7	1161.0	988.2	3273.5
27	263.3	176.1	1674.0	2773.7	4377.0	2283.2	1159.0	982.9	3274.5
28	263.3	178.6	1676.3	2789.2	4391.1	2287.9	1160.7	986.4	3282.8
29	263.4	177.4	1680.2	2807.5	4389.9	2286.6	1161.7	988.3	3282.4
30	263.4	177.7	1678.2	2801.3	4388.0	2290.4	1160.5	986.8	3283.3

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S

TIME SLICE NO	SPEED RPM	INDUCER DISCH PRESS PSIA	PUMP BRG D/S PRESS PSIA	BAL PIST RECIRC TEMP AT PUMP IN DEG R	PUMP BRG DELTA P PSID
1	69160.	689.4	1388.8	253.05	115.34
2	69203.	690.4	1389.2	253.40	116.66
3	69246.	691.6	1390.5	253.64	117.41
4	69250.	691.6	1390.6	253.96	116.71
5	69252.	690.1	1392.2	254.12	115.69
6	69263.	690.7	1394.2	254.25	115.37
7	69301.	691.6	1396.9	254.43	113.94
8	69340.	691.6	1399.0	254.55	113.77
9	69324.	693.4	1402.6	254.80	112.28
10	69340.	692.4	1403.0	255.05	111.73
11	69340.	693.5	1402.7	255.05	112.69
12	69175.	692.9	1398.5	255.14	111.90
13	68847.	694.1	1394.2	255.20	109.75
14	67894.	677.6	1192.2	254.99	22.50
15	68226.	636.1	1038.9	254.37	107.07
16	68171.	640.4	1032.4	254.12	115.69
17	68226.	640.5	1026.4	254.05	120.66
18	68337.	639.9	1026.4	253.93	125.89
19	68410.	643.5	1033.1	254.18	125.81
20	68390.	644.9	1040.3	254.42	122.13
21	68316.	645.3	1039.4	255.66	125.55
22	68308.	644.2	1025.4	258.23	134.44
23	68238.	641.4	1018.1	260.13	137.59
24	68214.	638.4	1015.2	261.14	139.42
25	68173.	638.0	1016.2	261.53	140.25
26	68124.	639.1	1017.5	261.75	140.95
27	68202.	636.2	1017.2	261.71	139.55
28	68277.	636.8	1016.3	261.73	142.52
29	68208.	639.1	1017.9	261.73	141.14
30	68230.	638.5	1018.6	261.80	139.50

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MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

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P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S (CONTINUED)

TIME SLICE NO	BAL PIST RECIRC U/S ORIF PR PSIA	BAL PIST RECIRC U/S ORIF TEMP DEG R	BAL PIST RECICR DELTA P PSI	BAL PIST FLOW LB/SEC	BAL PIST FLOW TEMP RISE DEG R
1	1235.5	261.8	205.76	3.623	55.94
2	1236.6	262.0	205.63	3.620	56.12
3	1238.4	262.2	205.87	3.620	56.26
4	1237.6	262.3	205.72	3.618	56.27
5	1237.2	262.5	204.68	3.607	56.45
6	1238.2	262.5	205.04	3.610	56.45
7	1238.8	262.5	205.66	3.615	56.45
8	1238.8	262.6	205.29	3.611	56.39
9	1241.8	262.6	205.64	3.614	56.45
10	1241.5	262.7	205.93	3.616	56.43
11	1239.8	262.8	205.77	3.614	56.50
12	1235.3	262.8	206.30	3.617	56.54
13	1237.8	263.0	213.91	3.681	56.77
14	1008.1	263.1	147.27	3.016	56.02
15	957.1	266.5	125.23	2.737	61.92
16	956.8	269.2	125.63	2.710	64.83
17	952.8	270.2	129.73	2.741	65.72
18	961.5	270.4	132.09	2.765	66.03
19	964.5	270.6	133.80	2.782	66.21
20	965.8	270.5	137.16	2.818	66.10
21	960.3	270.4	140.70	2.853	65.84
22	953.2	270.2	141.00	2.857	65.33
23	948.9	270.0	142.40	2.873	65.10
24	947.9	269.9	145.09	2.901	64.95
25	948.1	269.8	145.86	2.910	64.86
26	949.9	269.6	146.92	2.923	64.69
27	945.4	269.6	147.66	2.931	64.61
28	948.1	269.5	146.47	2.920	64.54
29	949.7	269.4	148.37	2.941	64.48
30	948.5	269.4	148.37	2.941	64.44

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S

TIME SLICE NO	PUMP INLET TEMP (DEG R)	PUMP DISCH TEMP (DEG R)	BAL PIST RETURN TEMP (DEG R)	PUMP DISCH VENT U/S TEMP (DEG R)	PUMP DISCH VENT U/S PR (PSIA)	PUMP DISCH VENT DELTA PR (PSI)	HP (TEMP)
1	175.61	205.86	492.09	204.23	4229.4	51.92	1054.04
2	175.61	205.89	492.09	204.37	4234.0	52.38	1059.03
3	175.61	205.92	492.09	204.52	4237.1	52.06	1057.04
4	175.61	206.00	492.09	204.53	4238.5	52.20	1060.19
5	175.61	206.03	492.09	204.54	4239.5	52.02	1059.16
6	175.61	206.05	492.09	204.50	4242.6	52.49	1064.26
7	175.61	206.10	492.09	204.64	4242.6	52.57	1066.05
8	175.61	206.19	492.09	204.77	4246.0	51.94	1062.38
9	175.61	206.18	492.09	204.78	4246.4	51.87	1061.65
10	175.61	206.27	492.09	204.85	4246.0	52.46	1069.24
11	175.61	206.27	492.09	204.85	4250.7	52.09	1066.35
12	175.61	206.27	492.09	204.85	4238.7	51.38	1058.34
13	175.61	206.27	492.09	204.85	4218.8	51.03	1054.14
14	175.61	207.10	492.09	204.88	4220.4	51.44	1060.00
15	175.61	204.56	492.09	205.34	4283.7	53.14	1018.56
16	175.61	204.38	492.09	205.22	4290.2	52.58	1009.10
17	175.61	204.44	492.09	205.88	4293.9	52.78	1013.28
18	175.60	204.38	492.09	204.58	4311.3	53.58	1022.55
19	175.61	204.39	492.09	204.30	4324.6	53.00	1019.56
20	175.61	204.40	492.09	203.74	4328.3	53.56	1026.13
21	175.61	204.60	492.09	203.68	4320.8	53.14	1027.20
22	175.60	204.91	492.09	203.47	4318.8	52.73	1030.93
23	175.58	204.93	492.09	203.43	4314.9	53.35	1037.27
24	175.56	204.95	492.09	203.55	4315.4	53.14	1037.28
25	175.57	204.95	492.09	203.70	4309.6	53.09	1035.93
26	175.55	204.95	492.09	203.78	4306.1	53.12	1036.73
27	175.56	204.95	492.09	203.82	4307.9	53.11	1036.98
28	175.55	204.95	492.09	203.94	4322.6	52.85	1035.56
29	175.59	204.95	492.09	204.33	4320.8	52.70	1033.65
30	175.57	204.95	492.09	204.30	4320.1	53.01	1036.74

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LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

C A L C U L A T E D   P U M P   P A R A M E T E R S

TIME SLICE NO	TEST SPEED (RPM)	PUMP FLOW GPM	PUMP FLOW (LB/SEC)	HEAD FT	PRESS RISE (PSI)	FLUID HP (HP)	TURB HP (HP)	EFF (%)	ISEN EFF (%)	SPECIFIC SPEED
1	69160.	243.22	37.2339	8720.6	4114.2	590.4	652.68	90.49	56.01	1195.
2	69203.	244.32	37.3945	8729.0	4117.8	593.5	652.29	91.02	56.04	1198.
3	69246.	243.62	37.2771	8734.4	4120.6	592.0	653.03	90.69	56.00	1196.
4	69250.	243.96	37.3283	8740.0	4122.8	593.2	653.23	90.84	55.95	1197.
5	69252.	243.54	37.2647	8746.8	4126.2	592.6	651.60	90.98	55.95	1195.
6	69263.	244.64	37.4294	8749.8	4127.2	595.5	654.94	90.95	55.95	1197.
7	69301.	244.84	37.4565	8752.0	4127.9	596.0	653.69	91.21	55.91	1198.
8	69340.	243.39	37.2274	8756.7	4130.5	592.7	652.57	90.86	55.79	1195.
9	69324.	243.23	37.2074	8759.7	4132.1	592.5	654.37	90.58	55.81	1194.
10	69340.	244.62	37.4091	8761.9	4132.1	596.0	654.78	91.05	55.74	1198.
11	69340.	243.77	37.2813	8768.3	4135.7	594.3	655.81	90.66	55.74	1195.
12	69175.	242.10	37.0205	8741.2	4123.1	588.4	653.40	90.08	55.59	1191.
13	68847.	241.31	36.8888	8682.9	4095.2	582.4	655.78	88.84	55.25	1189.
14	67894.	242.30	37.0394	8715.6	4107.0	586.9	654.50	89.71	55.37	1172.
15	68226.	246.21	37.6574	8829.8	4172.4	604.6	656.08	92.18	59.35	1175.
16	68171.	244.94	37.4527	8837.0	4177.4	601.8	653.64	92.10	59.63	1171.
17	68226.	245.58	37.5014	8858.0	4186.9	604.0	655.73	92.14	59.61	1171.
18	68337.	247.06	37.8297	8889.4	4202.2	611.4	654.85	93.40	59.79	1173.
19	68410.	245.51	37.6528	8913.9	4215.0	610.2	654.72	93.24	59.85	1168.
20	68390.	246.73	37.8624	8920.0	4217.4	614.1	655.22	93.75	59.84	1170.
21	68316.	245.77	37.7160	8908.4	4211.2	610.9	655.62	93.21	59.47	1168.
22	68308.	244.76	37.5762	8906.3	4209.2	608.5	653.89	93.09	59.02	1166.
23	68238.	246.19	37.7965	8899.0	4205.0	611.5	654.99	93.40	58.96	1169.
24	68214.	245.75	37.7192	8900.3	4205.8	610.4	654.29	93.33	58.84	1167.
25	68173.	245.68	37.6942	8887.3	4199.5	609.1	655.62	92.94	58.80	1167.
26	68174.	245.77	37.7005	8880.8	4196.3	608.7	656.11	92.82	58.72	1167.
27	68202.	245.75	37.6954	8890.5	4200.9	609.3	653.96	93.21	58.76	1168.
28	68277.	245.15	37.6011	8913.1	4212.5	609.3	655.06	93.06	58.84	1165.
29	68208.	244.83	37.5446	8913.4	4212.5	608.5	655.86	92.81	58.86	1163.
30	68230.	245.54	37.6556	8909.1	4210.2	610.0	653.51	93.37	58.83	1166.

MK4
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

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CALCULATED PUMP PARAMETERS

TIME SLICE NO	TEST SPEED (RPM)	NPSH (FT)	SUCTION SPECIFIC SPEED	INLET FLOW COEFF	HEAD COEFF	PUMP DELTA T (DEG R)	(Q/N) OVER (Q/N)DES
1	69160.	332.88	13840.04	0.08939	0.47384	30.25	1.0611
2	69203.	333.17	13870.98	0.08974	0.47371	30.27	1.0652
3	69246.	333.48	13849.82	0.08942	0.47341	30.31	1.0615
4	69250.	331.58	13919.69	0.08954	0.47366	30.38	1.0629
5	69252.	330.36	13946.67	0.08939	0.47400	30.41	1.0611
6	69263.	331.97	13929.80	0.08977	0.47430	30.44	1.0657
7	69301.	332.31	13932.22	0.08980	0.47362	30.48	1.0660
8	69340.	332.69	13886.72	0.08922	0.47333	30.58	1.0591
9	69324.	332.77	13876.57	0.08918	0.47371	30.56	1.0586
10	69340.	333.62	13897.63	0.08967	0.47351	30.66	1.0644
11	69340.	331.79	13925.69	0.08936	0.47396	30.67	1.0607
12	69175.	333.98	13777.29	0.08896	0.47474	30.66	1.0560
13	68847.	346.73	13310.04	0.08909	0.47608	30.66	1.0575
14	67894.	338.80	13382.92	0.09071	0.49140	31.49	1.0768
15	68226.	328.24	13882.10	0.09172	0.49300	28.95	1.0888
16	68171.	331.84	13722.36	0.09132	0.49419	28.76	1.0841
17	68226.	321.92	14068.23	0.09149	0.49457	28.82	1.0861
18	68337.	327.43	13954.73	0.09189	0.49471	28.78	1.0908
19	68410.	330.36	13832.70	0.09122	0.49502	28.78	1.0828
20	68390.	329.79	13881.20	0.09170	0.49564	28.78	1.0885
21	68316.	330.76	13808.55	0.09144	0.49607	28.98	1.0855
22	68308.	327.43	13883.52	0.09107	0.49607	29.31	[illegible]
23	68238.	328.65	13870.99	0.09170	0.49669	29.34	1.0886
24	68214.	326.93	13908.30	0.09157	0.49710	29.40	1.0870
25	68173.	330.94	13771.65	0.09160	0.49698	29.38	1.0873
26	68124.	329.35	13814.27	0.09170	0.49732	29.40	1.0885
27	68202.	323.77	14007.93	0.09159	0.49673	29.40	1.0872
28	68277.	328.89	13842.08	0.09126	0.49690	29.40	1.0833
29	68208.	326.32	13900.79	0.09123	0.49792	29.36	1.0830
30	68230.	327.18	13897.67	0.09147	0.49737	29.38	1.0858

MK48
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

SCALED TO TARGET SPEED = 70000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	246.17	37.68627	8933.76	4214.82	1092.92	341.02
2	247.14	37.82526	8931.33	4213.21	1096.06	340.84
3	246.27	37.68309	8925.74	4210.89	1091.96	340.[illegible]9
4	246.60	37.73273	8930.40	4212.64	1095.02	338.81
5	246.17	37.66733	8936.82	4215.84	1093.86	337.54
6	247.24	37.82743	8936.89	4215.44	1098.58	339.07
7	247.31	37.83459	8929.59	4211.69	1098.65	339.05
8	245.71	37.58199	8924.25	4209.52	1093.03	339.06
9	245.60	37.56516	8931.40	4213.10	1093.01	339.29
10	246.95	37.76539	8929.56	4211.23	1100.08	340.01
11	246.09	37.63631	8936.08	4214.82	1097.11	338.14
12	244.99	37.46175	8950.82	4221.99	1096.64	341.99
13	245.35	37.50651	8976.14	4233.48	1107.98	358.44
14	249.82	38.18851	9264.82	4365.79	1161.75	360.15
15	252.61	38.63666	9295.05	4392.17	1100.11	345.53
16	251.51	38.45747	9317.52	4404.55	1092.52	349.89
17	251.97	38.47659	9324.65	4407.44	1094.40	338.88
18	253.07	38.75022	9327.30	4409.24	1099.03	343.55
19	251.21	38.52818	9333.18	4413.23	1092.34	345.90
20	252.54	38.75373	9344.93	4418.28	1100.32	345.50
21	251.83	38.64589	9353.05	4421.42	1105.06	347.28
22	250.82	38.50699	9353.04	4420.36	1109.46	343.86
23	252.55	38.77274	9364.59	4425.04	1119.74	345.85
24	252.18	38.70674	9372.38	4428.93	1120.90	344.27
25	252.26	38.70435	9370.03	4427.60	1121.47	348.91
26	252.54	38.73858	9376.57	4430.60	1124.75	347.73
27	252.73	38.68897	9365.38	4425.30	1121.16	341.06
28	251.34	38.55023	9368.68	4427.86	1115.97	345.70
29	251.26	38.53085	9387.83	4436.74	1117.27	343.68
30	251.91	38.63262	9377.43	4431.53	1119.55	344.38

RX4[illegible]

LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	246.17	37.68627	8933.76	4214.82	1092.42	341.02
2	247.14	37.82526	8931.30	4213.21	1096.06	340.89
3	246.27	37.68309	8925.74	4210.89	1091.96	340.79
4	246.60	37.73273	8930.40	4212.64	1095.02	338.81
5	246.17	37.66733	8936.82	4215.84	1093.86	337.54
6	247.24	37.82743	8936.89	4215.44	1098.58	339.07
7	247.31	37.83459	8929.59	4211.69	1098.65	339.05
8	245.71	37.58199	8924.25	4209.52	1093.03	339.06
9	245.60	37.56516	8931.40	4213.10	1093.01	339.29
10	246.95	37.76539	8929.56	4211.23	1100.08	340.01
11	246.09	37.63631	8936.08	4214.82	1097.11	338.14
12	244.99	37.46175	8950.82	4221.99	1096.64	341.99
13	245.35	37.50651	8976.14	4233.48	1107.98	358.44
14	249.82	38.18851	9264.82	4365.79	1161.75	360.15
15	252.61	38.63666	9295.05	4392.17	1100.11	345.53
16	251.51	38.45747	9317.52	4404.55	1092.52	349.89
17	251.97	38.47659	9324.65	4407.44	1094.40	338.88
18	253.07	38.75022	9327.30	4409.24	1099.03	343.55
19	251.21	38.52818	9333.18	4413.23	1092.34	345.90
20	252.54	38.75373	9344.93	4418.28	1100.32	345.50
21	251.83	38.64589	9353.05	4421.42	1105.06	347.28
22	250.82	38.50699	9353.04	4420.36	1109.46	343.86
23	252.55	38.77274	9364.59	4425.04	1119.74	345.85
24	252.18	38.70674	9372.38	4428.93	1120.90	344.27
25	252.26	38.70435	9370.03	4427.60	1121.47	348.91
26	252.54	38.73858	9376.57	4430.60	1124.75	347.73
27	252.23	38.68897	9365.38	4425.30	1121.16	341.06
28	251.34	38.55023	9368.68	4427.86	1115.97	345.70
29	251.26	38.53085	9387.83	4436.74	1117.27	343.68
30	251.91	38.63262	9377.43	4431.53	1119.55	344.38

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MK4[illegible]
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

SCALED TO TARGET SPEED = 70000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	521.56	1518.81
2	521.87	1520.16
3	522.24	1516.82
4	523.13	1514.04
5	522.13	1515.24
6	521.80	1516.45
7	522.07	1515.29
8	521.19	1512.82
9	523.15	1515.00
10	521.66	1516.94
11	523.61	1518.33
12	524.26	1520.97
13	524.13	1523.85
14	525.78	1623.43
15	481.95	1655.79
16	485.28	1661.82
17	489.73	1666.49
18	484.89	1668.99
19	485.97	1670.75
20	488.13	1669.39
21	489.08	1687.03
22	489.64	1688.08
23	487.16	1689.65
24	485.25	1696.92
25	483.38	1689.74
26	486.00	1690.47
27	484.73	1688.97
28	481.61	1683.80
29	486.34	1666.58
30	485.01	1670.10

MK48
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 11-15-78
TEST DURATION, SEC 25.00

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SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	521.56	1518.81
2	521.87	1520.16
3	522.24	1516.82
4	523.13	1514.04
5	522.13	1515.24
6	521.80	1516.45
7	522.07	1515.29
8	521.19	1512.82
9	523.15	1515.00
10	521.66	1516.94
11	523.61	1518.33
12	524.26	1520.97
13	524.13	1523.85
14	525.28	1623.43
15	481.95	1655.79
16	485.28	1661.82
17	489.73	1666.49
18	484.89	1668.99
19	485.97	1670.75
20	488.13	1669.39
21	489.08	1687.03
22	489.64	1688.08
23	487.16	1689.65
24	485.25	1696.92
25	483.38	1689.74
26	486.00	1690.47
27	484.73	1688.97
28	481.61	1683.80
29	486.34	1666.58
30	485.01	1670.10

APPENDIX B
TEST 12
EXPANDED

MK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

COMMENTS . . .

OBJECTIVE SECTION PERFORMANCE WITH B.P. FLUID RECIRCULATED TO IMP. INLET

AMBIENT PRESSURE		13.8000
LO2 VENTURI (CC)		
P/N V160248-SGR	UPSTREAM DIAMETER	0.9570
S/N 8871	THROAT DIAMETER	0.2480
	THROAT CD	0.9850
GH2 VENTURI (TURB)		
P/N VP031200-SCR	UPSTREAM DIAMETER	2.3000
S/N 9731	THROAT DIAMETER	1.3085
	THROAT CD	0.9873
LH2 VENTURI (CG)		
P/N V320471-SGR	UPSTREAM DIAMETER	1.6890
S/N 8873	THROAT DIAMETER	0.4710
	THROAT CD	0.9765
LOX VENTURI (PUMP DISCH)		
P/N V321059-SGR	UPSTREAM DIAMETER	1.6890
S/N 8877	THROAT DIAMETER	1.0590
	THROAT CD	0.9820
	BAL PIST RECIRC ORIFICE	0.2600
	LOX SEAL DRAIN ORIFICE	0.5000
	TURBINE EFFECTIVE AREA	0.2319
	TURBINE EXHAUST ORIFICE	0.6600
	PRIMARY H.G. DRAIN ORIFICE	0.6550
	SEC. H.G. DRAIN ORIFICE	0.6000
	REAR BRG COOLANT ORIFICE	0.1800
	INTERMEDIATE SEAL PURGE ORIFICE	0.1260

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PK.
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST CURATION, SEC 25.00

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CASEOUS HYDRCGEN TURBINE CRIVE PARAMETERS

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	VENTURI U/S PR (PSIA)	VENTURI U/S TEMP (DEG R)	VENTURI DELTA PP (PSID)	SPIN VALVE FCSN	SPIN VALVE U/S PR (PSIA)	SPIN VALVE DELTA P (PSID)	TURB GH2 FLOW (LB/SEC)	SPEED (RPM)
1	22.025	22.293	4322.8	539.4	0.06	1.125	4320.0	4079.078	0.26935	15674.
2	24.004	24.272	4313.0	539.7	0.39	3.900	4309.3	3760.919	0.70148	28887.
3	27.015	27.283	4250.2	539.9	0.39	3.916	4287.6	3734.091	0.69196	29619.
4	30.521	30.785	4267.0	540.2	0.39	3.911	4263.0	3710.188	0.65402	29496.
5	34.522	34.790	4237.3	540.5	0.50	4.595	4234.3	3612.659	0.72948	31511.
6	37.038	37.306	4218.3	540.5	0.50	4.603	4214.8	3591.770	0.73673	31516.
7	38.275	38.543	4206.5	540.6	0.50	4.608	4205.6	3582.825	0.73800	31565.
8	39.017	39.285	4177.9	540.9	14.59	27.763	4143.4	1084.739	3.95866	65961.
9	40.007	40.275	4141.9	541.4	14.04	29.561	4104.8	955.307	3.86784	68052.
10	41.038	41.306	4104.1	541.7	14.62	31.098	4065.6	864.550	3.93089	68847.
11	42.028	42.296	4066.2	541.7	14.92	32.097	4028.8	809.686	3.95583	69191.
12	43.018	43.286	4031.2	541.6	15.12	32.927	3993.5	769.175	3.96735	69239.
13	44.008	44.276	3995.4	541.4	15.25	33.716	3956.6	729.014	3.97009	68313.

MK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

TURBINE PARAMETERS

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	SPEED (RPM)	TURB INLET STAT PR (PSIA)	TURB INLET TOT PR (PSIA)	TURB INLET TOT TEMP (DEG R)	TURB NOZZ D/S PR (PSIA)	TURB EXH STAT PR (PSIA)	TURB EXH TOT PR (PSIA)	TURB EXH TOT TEMP (DEG R)	TURB DSCH ORIFICE DELTA P (PSID)
1	22.025	22.293	15674.	225.2	216.4	502.0	167.5	169.7	175.8	230.9	161.7
2	24.004	24.272	26887.	528.0	519.8	496.6	353.0	357.0	365.0	393.4	351.1
3	27.015	27.283	25619.	535.4	526.5	495.9	354.8	359.4	369.8	424.3	355.9
4	30.521	30.789	25456.	529.1	523.0	495.6	354.8	358.7	367.2	430.2	353.2
5	34.522	34.790	31511.	558.5	592.5	495.8	396.3	401.7	410.6	441.9	396.6
6	37.038	37.306	31516.	552.5	591.7	496.6	396.3	401.1	410.5	442.9	396.5
7	38.275	38.543	31505.	553.6	591.7	496.8	396.5	401.4	410.6	443.1	396.6
8	39.017	39.215	65561.	3037.4	2988.0	504.8	1860.7	1878.2	1898.3	481.0	1860.5
9	40.007	40.275	66052.	3129.0	3090.2	508.5	1907.7	1926.4	1953.3	478.2	1914.3
10	41.038	41.306	66647.	3172.8	3140.2	509.4	1934.5	1955.1	1981.5	478.0	1941.7
11	42.028	42.296	65191.	3184.3	3157.1	509.7	1942.7	1964.0	1991.5	477.8	1951.7
12	43.018	43.286	65235.	3200.1	3163.0	509.8	1945.1	1967.2	1994.0	477.6	1954.0
13	44.008	44.276	66313.	3155.5	3165.8	509.6	1956.9	1972.8	2000.3	478.6	1960.1

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LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

TURBINE PARAMETERS (CONTINUED)

TIME SLICE NO	SPEED RPM	FLOW (LB/SEC)	PR RATIO (T-S)	BHP (CALIB) (HP)	BHP (DELTA T) (HP)	TORQUE (FT-LB)	U/C (T-S)	EFF (T-S)	TURB NOZ IN TOT P (PSIA)
1	15674.	0.2693	1.2455	12.4	371.8	4.[illegible]7	0.1384	30.31	212.1
2	28887.	0.7015	1.4265	66.1	371.2	12.01	0.2038	39.45	509.4
3	29615.	0.6920	1.4356	66.9	253.9	11.86	0.2074	39.90	516.0
4	29496.	0.6540	1.4289	62.5	219.2	11.13	0.2079	39.96	512.6
5	31511.	0.7355	1.4454	75.4	204.8	12.55	0.2185	41.24	580.7
6	31516.	0.7387	1.4459	75.4	203.4	12.56	0.2183	41.21	579.9
7	31505.	0.7380	1.4449	75.2	203.2	12.54	0.2184	41.22	579.9
8	65961.	3.5587	1.5590	638.1	493.1	50.79	0.4057	51.33	2928.2
9	68052.	3.6678	1.5720	636.1	613.5	49.08	0.4135	51.11	3028.4
10	68847.	3.5305	1.5740	648.0	647.0	49.41	0.4174	50.98	3077.4
11	69191.	3.5558	1.5754	652.8	659.7	49.53	0.4190	50.93	3094.0
12	69239.	3.5673	1.5757	655.2	668.5	49.68	0.4191	50.92	3099.8
13	68313.	3.5701	1.5726	654.8	640.9	50.32	0.4144	51.08	3102.5

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

T U R B I N E P A R A M E T E R S (CONTINUED)

TIME SLICE NO	SPEED RPM	AVAIL. ENERGY(T-S) (BTU/LB)	GAMMA	CP (BTU/LBM-R)	SPEED PARA-METER	FLOW PARA-METER	TORQUE PARA-METER	TURB WHEEL EXH PRESS PSIA
1	15674.	167.71	1.3813	3.5980	118.7	3.3982	0.0180	163.8
2	28687.	168.72	1.3834	3.6208	220.0	3.6653	0.0216	353.8
3	29619.	171.27	1.3834	3.6222	225.8	3.5664	0.0211	356.5
4	29496.	169.05	1.3833	3.6223	224.9	3.3925	0.0199	354.9
5	31511.	174.64	1.3840	3.6256	240.2	3.3866	0.0198	399.5
6	31516.	175.05	1.3841	3.6245	240.1	3.3901	0.0199	399.2
7	31505.	174.80	1.3841	3.6242	239.9	3.3876	0.0198	399.6
8	65961.	221.93	1.3980	3.7025	498.3	3.6273	0.0159	1915.3
9	68052.	227.42	1.3984	3.6992	512.2	3.4394	0.0149	1962.6
10	68847.	228.49	1.3985	3.6989	517.7	3.4431	0.0147	1991.2
11	69191.	229.01	1.3985	3.6989	520.2	3.4472	0.0147	2000.6
12	69235.	229.19	1.3986	3.6988	520.5	3.4513	0.0147	2002.4
13	68313.	228.18	1.3985	3.6993	513.6	3.4499	0.0149	2010.1

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LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

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TEST DURATION, SEC 25.00

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SEAL AND BEARING DATA

TIME SLICE NO	PRIM LOX SEAL DR PR (PSIA)	PRIM LOX SEAL DR TEMP (DEG R)	I/S PURGE PR (PSIA)	I/S PURGE TEMP (DEG R)	PRIM HG SEAL ORIF U/S PR (PSIA)	PRIM HG SEAL ORIF U/S TEMP (DEG R)	PRIM HG SEAL DR FLOW (LB/SEC)	SEC HG SEAL DR PR (PSIA)	SEC HG SEAL DR TEMP (DEG R)	SEC HG SEAL ORIF U/S PR (PSIA)	SEC HG SEAL ORIF U/S TEMP (DEG R)
1	36.47	157.09	226.68	554.22	14.63	356.69	0.0238	17.3	423.53	13.96	468.70
2	38.32	161.40	227.54	554.22	15.31	318.91	0.0334	20.7	363.84	14.19	438.16
3	40.30	163.51	226.70	554.40	15.19	289.79	0.0336	20.3	337.49	14.18	396.56
4	41.01	163.90	229.33	554.81	15.08	269.99	0.0336	20.0	326.46	14.19	370.60
5	41.16	164.27	229.15	554.89	15.11	263.26	0.0346	20.8	318.94	14.23	350.70
6	40.96	164.16	228.51	554.61	15.08	258.61	0.0342	20.7	316.56	14.25	343.51
7	40.53	164.00	228.62	554.69	15.05	257.78	0.0339	20.7	316.03	14.21	340.57
8	43.51	165.80	230.63	554.81	27.01	288.09	0.0893	23.6	355.41	14.33	346.87
9	41.48	167.34	230.65	554.90	31.54	347.73	0.0955	27.3	355.64	14.55	365.67
10	42.80	168.16	230.89	554.90	34.08	385.85	0.0982	29.6	415.75	14.70	382.69
11	42.65	168.30	230.85	554.90	35.56	407.72	0.0999	30.8	427.28	14.76	396.56
12	40.89	167.53	230.63	554.72	36.48	421.38	0.1009	31.4	434.80	14.81	407.84
13	36.34	170.24	230.47	554.60	37.28	425.11	0.1027	32.9	435.03	14.92	415.52

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MK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	SEC FC SEAL DR FLOW (LB/SEC)	RR BRG COOLANT SUPPL.PR (PSIA)	RR BRG COOLANT SUPPL.TEMP (DEG R)	RR BRG DRAIN PR (PSIA)	RR BRG DRAIN TEMP (DEG R)	RR BRG COOL.ORIF U/S PR (PSIA)	RR BRG COOL.ORIF U/S TEMP (DEG R)	RR BRG COOLANT FLOW (LB/SEC)
1	0.0	3460.2	98.19	204.9	95.73	13.8	460.00	0.0
2	0.0	3479.0	95.69	209.3	94.28	13.8	460.00	0.0
3	0.0	3482.9	93.50	210.3	93.08	13.8	460.00	0.0
4	0.0	3480.6	92.69	211.7	92.91	13.8	460.00	0.0
5	0.0	3480.6	91.00	211.8	92.33	13.8	460.00	0.0
6	0.0	3475.4	89.63	211.2	91.38	13.8	460.00	0.0
7	0.0	3475.1	89.56	210.2	90.67	13.8	460.00	0.0
8	0.0	3490.7	89.25	198.0	93.57	13.8	460.00	0.0
9	0.0	3491.5	88.31	198.2	94.82	13.8	460.00	0.0
10	0.0	3491.6	88.94	199.2	96.67	13.8	460.00	0.0
11	0.0	3492.5	88.38	199.9	97.14	13.8	460.00	0.0
12	0.0	3493.7	89.31	201.0	98.43	13.8	460.00	0.0
13	0.0	3492.9	89.19	202.2	99.23	13.8	460.00	0.0

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PKA
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-1J-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

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SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	LOX SEAL DRAIN ORIF L/S PRESS PSIA	LOX SEAL DRAIN ORIF U/S TEMP DEG R	LOX SEAL DRAIN FLOWRATE (LB/SEC)
1	31.9	513.41	0.148
2	32.6	510.11	0.151
3	34.8	506.77	0.160
4	35.6	502.60	0.164
5	35.9	500.69	0.165
6	35.8	500.40	0.164
7	35.3	499.84	0.163
8	35.3	500.62	0.163
9	36.5	501.10	0.167
10	38.5	501.35	0.173
11	38.9	501.02	0.175
12	37.3	502.38	0.169
13	33.6	503.60	0.156

PK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

P U M P   P R E S S U R E S

TIME SLICE NO	SUPPLY TANK PR (PSIA)	PUMP INLET PR (PSIA)	IMPELLER DISCH PR (PSIA)	DIFFUSER DISCH PR (PSIA)	PUMP DISCH PR (PSIA)	BAL PIST CAV PR #1 (PSIA)	BAL PIST SUMP PR (PSIA)	BAL PIST RETURN PR (PSIA)	IMPELLER FRONT SHROUD PR (PSIA)
1	266.2	263.2	324.0	342.2	407.9	347.7	306.8	256.3	392.1
2	266.5	251.4	557.4	661.4	875.9	616.2	465.3	397.6	726.9
3	267.2	253.7	581.6	708.3	943.4	643.8	486.1	414.5	759.4
4	267.0	253.1	576.3	704.2	939.2	638.5	486.1	414.1	756.0
5	266.5	250.4	626.3	774.0	1044.8	692.8	518.7	441.5	829.0
6	266.4	250.9	627.6	775.9	1045.4	692.4	519.6	441.5	829.6
7	266.3	250.1	628.2	773.6	1044.5	690.8	519.0	440.6	828.0
8	264.8	188.2	1824.0	2582.5	3944.7	2036.2	1401.0	1214.7	2904.1
9	262.9	181.8	1893.1	2734.7	4181.9	2111.6	1456.0	1258.5	3046.9
10	262.9	180.2	1930.9	2793.2	4261.8	2142.1	1490.4	1281.3	3100.8
11	263.0	180.5	1949.7	2812.5	4297.1	2148.5	1509.8	1293.7	3125.1
12	263.2	180.7	1955.8	2820.2	4307.6	2137.2	1516.4	1293.7	3129.0
13	263.2	178.8	1615.4	2785.3	4389.4	2272.9	1164.5	994.2	3261.2

MK
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-76
TEST DURATION, SEC 25.00

PUMP PRESSURES AND TEMPERATURES

TIME SLICE NO	SPEED RPM	INDUCER DISCH PRESS PSIA	PUMP BRG D/S PRESS PSIA	BAL PIST RECIRC TEMP AT PUMP IN DEG R	PUMP BRG DELTA P PSID
1	15674.	248.7	282.5	227.95	21.66
2	28887.	304.6	419.0	220.07	42.30
3	29619.	316.7	432.4	220.11	50.41
4	29496.	315.5	430.1	209.55	50.97
5	31511.	325.1	458.6	202.93	56.48
6	31516.	325.7	460.3	201.56	56.13
7	31505.	324.3	458.4	200.79	56.22
8	65561.	531.0	1408.7	201.60	-11.75
9	66052.	667.7	1296.6	236.57	151.74
10	66647.	683.1	1334.0	249.11	149.95
11	69191.	690.2	1389.2	253.26	116.34
12	69239.	693.2	1399.8	255.14	112.08
13	68313.	644.6	1032.9	256.82	129.05

MK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S (CONTINUED)

TIME SLICE NO	**073** BAL PIST RECIRC L/S ORIF PR PSIA	**044** BAL PIST RECIRC U/S ORIF TEMP DEG R	**105** BAL PIST RECICR DELTA P PSI	BAL PIST FLOW LB/SEC	**044-045** BAL PIST FLOW TEMP RISE DEG R
1	275.6	213.5	15.90	1.094	34.81
2	406.2	212.1	34.71	1.624	28.02
3	424.8	211.5	45.27	1.857	27.33
4	422.3	207.8	37.00	1.689	24.55
5	446.3	206.6	39.91	1.759	23.30
6	448.5	205.8	39.38	1.749	22.67
7	447.6	205.7	39.33	1.748	22.69
8	1158.7	234.3	200.31	3.799	35.68
9	1202.9	256.0	201.40	3.636	52.51
10	1224.6	260.3	203.91	3.620	55.05
11	1236.5	261.9	205.77	3.622	56.06
12	1236.9	262.8	206.37	3.618	56.54
13	958.1	270.3	140.64	2.854	65.63

LIQUID OXYGEN TURBOPUMP ASSEMBLY

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

RUN NUMBER 12
TEST DATE 10-10-78

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P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S

TIME SLICE NO	PUMP INLET TEMP (DEG R)	PUMP DISCH TEMP (DEG R)	BAL PIST RETURN TEMP (DEG R)	PUMP DISCH VENT U/S TEMP (DEG R)	PUMP DISCH VENT U/S PR (PSIA)	PUMP DISCH VENT DELTA PR (PSI)	HP (TEMP)
1	176.28	176.72	0.0	178.43	394.9	9.59	29.32
2	176.01	184.09	0.0	182.57	855.7	15.58	132.79
3	175.80	184.16	0.0	183.84	921.2	15.89	140.33
4	175.74	183.26	0.0	183.22	917.1	15.63	127.44
5	175.64	183.26	0.0	182.99	1020.9	16.39	137.18
6	175.65	183.16	0.0	183.00	1021.9	16.39	135.70
7	175.64	183.02	0.0	182.91	1020.7	16.36	133.90
8	175.62	198.56	0.0	192.41	3879.7	50.83	861.30
9	175.58	203.50	0.0	200.30	4120.2	52.80	1002.64
10	175.61	205.27	0.0	203.24	4198.7	52.63	1045.04
11	175.61	205.89	0.0	204.33	4232.4	52.17	1056.98
12	175.61	206.27	0.0	204.85	4242.2	51.84	1063.07
13	175.60	204.70	0.0	203.59	4320.6	53.07	1029.15

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MK48-D
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

C A L C U L A T E D P U M P P A R A M E T E R S

TIME SLICE NO	TEST SPEED (RPM)	PUMP FLOW GPM	PUMP FLOW (LB/SEC)	HEAD FT	PRESS RISE (PSI)	FLUID HP (HP)	TURB HP (HP)	EFF (%)	ISEN EFF (%)	SPECIFIC SPEED
1	15674.	104.26	15.9807	322.7	144.7	9.4	12.44	75.39	31.98	2102.
2	28887.	134.80	20.5996	1342.8	624.5	50.3	66.07	76.16	37.87	1512.
3	29619.	134.58	20.5230	1478.3	689.8	55.2	66.90	82.49	39.31	1441.
4	29498.	133.37	20.3681	1468.3	686.1	54.4	62.51	87.02	42.67	1436.
5	31511.	136.42	20.8824	1694.8	794.4	64.3	75.35	85.43	46.91	1393.
6	31516.	136.42	20.8824	1695.0	794.6	64.4	75.41	85.38	47.43	1393.
7	31505.	136.28	20.8656	1694.1	794.3	64.3	75.24	85.45	48.00	1393.
8	65561.	238.05	37.1657	7930.7	3758.4	535.9	638.08	84.02	62.22	1211.
9	68052.	244.40	37.6432	8466.6	4030.1	579.9	636.15	91.19	57.84	1205.
10	68847.	244.66	37.5157	8650.4	4081.6	590.0	647.96	91.10	56.46	1201.
11	69191.	243.62	37.3204	8726.2	4116.6	592.1	652.82	90.74	56.02	1197.
12	69239.	243.18	37.1664	8749.7	4126.8	591.6	655.16	90.33	55.65	1193.
13	68313.	245.57	37.6913	8907.6	4210.5	610.4	654.80	93.26	59.31	1168.

MKA LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

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C A L C U L A T E D   P U M P   P A R A M E T E R S

TIME SLICE NO	TEST SPEED (RPM)	NPSH (FT)	SUCTION SPECIFIC SPEED	INLET FLOW COEFF	HEAD COEFF	PUMP DELTA T (DEG R)	(Q/N) OVER (Q/N)DES
1	15634.	487.58	1541.47	0.16907	0.34135	2.44	2.0070
2	28887.	485.49	3346.67	0.11861	0.41822	8.08	1.4080
3	29619.	470.02	3403.92	0.11549	0.43796	8.36	1.3710
4	29496.	466.61	3382.08	0.11492	0.43860	7.52	1.3642
5	31511.	463.13	3666.66	0.11004	0.44357	7.62	1.3063
6	31516.	464.06	3661.73	0.11002	0.44350	7.51	1.3061
7	31505.	462.57	3687.37	0.10995	0.44359	7.38	1.3052
8	65561.	342.57	12781.10	0.09173	0.47372	22.96	1.0889
9	68052.	333.56	13618.27	0.09128	0.47525	27.92	1.0836
10	68847.	336.78	13863.89	0.09032	0.47430	29.66	1.0722
11	69191.	331.22	13915.47	0.08957	0.47372	30.27	1.0633
12	69235.	331.66	13892.80	0.08927	0.47433	30.66	1.0557
13	68313.	327.35	13910.08	0.09137	0.49607	29.10	1.0846

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MK48
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

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SCALED TO TARGET SPEED = 70000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	465.64	71.37051	6435.78	2885.13	2611.71	9733.01
2	326.65	49.91812	7885.23	3667.29	1887.59	2733.41
3	318.07	48.50356	8257.34	3852.69	1852.38	2625.28
4	316.50	48.33657	8269.37	3863.86	1703.25	2639.17
5	303.05	46.38867	8363.19	3919.97	1503.76	2285.43
6	303.01	46.38136	8361.80	3919.86	1486.82	2289.27
7	302.81	46.36132	8363.55	3921.49	1468.81	2283.61
8	252.63	39.44122	8931.60	4232.75	1029.39	385.80
9	251.40	38.74149	8960.43	4232.43	1091.25	353.35
10	248.76	38.14393	8942.50	4219.45	1098.42	341.95
11	246.68	37.75700	8931.54	4213.52	1094.51	339.01
12	245.85	37.59509	8943.05	4218.02	1098.50	338.99
13	251.63	38.62214	9353.02	4421.04	1107.30	343.72

PK

LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	465.64	71.37051	6435.78	2885.13	2611.71	9733.01
2	326.65	49.91812	7885.23	3667.29	1889.59	2733.41
3	318.07	48.50356	8257.34	3852.69	1852.38	2625.28
4	316.50	48.33697	8269.37	3863.86	1703.25	2639.17
5	303.05	46.36867	8363.19	3919.97	1503.76	2285.43
6	303.01	46.36136	8361.80	3919.86	1486.82	2289.27
7	302.81	46.36132	8363.55	3921.49	1468.81	2283.61
8	252.63	39.44122	8931.60	4232.75	1029.39	385.80
9	251.40	38.74149	8960.43	4232.43	1091.25	353.35
10	248.76	38.14353	8942.50	4219.45	1098.42	341.95
11	246.68	37.75760	8931.54	4213.52	1094.51	339.01
12	245.65	37.59509	8943.05	4218.02	1098.50	338.99
13	251.63	38.62214	9353.02	4421.04	1107.30	343.72

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MK48
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

SCALED TO TARGET SPEED = 70000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	-250.04	1309.15
2	312.52	1259.96
3	352.30	1313.43
4	351.30	1323.57
5	368.75	1336.39
6	369.33	1325.66
7	366.13	1337.42
8	388.23	1534.11
9	514.12	1531.23
10	519.86	1516.25
11	521.70	1519.54
12	523.74	1520.26
13	489.03	1684.24

PKA LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 12
TEST DATE 10-10-78

PROCESSING DATE 10-11-78
TEST DURATION, SEC 25.00

SCALED TO DESIGN SPEED = 70,000. RPM

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TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	-290.04	1309.15
2	312.52	1255.56
3	352.30	1313.43
4	351.30	1323.57
5	368.75	1336.35
6	369.33	1325.66
7	366.13	1337.42
8	388.23	1534.11
9	514.12	1531.23
10	519.86	1518.25
11	521.70	1519.54
12	523.74	1520.26
13	489.03	1664.24

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APPENDIX C

MARK 48-OXIDIZER TURBOPUMP APRIL 1981 TEST DATA

APPENDIX C
TEST 3

MK48
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

Corrected 4-15

COMMENTS . . .

BALANCE PISTON OVERBOARD.
HQ TEST AT TARGET SPEED=30,000 RPM.
HQ 100 PERCENT TO 70 PERCENT OF DESIGN FLOW.

AMBIENT PRESSURE		13.8000
LO2 VENTURI (GG)		
P/N V160248-SGR	UPSTREAM DIAMETER	0.9570
S/N 8871	THROAT DIAMETER	0.2480
	THROAT CD	0.9850
GH2 VENTURI (TURB)		
P/N VP031200-SGR	UPSTREAM DIAMETER	2.3000
S/N 9731	THROAT DIAMETER	1.3085
	THROAT CD	0.9873
LH2 VENTURI (GG)		
P/N V320471-SGR	UPSTREAM DIAMETER	1.6890
S/N 8873	THROAT DIAMETER	0.4710
	THROAT CD	0.9765
LOX VENTURI (PUMP DISCH)		
P/N V321059-SGR	UPSTREAM DIAMETER	1.6890
S/N 8877	THROAT DIAMETER	1.0590
	THROAT CD	0.9820
	BAL PIST OVBD CONTROL ORIFICE	0.2420
	BAL PIST OVBD ORIFICE	0.2210
	BRG FLOW DRAIN ORIFICE	0.7500
	TURBINE EFFECTIVE AREA	0.2319
	TURBINE EXHAUST ORIFICE	0.4600
	PRIMARY H.G. DRAIN ORIFICE	0.4550
	SEC. H.G. DRAIN ORIFICE	0.6000
	REAR BRG COOLANT ORIFICE	0.1000
	INTERMEDIATE SEAL PURGE ORIFICE	0.1260

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MK48-U
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

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GASEOUS HYDROGEN TURBINE DRIVE PARAMETERS

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	VENTURI U/S PR (PSIA)	VENTURI U/S TEMP (DEG R)	VENTURI DELTA PR (PSID)	SPIN VALVE POSN	SPIN VALVE U/S PR (PSIA)	SPIN VALVE DELTA P (PSID)	TURB GH2 FLOW (LB/SEC)	SPEED (RPM)
9	59.475	59.743	3928.3	531.0	0.26	4.955	3934.0	3504.756	0.54300	27439.
10	61.991	62.259	3913.0	531.2	0.27	4.962	3919.6	3491.454	0.54810	26852.
11	64.465	64.733	3900.1	531.3	0.27	4.962	3905.9	3478.847	0.54456	22616.
12	66.981	67.249	3885.7	531.4	0.27	5.038	3892.4	3461.193	0.55337	26291.
13	69.497	69.724	3871.7	531.4	0.39	5.782	3876.6	3369.135	0.65580	29609.
14	71.972	72.240	3855.3	531.4	0.38	5.782	3861.9	3355.707	0.65157	29037.
15	74.488	74.756	3840.2	531.3	0.38	5.792	3846.0	3341.701	0.64802	28872.
16	76.962	77.2[illegible]0	3824.6	531.2	0.39	5.780	3830.4	3328.405	0.65086	28768.
17	79.478	79.746	3809.2	531.2	0.40	5.870	3815.2	3301.067	0.65999	29301.
18	81.994	82.221	3794.4	531.1	0.41	5.930	3800.6	3283.911	0.66743	29285.
19	84.469	84.737	3779.2	531.1	0.41	5.934	3784.2	3267.750	0.66476	29851.
20	86.985	87.253	3762.3	531.1	0.41	5.978	3768.4	3252.280	0.66813	30497.
21	89.459	89.728	3747.0	531.1	0.41	6.017	3754.3	3238.188	0.66238	30609.
22	91.975	92.243	3732.8	531.1	0.41	6.057	3738.1	3221.631	0.66668	30588.
23	94.491	94.759	3716.8	531.1	0.41	6.089	3723.9	3206.048	0.66241	[illegible]
24	96.966	97.234	3702.5	531.0	0.41	6.105	3708.5	3192.463	0.66190	[illegible]
25	99.482	99.750	3686.8	531.0	0.41	6.126	3692.6	3175.708	[illegible]	[illegible]
26	101.998	102.225	3671.0	531.0	0.41	6.140	3677.6	3160.202	0.66052	[illegible]
27	104.472	104.741	3656.0	530.9	0.41	6.158	3663.2	3145.947	0.65695	30960.
28	106.988	107.256	3641.5	530.9	0.42	6.174	3647.9	3131.958	0.66189	30217.
29	109.463	109.731	3626.5	530.9	0.42	6.230	3632.7	3115.793	0.66373	29662.
30	111.979	112.247	3611.2	530.9	0.42	6.248	3617.4	3100.519	0.66032	29684.
31	114.495	114.722	3596.0	530.9	0.41	6.253	3603.0	3086.741	0.65673	29590.
32	116.970	117.238	3581.6	530.9	0.42	6.266	3588.7	3072.031	0.65728	29329.
33	119.485	119.754	3567.0	530.9	0.42	6.301	3573.5	3056.370	0.66281	29679.
34	121.960	122.228	3552.2	530.9	0.42	6.313	3559.0	3043.268	0.66019	29672.

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MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

T U R B I N E   P A R A M E T E R S

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	SPEED (RPM)	TURB INLET STAT PR (PSIA)	TURB INLET TOT PR (PSIA)	TURB INLET TOT TEMP (DEG R)	TURB NOZZ D/S PR (PSIA)	TURB EXH STAT PR (PSIA)	TURB EXH TOT PR (PSIA)	TURB EXH TOT TEMP (DEG R)	TURB DSCH ORIFICE DELTA P (PSID)
9	59.475	59.743	27439.	425.2	431.4	543.1	291.0	298.1	292.9	421.1	288.6
10	61.991	62.259	26852.	422.6	429.1	544.1	291.5	298.2	293.2	428.7	289.5
11	64.465	64.733	22516.	422.4	429.0	544.3	292.1	299.1	294.5	432.7	295.4
12	66.981	67.249	26291.	425.0	432.7	544.8	293.8	302.0	295.8	432.8	295.5
13	69.497	69.724	29609.	503.5	508.8	544.5	341.2	348.2	344.6	442.8	337.5
14	71.972	72.240	29037.	504.9	507.3	544.7	340.9	347.9	343.6	443.9	336.8
15	74.488	74.756	28972.	503.1	506.4	544.7	340.7	347.3	342.8	443.8	334.9
16	76.962	77.230	28768.	498.6	504.0	544.9	340.2	347.3	342.3	443.4	332.9
17	79.478	79.746	25301.	509.1	516.1	544.6	346.5	354.2	350.0	444.7	337.8
18	81.994	82.221	29285.	520.0	517.9	544.8	349.0	356.2	351.3	445.3	341.8
19	84.469	84.737	29851.	519.0	517.8	544.7	348.7	355.5	350.6	445.2	343.6
20	86.985	87.253	30497.	520.4	517.7	544.7	348.4	355.5	350.6	444.9	345.3
21	89.459	89.728	30609.	517.2	517.6	544.6	348.4	355.5	350.6	444.9	347.4
22	91.975	92.243	30988.	519.6	518.6	544.5	348.5	355.5	350.9	445.1	346.2
23	94.491	94.759	31199.	520.4	518.5	544.4	348.5	355.5	350.8	445.1	344.3
24	96.966	97.234	31461.	519.2	517.8	544.4	347.9	355.5	350.6	445.1	345.6
25	99.482	99.750	31530.	520.6	518.5	544.4	348.2	355.5	350.7	445.3	343.9
26	101.998	102.225	31550.	520.9	519.4	544.4	348.7	355.7	350.9	445.6	344.2
27	104.472	104.741	30960.	522.0	518.8	544.4	348.2	355.6	350.8	445.9	347.1
28	106.988	107.256	30217.	517.8	517.6	544.3	347.6	355.4	350.6	446.0	344.2
29	109.463	109.731	29662.	522.4	519.0	544.2	348.9	356.0	351.2	446.5	346.0
30	111.979	112.247	29584.	518.8	518.7	544.2	348.7	355.5	350.9	446.7	345.1
31	114.495	114.722	29590.	512.6	517.6	544.1	347.2	355.5	350.6	446.4	345.4
32	116.970	117.238	29629.	514.1	517.7	544.1	347.6	355.5	350.6	446.5	347.2
33	119.485	119.754	29679.	519.0	519.0	544.1	348.7	355.6	350.8	446.5	346.3
34	121.960	122.228	29672.	515.3	517.6	544.1	347.5	355.5	350.6	446.4	348.2

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

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T U R B I N E   P A R A M E T E R S (CONTINUED)

TIME SLICE NO	SPEED RPM	FLOW (LB/SEC)	PR RATIO (T-S)	BHP (CALIB) (HP)	BHP (DELTA T) (HP)	TORQUE (FT-LB)	U/C (T-S)	EFF (T-S)	TURB NOZ IN TOT P (PSIA)
9	27439.	0.5430	1.4183	51.7	333.9	9.89	0.1873	37.33	422.7
10	26852.	0.5481	1.4103	51.0	318.9	9.96	0.1846	36.96	420.5
11	22516.	0.5446	1.4055	44.6	306.4	10.41	0.1554	32.89	420.4
12	26291.	0.5534	1.4043	50.4	312.4	10.06	0.1816	36.57	424.1
13	29609.	0.6358	1.4320	67.0	336.7	11.88	0.1991	38.85	498.6
14	29037.	0.6516	1.4289	65.5	331.1	11.84	0.1958	38.43	497.1
15	28972.	0.6480	1.4288	65.0	329.8	11.78	0.1953	38.38	496.3
16	28768.	0.6509	1.4221	64.5	333.3	11.76	0.1952	38.35	493.9
17	29301.	0.6600	1.4277	66.6	332.7	11.93	0.1977	38.69	505.8
18	29285.	0.6674	1.4249	67.1	335.0	12.03	0.1981	38.74	507.6
19	29851.	0.6648	1.4272	67.9	334.1	11.94	0.2015	39.17	507.4
20	30497.	0.6681	1.4269	69.1	336.7	11.90	0.2059	39.72	507.3
21	30609.	0.6624	1.4266	68.7	333.3	11.78	0.2060	39.82	507.2
22	30988.	0.6667	1.4294	69.9	334.7	11.84	0.2088	40.07	608.2
23	31199.	0.6624	1.4291	69.7	332.0	11.73	0.2103	40.25	608.1
24	31461.	0.6620	1.4272	69.9	331.6	11.66	0.2125	40.52	507.4
25	31530.	0.6631	1.4294	70.3	331.6	11.70	0.2125	40.52	508.2
26	31550.	0.6625	1.4312	70.4	330.3	11.72	0.2123	40.49	609.0
27	30960.	0.6569	1.4294	68.8	326.4	11.67	0.2086	40.05	508.4
28	30217.	0.6619	1.4271	68.1	328.4	11.83	0.2041	39.40	507.2
29	29662.	0.6637	1.4286	67.6	327.3	11.96	0.2001	38.98	508.6
30	29584.	0.6603	1.4296	67.2	324.9	11.92	0.1994	38.89	508.3
31	29590.	0.6567	1.4266	66.6	324.0	11.81	0.2000	38.97	507.2
32	29629.	0.6573	1.4269	66.7	323.9	11.82	0.2002	39.00	507.3
33	29679.	0.6628	1.4300	67.6	326.3	11.96	0.2000	38.97	508.6
34	29672.	0.6602	1.4266	67.0	325.7	11.86	C.2005	39.04	507.2

MK48-J
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

TURBINE PARAMETERS (CONTINUED)

TIME SLICE NO	SPEED RPM	AVAIL. ENERGY(T-S) (BTU/LB)	GAMMA	CP (BTU/LBM-R)	SPEED PARA-METER	FLOW PARA-METER	TORQUE PARA-METER	TURB WHEEL EXH PRESS PSIA
9	27439.	180.24	1.3883	3.5642	199.8	3.5744	0.0215	285.9
10	26852.	177.76	1.3884	3.5632	195.4	3.6305	0.0217	286.1
11	22516.	176.17	1.3884	3.5630	163.8	3.6087	0.0227	286.7
12	26291.	175.91	1.3885	3.5628	191.2	3.6368	0.0218	288.7
13	29609.	185.76	1.3890	3.5662	215.4	3.6648	0.0219	347.6
14	29037.	184.76	1.3890	3.5660	211.2	3.6525	0.0218	347.0
15	28972.	184.74	1.3390	3.5659	210.7	3.6392	0.0218	345.6
16	28768.	182.47	1.3890	3.5657	209.2	3.6728	0.0218	354.7
17	29301.	184.36	1.3890	3.5664	213.1	3.6364	0.0216	362.0
18	29285.	183.43	1.3891	3.5663	213.0	3.6650	0.0217	363.3
19	29851.	184.23	1.3891	3.5664	217.1	3.6513	0.0216	353.4
20	30497.	184.12	1.3891	3.5664	221.6	3.6704	0.0215	353.5
21	30609.	183.98	1.3891	3.5665	222.6	3.6398	0.0213	353.3
22	30988.	184.92	1.3891	3.5666	225.4	3.6556	0.0214	353.4
23	31199.	184.79	1.3890	3.5667	226.9	3.6325	0.0212	353.8
24	31461.	184.11	1.3890	3.5667	228.9	3.6348	0.0211	353.2
25	31530.	184.87	1.3890	3.5667	229.4	3.6354	0.0211	353.5
26	31550.	185.48	1.3890	3.5668	229.5	3.6262	0.0211	353.7
27	30960.	184.09	1.3890	3.5667	225.2	3.6002	0.0211	353.5
28	30217.	184.05	1.3890	3.5667	219.8	3.6354	0.0214	353.1
29	29662.	184.54	1.3890	3.5669	215.8	3.6356	0.0216	353.6
30	29584.	184.91	1.3890	3.5668	215.2	3.6198	0.0215	353.3
31	29590.	183.84	1.3890	3.5669	215.3	3.6065	0.0214	352.9
32	29629.	183.92	1.3890	3.5669	215.6	3.6087	0.0214	353.1
33	29679.	184.98	1.3890	3.5670	216.0	3.6304	0.0216	353.4
34	29672.	183.83	1.3890	3.5669	215.9	3.6254	0.0215	353.1

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MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

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TEST DURATION, SEC 74.08

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SEAL AND BEARING DATA

TIME SLICE NO	PRIM LOX SEAL DR PR (PSIA)	PRIM LOX SEAL DR TEMP (DEG R)	I/S PURGE PR (PSIA)	I/S PURGE TEMP (DEG R)	PRIM HG SEAL ORIF U/S PR (PSIA)	PRIM HG SEAL ORIF U/S TEMP (DEG R)	PRIM HG SEAL DR FLOW (LB/SEC)	SEC HG SEAL DR PR (PSIA)	SEC HG SEAL DR TEMP (DEG R)	SEC HG SEAL ORIF U/S PR (PSIA)	SEC HG SEAL ORIF U/S TEMP (DEG R)
9	14.58	355.58	222.45	539.00	17.72	333.41	0.0507	19.3	397.81	14.07	424.36
10	14.56	349.07	222.33	538.59	16.83	303.54	0.0475	18.8	367.86	14.07	370.03
11	14.50	346.16	220.66	538.58	17.49	284.74	0.0533	17.3	379.79	13.98	365.34
12	14.57	345.27	220.28	539.00	17.29	273.15	0.0532	17.2	434.63	13.96	399.78
13	14.63	343.11	225.74	539.20	16.90	264.85	0.0513	17.0	434.36	13.96	412.77
14	14.63	341.89	226.83	539.32	16.48	257.80	0.0487	17.4	413.70	13.97	409.26
15	14.63	342.59	227.74	539.39	16.44	251.04	0.0491	17.3	421.51	13.97	413.10
16	14.64	340.73	228.51	539.49	16.44	245.16	0.0496	16.8	415.43	13.95	408.00
17	14.67	339.11	229.34	539.73	16.29	240.10	0.0488	17.1	401.40	13.97	397.66
18	14.67	337.57	229.90	539.75	16.27	234.23	0.0492	17.4	409.06	13.97	401.34
19	14.73	334.40	230.70	539.81	16.29	229.97	0.0499	17.5	392.44	13.97	394.96
20	14.69	332.73	231.65	540.16	16.17	224.98	0.0493	17.4	378.98	13.97	383.81
21	14.69	330.87	230.89	540.16	16.17	220.53	0.0498	17.9	348.31	14.01	354.03
22	14.66	327.89	229.63	539.98	16.01	216.62	0.0488	18.0	332.00	14.05	331.32
23	14.66	326.26	228.22	539.86	16.13	212.86	0.0503	18.1	323.35	14.06	316.86
24	14.63	325.04	226.87	540.14	16.17	209.41	0.0511	18.1	316.73	14.07	307.30
25	14.64	323.82	225.71	540.16	16.09	206.03	0.0507	18.1	312.30	14.07	300.21
26	14.65	321.88	224.45	540.40	16.18	203.01	0.0519	18.1	307.45	14.08	295.36
27	14.64	320.83	223.44	540.70	16.01	200.05	0.0507	18.2	303.86	14.08	291.20
28	14.68	318.01	222.64	540.85	16.01	197.33	0.0510	18.3	299.83	14.07	287.06
29	14.74	313.74	221.89	540.85	15.86	196.20	0.0495	18.5	294.53	14.07	283.49
30	14.67	311.12	221.28	540.88	15.94	194.34	0.0506	18.6	291.74	14.08	279.75
31	14.67	310.00	220.76	540.98	16.00	191.85	0.0515	18.7	288.34	14.08	275.69
32	14.64	309.46	220.38	541.15	15.78	189.22	0.0496	18.8	285.09	14.08	273.25
33	14.64	308.65	219.96	541.50	15.82	187.23	0.0503	18.8	282.89	14.08	270.68
34	14.63	307.79	219.66	541.51	15.94	185.63	0.0517	18.8	281.09	14.07	268.98

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	SEC HG SEAL PR FLOW (LB/SEC)	RR BRG COOLANT SUPPL.PR (PSIA)	RR BRG COOLANT SUPPL.TEMP (DEG R)	RR BRG DRAIN PR (PSIA)	RR BRG DRAIN TEMP (DEG R)	RR BRG COOL.ORIF U/S PR (PSIA)	RR BRG COOL.ORIF U/S TEMP (DEG R)	RR BRG COOL.ORIF D/S PR (PSIA)	RR BRG COOLANT FLOW (LB/SEC)
9	0.0	3446.7	0.0	224.7	125.03	224.7	119.09	103.6	0.1130
10	0.0	3446.0	0.0	225.6	124.11	225.6	118.75	103.7	0.1138
11	0.0	3444.6	0.0	226.8	123.51	226.8	119.14	104.0	0.1143
12	0.0	3445.4	0.0	226.2	123.06	226.2	118.80	103.7	0.1142
13	0.0	3445.5	0.0	225.4	122.50	225.4	117.98	103.1	0.1143
14	0.0	3443.8	0.0	226.2	122.50	226.2	118.79	103.4	0.1143
15	0.0	3443.5	0.0	223.5	121.59	223.5	115.95	102.5	0.1144
16	0.0	3442.4	0.0	220.3	118.96	220.3	112.32	101.1	0.1150
17	0.0	3442.8	0.0	220.0	117.79	220.0	111.27	100.8	0.1155
18	0.0	3442.3	0.0	219.2	117.61	219.2	110.65	100.3	0.1156
19	0.0	3441.9	0.0	218.5	117.24	218.5	109.97	100.0	0.1156
20	0.0	3441.6	0.0	217.3	117.19	217.3	108.80	99.5	0.1157
21	0.0	3440.6	0.0	216.9	116.60	216.9	107.93	99.1	0.1161
22	0.0	3440.9	0.0	216.4	116.62	216.4	107.49	98.9	0.1161
23	0.0	3440.3	0.0	215.5	116.40	215.5	106.92	98.6	0.1160
24	0.0	3440.3	0.0	215.5	116.35	215.5	106.63	98.3	0.1163
25	0.0	3440.2	0.0	215.2	116.52	215.2	106.25	98.1	0.1164
26	0.0	3439.6	0.0	214.7	116.61	214.7	105.35	97.8	0.1168
27	0.0	3441.9	0.0	215.1	116.95	215.1	105.97	98.0	0.1166
28	0.0	3470.2	0.0	215.5	117.41	215.5	105.44	98.1	0.1173
29	0.0	3465.2	0.0	215.8	118.22	215.8	106.28	98.2	0.1169
30	0.0	3461.5	0.0	215.0	118.45	215.0	105.42	97.6	0.1171
31	0.0	3457.7	0.0	213.9	118.77	213.9	104.27	97.3	0.1172
32	0.0	3454.1	0.0	213.5	119.27	213.5	103.83	96.8	0.1174
33	0.0	3450.8	0.0	214.0	119.73	214.0	103.84	97.0	0.1178
34	0.0	3449.8	0.0	212.9	120.17	212.9	103.35	96.6	0.1175

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RUN NUMBER 3
TEST DATE 4-13-81

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TEST DURATION, SEC 74.00

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SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	PRIMARY LOX SEAL DRAIN ORIF U/S PR (PSIA)	PRIMARY LOX SEAL DRAIN ORIF U/S TEMP (DEG R)	PRIMARY LOX SEAL DRAIN FLOWRATE (LB/SEC)	PUMP BRG OVBD DRAIN ORIF U/S PR (PSIA)	PUMP BRG OVBD DRAIN ORIF U/S TEMP (DEG R)	PUMP BRG OVBD DRAIN BRG FLOWRATE (LB/SEC)
9	14.6	355.58	0.0	19.6	496.33	0.1923
10	14.6	349.07	0.0	27.8	487.48	0.2947
11	14.5	346.16	0.0	31.2	467.14	0.3327
12	14.6	345.27	0.0	30.1	445.08	0.3308
13	14.6	343.11	0.0	37.4	430.82	0.3987
14	14.6	341.89	0.0	38.9	399.92	0.4260
15	14.6	342.59	0.0	40.3	397.39	0.4373
16	14.6	340.73	0.0	43.1	380.93	0.4676
17	14.7	339.11	0.0	45.1	365.91	0.4911
18	14.7	337.57	0.0	43.5	361.46	0.4829
19	14.7	334.40	0.0	45.4	345.43	0.5077
20	14.7	332.73	0.0	46.0	317.05	0.5330
21	14.7	330.87	0.0	48.1	325.03	0.5631
22	14.7	327.89	0.0	49.9	309.87	0.5690
23	14.7	326.26	0.0	49.1	281.26	0.5911
24	14.6	325.04	0.0	49.9	295.23	0.5825
25	14.6	323.82	0.0	49.7	293.29	0.5831
26	14.6	321.88	0.0	49.6	278.19	0.5983
27	14.6	320.83	0.0	49.3	283.32	0.5904
28	14.7	318.01	0.0	47.7	256.99	0.6076
29	14.7	313.74	0.0	46.6	268.08	0.5868
30	14.7	311.12	0.0	45.8	282.09	0.5651
31	14.7	310.00	0.0	45.2	282.44	0.5598
32	14.6	309.46	0.0	44.5	290.91	0.5462
33	14.6	308.65	0.0	42.9	291.33	0.5329
34	14.6	307.79	0.0	44.3	291.62	0.5441

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LIQUID OXYGEN TURBOPUMP ASSEMBLY

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P U M P   P R E S S U R E S

TIME SLICE NO	SUPPLY TANK PR (PSIA)	PUMP INLET PR (PSIA)	IMPELLER DISCH PR (PSIA)	BAL PIST CAV PR #2 (PSIA)	PUMP DISCH PR (PSIA)	BAL PIST CAV PR #1 (PSIA)	BAL PIST SUMP PR (PSIA)	BAL PIST RETURN PR (PSIA)	IMPELLER FRONT SHROUD PR (PSIA)
9	260.0	243.7	765.7	519.9	859.4	533.2	355.8	363.3	696.3
10	259.1	244.5	745.2	510.9	852.6	527.4	321.6	363.9	676.5
11	259.5	250.7	602.9	440.6	674.4	452.4	265.7	302.3	555.2
12	260.0	246.8	737.6	511.4	854.4	526.7	323.7	364.2	672.0
13	259.4	242.6	867.4	574.0	1027.9	592.2	371.5	416.7	785.0
14	259.4	243.0	842.5	564.0	995.5	579.0	361.4	406.2	763.5
15	259.5	243.2	838.8	560.1	992.6	577.9	360.3	405.0	759.4
16	259.5	243.5	831.4	556.7	982.9	575.6	356.6	403.0	755.2
17	259.5	242.5	852.2	567.3	1011.3	586.6	365.5	412.4	773.8
18	259.4	242.4	851.8	566.5	1009.5	585.3	364.0	413.3	773.1
19	259.5	243.9	886.4	588.8	1075.8	610.3	378.2	438.0	806.9
20	259.5	244.8	920.8	609.6	1133.0	633.2	382.5	455.5	838.0
21	259.5	245.1	927.7	615.0	1150.4	639.3	396.9	460.4	844.3
22	259.6	246.5	951.6	631.2	1199.8	657.9	408.2	472.6	868.8
23	259.7	247.3	965.1	640.8	1226.6	668.0	413.4	479.4	882.0
24	259.9	248.3	984.3	653.9	1263.8	680.9	421.3	489.1	898.3
25	260.0	248.2	987.4	654.6	1268.5	683.3	422.8	490.5	901.4
26	260.0	248.3	989.1	655.4	1269.8	684.5	423.7	491.0	902.4
27	260.0	245.7	947.4	627.3	1188.0	654.1	405.8	471.3	864.9
28	259.7	242.7	901.1	597.1	1095.5	618.1	384.6	445.9	819.9
29	259.5	240.3	860.7	570.8	1017.2	590.0	367.6	426.5	782.9
30	259.2	239.3	854.4	564.2	1000.1	584.6	364.3	422.5	775.6
31	259.1	239.3	854.1	565.8	1001.0	584.4	364.1	422.8	775.8
32	259.0	238.9	854.9	565.7	1003.1	585.2	365.0	423.2	777.2
33	258.9	238.6	856.6	566.6	1004.6	585.2	365.1	423.2	779.5
34	258.8	238.6	855.0	566.6	1003.5	586.2	364.0	422.9	777.7

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PUMP PRESSURES AND TEMPERATURES

TIME SLICE NO	SPEED RPM	INDUCER DISCH PRESS PSIA	PUMP BRG U/S PRESS PSIA	PUMP BRG D/S PRESS PSIA	PUMP BRG DELTA P PSID	PUMP BRG OVBD TEMP DEG R	PUMP BRG OVBD PRESS PSIA	PUMP BRG SLINGER SUMP TEMP DEG R	PUMP BRG SLINGER SUMP PR PSIA
9	27459.	313.6	383.3	379.5	3.876	177.46	27.1	184.07	42.4
10	26852.	316.6	363.9	359.1	4.761	181.68	33.9	184.49	43.3
11	22516.	300.5	302.3	296.8	5.515	184.46	38.2	183.27	41.3
12	24291.	326.2	364.2	360.0	4.170	186.01	40.8	183.21	45.5
13	29609.	349.4	416.7	410.7	5.962	188.23	45.9	185.68	51.1
14	29037.	344.8	406.2	401.4	4.834	190.23	49.2	186.49	53.2
15	28972.	344.5	405.0	399.4	5.581	191.84	51.1	187.00	53.8
16	28768.	343.1	403.0	397.6	5.439	192.20	52.7	187.82	56.4
17	29301.	347.2	412.4	407.8	4.591	193.00	54.9	188.40	59.8
18	29285.	346.4	413.3	409.7	3.606	193.78	55.5	188.88	60.2
19	29851.	365.1	438.0	436.1	1.904	194.32	57.6	189.43	61.0
20	30497.	379.2	455.5	452.6	2.909	195.17	59.2	189.97	63.5
21	30609.	384.2	460.4	457.5	2.880	195.46	60.4	190.24	65.2
22	30988.	398.7	472.6	470.9	1.683	195.88	61.0	190.59	66.2
23	31199.	407.2	479.4	477.1	2.211	196.38	61.9	190.92	67.1
24	31441.	419.8	489.1	487.2	1.936	196.29	62.5	191.04	67.4
25	31530.	420.7	490.5	487.6	2.886	196.54	62.7	191.29	67.4
26	31550.	421.1	491.0	487.8	3.177	196.62	63.1	191.40	67.4
27	30960.	393.8	471.3	468.7	2.647	196.74	62.9	191.36	67.4
28	30217.	367.4	445.9	443.1	2.769	196.55	62.1	190.94	67.0
29	29662.	343.8	426.5	423.6	2.767	196.38	61.4	190.57	65.2
30	29584.	337.7	422.5	418.3	4.139	195.75	60.2	190.14	63.4
31	29590.	337.4	422.8	418.8	4.041	195.52	59.7	189.86	62.8
32	29629.	337.8	423.2	420.0	3.154	195.26	58.7	189.70	62.0
33	29679.	338.2	423.2	419.6	3.628	195.17	58.6	189.52	62.0
34	29672.	337.2	422.9	419.4	3.509	195.17	58.3	189.44	61.3

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P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S (CONTINUED)

TIME SLICE NO	BAL PIST RECIRC U/S ORIF PR PSIA	BAL PIST RECIRC U/S ORIF TEMP DEG R	BAL PIST RECICR DELTA P PSI	BAL PIST FLOW LB/SEC	BAL PIST FLOW TEMP RISE DEG R
9	288.2	179.7	49.33	1.467	-6.48
10	272.9	179.6	44.46	1.393	-6.41
11	216.7	178.6	30.99	1.152	-5.49
12	264.5	179.3	42.22	1.357	-6.19
13	314.6	181.0	54.78	1.543	-8.03
14	306.1	180.6	52.47	1.511	-7.67
15	305.7	180.6	52.24	1.508	-7.72
16	302.6	180.5	51.53	1.498	-7.52
17	309.9	180.8	53.38	1.524	-7.85
18	310.0	180.9	53.34	1.523	-7.93
19	321.4	181.1	56.33	1.565	-8.13
20	333.4	181.6	59.43	1.606	-8.61
21	336.9	181.7	60.18	1.616	-8.64
22	346.5	182.0	62.62	1.648	-9.07
23	350.7	182.2	63.86	1.664	-9.16
24	358.1	182.5	65.62	1.686	-9.47
25	359.5	182.6	65.79	1.688	-9.51
26	360.5	182.6	65.85	1.689	-9.53
27	344.7	182.2	62.00	1.640	-9.15
28	327.9	181.6	57.38	1.579	-8.58
29	312.5	181.1	53.47	1.525	-8.01
30	310.2	181.0	52.79	1.515	-8.00
31	310.3	181.0	52.73	1.514	-8.06
32	310.5	181.0	52.90	1.516	-8.02
33	310.4	181.0	52.97	1.518	-8.03
34	310.4	181.0	52.77	1.515	-8.02

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P U M P   P R E S S U R E S   A N D   T E M P E R A T U R E S

TIME SLICE NO	PUMP INLET TEMP (DEG R)	PUMP DISCH TEMP (DEG R)	BAL PIST RETURN TEMP (DEG R)	PUMP DISCH VENT U/S TEMP (DEG R)	PUMP DISCH VENT U/S PR (PSIA)	PUMP DISCH VENT DELTA PR (PSI)	HP (TEMP)
9	173.23	177.13	0.0	176.46	775.3	10.23	54.27
10	173.15	176.88	0.0	176.95	818.8	9.80	58.41
11	173.13	176.02	0.0	176.52	709.4	6.67	67.29
12	173.08	176.75	0.0	176.56	804.9	7.57	63.29
13	173.00	177.60	0.0	177.41	1015.7	9.16	74.62
14	172.96	177.32	0.0	177.37	980.1	8.82	69.59
15	172.93	177.29	0.0	177.37	980.7	8.59	68.66
16	173.03	177.27	0.0	177.34	966.3	8.49	76.08
17	172.97	177.39	0.0	177.40	991.0	8.65	70.26
18	172.94	177.38	0.0	177.43	994.4	8.69	70.54
19	173.01	177.60	0.0	177.67	1048.3	7.94	71.56
20	173.03	177.83	0.0	177.78	1117.7	7.81	75.10
21	173.05	177.93	0.0	177.90	1132.0	7.40	74.60
22	172.97	178.01	0.0	178.15	1180.5	6.89	75.45
23	173.09	178.17	0.0	178.20	1211.8	6.67	75.61
24	173.03	178.42	0.0	178.46	1245.3	6.18	76.02
25	173.08	178.42	0.0	178.48	1256.6	6.18	76.69
26	173.07	178.42	0.0	178.52	1256.8	6.15	76.58
27	173.06	178.14	0.0	178.29	1192.0	7.61	75.95
28	172.99	177.83	0.0	178.08	1085.6	7.91	74.47
29	173.07	177.60	0.0	177.70	1009.3	8.89	72.47
30	173.03	177.60	0.0	177.67	981.7	9.09	73.03
31	172.97	177.60	0.0	177.67	982.7	9.01	73.38
32	173.01	177.60	0.0	177.67	985.4	9.12	73.42
33	173.00	177.60	0.0	177.67	986.5	9.10	73.53
34	173.00	177.60	0.0	177.67	985.7	9.18	73.72

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C A L C U L A T E D   P U M P   P A R A M E T E R S

TIME SLICE NO	TEST SPEED (RPM)	PUMP FLOW GPM	PUMP FLOW (LB/SEC)	HEAD FT	PRESS RISE (PSI)	FLUID HP (HP)	TURB HP (HP)	EFF (%)	ISEN EFF (%)	SPECIFIC SPEED
9	27439.	107.04	16.5893	1296.3	615.7	39.1	51.69	75.67	60.83	1314.
10	26852.	100.47	15.5620	1277.4	608.0	36.1	50.96	70.95	61.87	1260.
11	22516.	86.50	13.3899	891.3	423.8	21.7	44.65	48.62	58.18	1284.
12	26291.	92.07	14.2728	1273.1	607.6	33.0	50.58	65.61	62.00	1184.
13	29609.	101.21	15.7065	1643.6	785.3	46.9	66.98	70.11	62.90	1154.
14	29037.	99.36	15.4119	1574.7	752.5	44.1	65.46	67.43	63.40	1158.
15	28972.	98.07	15.2122	1567.8	749.4	43.4	65.01	66.73	63.15	1152.
16	28768.	97.51	15.1240	1547.2	739.4	42.5	64.45	66.03	63.60	1152.
17	29301.	98.42	15.2676	1608.2	768.8	44.6	66.61	67.05	63.54	1145.
18	29285.	98.60	15.2954	1604.6	767.1	44.6	67.11	66.52	63.26	1147.
19	29851.	94.24	14.6227	1736.7	831.9	46.2	67.87	68.06	64.53	1077.
20	30497.	93.47	14.5137	1854.4	889.0	48.9	69.14	70.81	65.09	1043.
21	30609.	91.00	14.1298	1887.2	905.3	48.5	68.67	70.63	64.98	1020.
22	30988.	87.80	13.6339	1984.6	953.3	49.2	69.90	70.41	65.21	977.
23	31199.	86.36	13.4151	2038.1	979.3	49.7	69.72	71.33	65.74	956.
24	31461.	83.13	12.9119	2111.9	1015.5	49.6	69.87	70.98	64.45	921.
25	31530.	83.13	12.9126	2121.9	1020.3	49.8	70.28	70.91	64.96	919.
26	31550.	82.92	12.8797	2124.2	1021.5	49.7	70.41	70.68	64.96	918.
27	30960.	88.56	13.7499	1962.9	942.3	49.1	68.83	71.32	64.61	988.
28	30217.	94.08	14.5914	1780.2	852.8	47.2	68.07	69.41	63.42	1069.
29	29662.	99.76	15.4681	1626.0	776.9	45.7	67.57	67.71	63.10	1157.
30	29584.	100.98	15.6396	1593.2	760.8	45.3	67.19	67.45	62.03	1178.
31	29590.	100.47	15.5737	1594.7	761.7	45.2	66.58	67.85	61.54	1175.
32	29629.	101.07	15.6667	1600.3	764.2	45.6	66.71	68.36	62.08	1177.
33	29679.	100.95	15.6491	1603.8	766.0	45.6	67.61	67.53	62.06	1177.
34	29672.	101.38	15.7155	1601.7	764.8	45.8	67.04	68.29	62.88	1180.

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CALCULATED PUMP PARAMETERS

TIME SLICE NO	TEST SPEED (RPM)	NPSH (FT)	SUCTION SPECIFIC SPEED	INLET FLOW COEFF	HEAD COEFF	PUMP DELTA T (DEG R)	(Q/N) OVER (Q/N)DES	BAL PIST K	FR SHRD K
9	27439.	453.21	2890.16	0.09916	0.44746	3.90	1.1771	0.1801	0.6007
10	26852.	454.44	2734.54	0.09510	0.46042	3.73	1.1289	0.2053	0.6110
11	22516.	466.18	2087.27	0.09764	0.45690	2.88	1.1591	0.2062	0.6087
12	26291.	458.44	2546.29	0.08902	0.47869	3.67	1.0567	0.2017	0.6096
13	29609.	450.36	3047.01	0.08688	0.48723	4.60	1.0314	0.1947	0.6068
14	29037.	451.11	2956.97	0.08697	0.48537	4.35	1.0324	0.1811	0.6056
15	28972.	451.40	2929.69	0.08604	0.48542	4.35	1.0213	0.1974	0.6085
16	28768.	451.94	2898.23	0.08616	0.48585	4.25	1.0227	0.2043	0.6006
17	29301.	449.91	2975.66	0.08537	0.48680	4.42	1.0134	0.2027	0.5981
18	29285.	449.68	2977.94	0.08558	0.48624	4.44	1.0159	0.2007	0.5994
19	29851.	452.68	2952.86	0.08024	0.50652	4.59	0.9525	0.2099	0.5912
20	30497.	454.59	2994.79	0.07790	0.51819	4.80	0.9247	0.2159	0.5904
21	30609.	454.97	2963.96	0.07557	0.52350	4.87	0.8970	0.2181	0.5906
22	30988.	457.71	2934.22	0.07201	0.53714	5.04	0.8549	0.2257	0.5810
23	31199.	459.44	2921.56	0.07035	0.54419	5.08	0.8352	0.2264	0.5785
24	31461.	461.27	2881.96	0.06716	0.55451	5.39	0.7972	0.2237	0.5832
25	31530.	460.97	2889.54	0.06701	0.55471	5.34	0.7955	0.2302	0.5822
26	31550.	461.22	2886.64	0.06680	0.55462	5.34	0.7930	0.2316	0.5841
27	30960.	456.06	2952.22	0.07271	0.53223	5.08	0.8631	0.2263	0.5807
28	30217.	450.20	2998.82	0.07914	0.50669	4.84	0.9394	0.2054	0.5900
29	29662.	445.61	3054.65	0.08548	0.48028	4.53	1.0147	0.1999	0.5886
30	29584.	443.60	3074.33	0.08669	0.47310	4.58	1.0290	0.2068	0.5936
31	29590.	443.47	3069.13	0.08630	0.47335	4.64	1.0245	0.1974	0.5919
32	29629.	442.68	3086.42	0.08670	0.47375	4.59	1.0292	0.2016	0.5889
33	29679.	442.07	3093.08	0.08645	0.47321	4.60	1.0263	0.1966	0.5857
34	29672.	442.22	3098.15	0.08684	0.47277	4.60	1.0309	0.2018	0.5866

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SCALED TO TARGET SPEED = 30000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
9	117.03	18.13761	1549.54	735.99	84.00	541.76
10	112.24	17.38618	1594.43	758.94	81.46	567.23
11	115.25	17.84044	1582.23	752.27	80.21	527.58
12	105.07	16.28651	1657.70	791.15	79.17	596.93
13	102.55	15.91384	1687.27	806.19	77.61	462.33
14	102.65	15.92295	1680.84	803.18	76.75	481.52
15	101.55	15.75197	1681.02	803.51	76.24	484.00
16	101.69	15.77162	1682.51	804.07	75.86	491.48
17	100.76	15.63168	1685.78	805.92	75.41	471.62
18	101.01	15.66845	1683.86	804.99	75.84	471.89
19	94.71	14.69555	1754.08	840.19	72.63	457.20
20	91.95	14.27735	1794.49	860.31	71.56	439.91
21	89.19	13.84835	1812.88	869.64	70.24	437.06
22	85.00	13.19922	1860.11	893.48	68.46	428.99
23	83.04	12.89964	1884.53	905.47	67.23	424.81
24	79.27	12.31224	1920.26	923.37	66.69	419.42
25	79.69	12.28610	1920.97	923.71	66.06	417.33
26	78.85	12.24702	1920.64	923.60	65.84	417.02
27	85.81	13.32372	1843.11	884.81	69.10	428.22
28	93.40	14.48639	1754.66	840.59	72.87	443.75
29	100.89	15.64413	1663.21	794.71	74.97	455.81
30	102.32	15.85964	1638.35	782.37	76.16	456.17
31	101.86	15.78964	1639.20	782.93	76.47	455.85
32	102.33	15.86288	1640.60	783.48	76.21	453.83
33	102.04	15.81826	1638.71	782.64	75.94	451.68
34	102.50	15.88903	1637.22	781.82	76.18	452.04

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
9	273.08	42.32110	8436.41	4007.07	1067.12	2049.57
10	261.90	40.56774	8680.80	4132.01	1034.83	3088.26
11	268.91	41.62770	8614.38	4095.67	1120.41	4505.73
12	245.15	38.00186	9025.26	4307.35	1005.81	3249.96
13	239.28	37.13228	9186.25	4389.24	985.97	2517.14
14	239.52	37.15356	9151.21	4372.86	974.98	2621.59
15	236.95	36.75461	9152.22	4374.69	968.48	2635.13
16	237.28	36.80046	9160.32	4377.70	963.71	2675.02
17	235.12	36.47392	9178.11	4387.79	957.94	2567.69
18	235.68	36.56018	9167.69	4382.74	963.39	2569.18
19	220.99	34.28961	9550.01	4574.34	922.72	2489.18
20	214.54	33.31381	9770.02	4683.09	909.13	2395.05
21	208.11	32.31282	9870.14	4734.69	892.34	2379.56
22	198.33	30.79819	10127.24	4864.52	869.69	2335.61
23	193.76	30.09915	10260.24	4929.76	854.06	2312.87
24	184.96	28.72855	10454.77	5027.24	847.25	2283.49
25	184.55	28.66756	10458.64	5029.11	839.21	2272.13
26	183.98	28.57637	10456.83	5028.49	836.38	2270.47
27	200.23	31.08868	10034.70	4817.31	877.89	2331.45
28	217.94	33.80157	9553.17	4576.55	925.75	2415.47
29	235.41	36.50296	9055.25	4326.73	952.45	2481.62
30	238.74	37.00582	8919.91	4259.56	967.50	2483.58
31	237.68	36.84250	8924.52	4262.60	971.47	2481.85
32	238.77	37.01338	8932.15	4265.62	968.21	2470.87
33	238.10	36.90927	8921.89	4261.05	964.76	2459.12
34	239.16	37.07441	8913.74	4256.60	967.83	2461.08

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

SCALED TO TARGET SPEED = 30000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
9	83.54	0.0
10	89.89	0.0
11	88.44	0.0
12	103.39	0.0
13	109.61	0.0
14	108.57	0.0
15	108.61	0.0
16	108.36	0.0
17	109.75	0.0
18	109.18	0.0
19	122.43	0.0
20	130.06	0.0
21	133.64	0.0
22	142.58	0.0
23	147.82	0.0
24	155.95	0.0
25	156.19	0.0
26	156.27	0.0
27	139.10	0.0
28	122.85	0.0
29	105.89	0.0
30	101.19	0.0
31	100.82	0.0
32	101.38	0.0
33	101.74	0.0
34	100.77	0.0

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 3
TEST DATE 4-13-81

PROCESSING DATE 4-15-81
TEST DURATION, SEC 74.00

SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
9	454.82	0.0
10	489.37	0.0
11	481.52	0.0
12	562.92	0.0
13	596.74	0.0
14	591.09	0.0
15	591.33	0.0
16	589.98	0.0
17	597.55	0.0
18	594.43	0.0
19	666.57	0.0
20	708.09	0.0
21	727.58	0.0
22	776.24	0.0
23	804.77	0.0
24	849.06	0.0
25	850.39	0.0
26	850.79	0.0
27	757.31	0.0
28	668.85	0.0
29	576.53	0.0
30	550.94	0.0
31	548.89	0.0
32	551.97	0.0
33	553.90	0.0
34	548.66	0.0

MK40

LIQUID CXYGEN TURBOPUMP ASSEMBLY

PA___ 6

APPENDIX C
TEST 6

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.0

COMMENTS . . .

BALANCE PISTON DRAIN OVERBOARD WITH RECIRCULATION AT TARGET 67000 RPM.
BALANCE PISTON FLOW VDI ORIFICE ACTUAL DIA=0.3 IN.
AVERAGE OF PRE AND POST CALIBRATICNS FOR PID 063,PUMP VENTURI DELTA PRES

AMBIENT PRESSURE		13.8000
LO2 VENTURI (GG) P/N V160248-SGR S/N 8871	UPSTREAM DIAMETER	0.9570
	THROAT DIAMETER	0.2480
	THROAT CD	0.9850
GH2 VENTURI (TURB) P/N VP031200-SGR S/N 9731	UPSTREAM DIAMETER	2.3000
	THROAT DIAMETER	1.3085
	THRCAT CD	0.9873
LH2 VENTURI (GG) P/N V320471-SGR S/N 8873	UPSTREAM DIAMETER	1.6890
	THROAT DIAMETER	0.4710
	THROAT CD	0.9765
LOX VENTURI (PUMP DISCH) P/N V321059-SGR S/N 8877	UPSTREAM DIAMETER	1.6890
	THROAT DIAMETER	1.0590
	THRCAT CD	0.9820
	BAL PIST OVBD CONTROL ORIFICE	0.3000
	BAL PIST OVBD ORIFICE	0.2636
	BRG FLOW DRAIN ORIFICE	0.7500
	TURBINE EFFECTIVE AREA	0.2319
	TURBINE EXHAUST ORIFICE	0.6600
	PRIMARY H.G. DRAIN ORIFICE	0.6550
	SEC. H.G. DRAIN ORIFICE	0.6000
	REAR BRG COOLANT ORIFICE	0.1800
	INTERMEDIATE SEAL PURGE ORIFICE	0.1260

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MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

GASEOUS HYDROGEN TURBINE DRIVE PARAMETERS

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	VENTURI U/S PR (PSIA)	VENTURI U/S TEMP (DEG R)	VENTURI DELTA PR (PSID)	SPIN VALVE PCSN	SPIN VALVE U/S PR (PSIA)	SPIN VALVE DELTA P (PSID)	TURB GH2 FLOW (LB/SEC)	SPEED (RPM)
1	83.573	84.241	4750.2	546.4	0.34	5.275	4755.4	4238.403	0.63851	30293.
2	90.565	91.253	4701.7	547.4	0.34	5.275	4706.2	4193.280	0.63522	29462.
5	111.578	112.246	4567.1	548.9	0.40	5.657	4571.7	4026.033	0.67351	30376.
6	116.569	117.237	4460.2	550.3	13.19	28.704	4434.4	1264.950	3.83490	68144.
7	121.465	121.733	4301.6	549.9	13.16	29.590	4276.8	1156.597	3.77474	67860.
8	125.560	126.228	4147.5	548.9	13.44	31.030	4120.2	1020.559	3.76080	67870.
9	126.551	127.259	4112.4	548.6	13.50	31.363	4085.5	991.606	3.75648	67554.
10	127.581	128.249	4079.3	548.2	13.64	31.870	4052.0	954.341	3.76388	67216.
11	128.571	129.239	4045.6	548.0	13.81	32.396	4018.4	913.716	3.77450	67096.
12	129.561	130.229	4012.5	547.9	13.80	32.671	3985.9	890.684	3.76128	66850.
13	130.552	131.260	3978.4	547.4	13.89	33.090	3951.2	862.815	3.76100	66887.
14	131.562	132.250	3945.7	547.1	13.96	33.650	3918.7	827.228	3.75897	67201.
15	132.572	133.240	3913.0	546.9	14.03	34.305	3886.4	797.374	3.75477	67328.
16	133.562	134.230	3880.6	546.8	14.18	34.643	3852.8	760.505	3.76180	67428.
17	134.593	135.261	3847.6	546.3	14.30	35.440	3820.0	727.984	3.76656	67462.
18	135.583	136.251	3815.5	546.2	14.40	35.991	3787.2	696.550	3.76685	67039.
19	136.572	137.241	3783.9	545.7	14.50	36.778	3755.4	664.717	3.76749	66960.
20	137.562	138.230	3751.4	545.4	14.56	37.530	3724.0	637.530	3.76322	67196.
21	138.593	139.220	3719.5	545.2	14.62	38.077	3692.5	608.513	3.75742	67583.
22	139.583	140.251	3687.6	544.6	14.75	39.025	3658.2	573.674	3.76194	68034.
23	140.573	141.241	3656.8	544.4	14.83	39.745	3628.4	548.261	3.76014	68607.
24	141.963	142.231	3625.5	543.9	14.88	40.718	3594.8	515.742	3.75442	68916.
25	142.554	143.221	3594.0	543.5	15.05	41.858	3563.8	482.276	3.76342	69272.
26	143.584	144.252	3562.3	543.2	15.13	42.882	3534.8	459.480	3.75928	69216.
27	144.574	145.242	3532.7	542.7	15.22	44.190	3502.8	427.944	3.75845	69187.
28	145.564	146.232	3503.9	542.4	15.24	44.780	3474.0	411.921	3.74898	69134.
29	146.555	147.222	3473.7	542.0	15.04	44.351	3445.7	414.135	3.71282	69106.
30	147.565	148.253	3444.5	541.6	14.88	44.312	3416.0	413.091	3.68064	68997.
31	[illegible]	149.243	3416.1	541.2	14.93	[illegible]	3387.4	388.268	3.67460	[illegible]
32	149.564	150.233	3387.6	540.9	15.02	46.725	3358.7	363.939	3.67381	69161.

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.0

T U R B I N E   P A R A M E T E R S

TIME SLICE NO	BEGIN TIME (SEC)	END TIME (SEC)	SPEED (RPM)	TURB INLET STAT PR (PSIA)	TURB INLET TOT PR (PSIA)	TURB INLET TOT TEMP (DEG R)	TURB NOZZ D/S PR (PSIA)	TURB EXH STAT PR (PSIA)	TURB EXH TOT PR (PSIA)	TURB EXH TOT TEMP (DEG R)	TURB DS ORIFIC DELTA (PSID)
1	83.973	84.241	30293.	514.1	516.4	564.4	348.0	353.0	349.4	452.1	338.8
2	90.985	91.253	29467.	502.5	512.3	566.6	348.6	353.1	349.9	463.0	338.5
5	111.978	112.246	30376.	552.9	546.0	567.3	369.0	374.8	371.9	469.1	362.4
6	116.969	117.237	68144.	3137.5	3166.4	555.7	1923.2	1934.1	1957.3	502.6	1923.9
7	121.465	121.733	67860.	3085.8	3111.9	555.5	1891.3	1906.8	1925.5	502.0	1893.6
8	125.960	126.228	67870.	3069.9	3091.1	554.4	1878.9	1895.8	1913.9	500.7	1882.9
9	126.991	127.259	67554.	3064.3	3086.6	554.2	1877.1	1893.4	1911.4	500.5	1880.8
10	127.981	128.249	67216.	3068.9	3089.4	554.0	1879.5	1895.6	1913.9	500.3	1882.6
11	128.971	129.239	67096.	3072.5	3096.6	553.4	1884.1	1899.9	1918.4	499.9	1887.0
12	129.961	130.229	66850.	3072.9	3087.8	553.0	1880.4	1895.4	1914.4	499.9	1883.4
13	130.992	131.260	66887.	3055.4	3080.2	552.8	1875.3	1891.1	1909.5	499.5	1877.7
14	131.982	132.250	67201.	3066.9	3083.6	552.5	1876.9	1892.7	1910.9	499.1	1880.1
15	132.972	133.240	67328.	3062.5	3081.1	552.0	1874.9	1890.7	1909.3	498.8	1878.2
16	133.962	134.230	67428.	3066.9	3084.6	551.9	1876.9	1892.7	1911.4	498.3	1879.8
17	134.993	135.261	67462.	3060.5	3084.9	551.3	1876.9	1892.5	1911.4	498.1	1880.1
18	135.983	136.251	67039.	3061.7	3082.6	551.1	1876.8	1892.0	1910.8	497.5	1879.8
19	136.972	137.241	66960.	3064.9	3082.7	550.8	1876.6	1892.5	1910.9	497.2	1880.1
20	137.962	138.230	67196.	3059.9	3078.8	550.5	1873.8	1889.6	1908.2	[illegible]7.0	1878.9
21	138.953	139.220	67583.	3060.1	3075.2	549.8	1871.2	1887.1	1905.7	496.6	1874.8
22	139.983	140.251	68034.	3057.0	3076.4	549.7	1871.6	1887.7	1905.8	496.0	1874.6
23	140.973	141.241	68607.	3057.4	3072.7	549.0	1869.3	1885.2	1903.8	495.7	1872.6
24	141.963	142.231	68916.	3049.6	3070.4	548.5	1868.2	1883.4	1902.2	495.0	1871.4
25	142.994	143.221	69272.	3058.9	3074.9	548.4	1869.9	1886.1	1904.4	494.7	1872.6
26	143.984	144.2[illegible]2	69216.	3045.0	3068.4	547.6	1866.8	1881.9	1900.5	494.4	1869.4
27	144.974	145.242	69187.	3052.0	3067.7	547.5	1867.0	1881.9	1900.1	494.1	1868.9
28	145.964	146.232	69134.	3028.7	3054.9	546.9	1858.6	1874.1	1892.6	493.5	1861.8
29	146.995	147.222	69106.	3003.2	3023.7	546.4	1840.6	1854.7	1873.8	493.4	1842.6
30	147.985	148.253	68997.	2972.4	2995.7	546.2	1823.4	1838.5	1857.0	492.7	1825.8
31	148.975	149.243	69072.	2972.4	2992.0	546.2	1820.5	1836.9	1854.2	492.6	1822.2
32	149.[illegible]	150.233	69161.	2953.7	2987.9	[illegible]5.4	1817.8	1833.0	1850.6	492.1	1818.6

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MK48-D
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

228

T U R B I N E   P A R A M E T E R S (CONTINUED)

TIME SLICE NO	SPEED RPM	FLOW (LB/SEC)	PR RATIO (T-S)	BHP (CALIB) (HP)	BHP (DELTA T) (HP)	TORQUE (FT-LB)	U/C (T-S)	EFF (T-S)	TURB NOZ IN TOT P (PSIA)
1	30253.	0.6385	1.4338	67.9	360.4	11.77	0.1999	38.95	506.1
2	29462.	0.6352	1.4220	65.5	330.4	11.68	0.1962	38.48	502.1
5	30376.	0.6735	1.4274	71.4	332.1	12.35	0.2010	39.10	535.0
6	68144.	3.8349	1.6044	714.9	1048.7	55.08	0.3908	51.60	3103.1
7	67860.	3.7747	1.5993	698.7	1038.3	54.06	0.3905	51.60	3049.7
8	67870.	3.7608	1.5979	693.5	1037.5	53.65	0.3913	51.59	3029.3
9	67554.	3.7565	1.5976	692.5	1038.1	53.82	0.3896	51.61	3024.8
10	67216.	3.7639	1.5972	693.5	1038.8	54.17	0.3878	51.63	3027.6
11	[illegible]	3.7745	1.5973	695.1	1040.5	54.39	0.3873	51.63	3034.6
12	66850.	3.7613	1.5965	691.6	1029.9	54.31	0.3862	51.64	3026.0
13	66887.	3.7610	1.5962	691.0	1032.3	54.24	0.3865	51.64	3018.6
14	67201.	3.7590	1.5966	690.4	1033.8	53.94	0.3883	51.62	3021.9
15	67328.	3.7548	1.5971	689.5	1030.3	53.76	0.3891	51.61	3019.5
16	67428.	3.7618	1.5971	690.6	1037.2	53.77	0.3897	51.61	3022.9
17	67462.	3.7666	1.5975	691.2	1033.4	53.79	0.3900	51.61	3023.2
18	67039.	3.7669	1.5967	690.5	1038.9	54.08	0.3878	51.63	3021.0
19	66560.	3.7675	1.5963	690.0	1040.1	54.10	0.3875	51.63	3021.1
20	67156.	3.7632	1.5967	689.1	1035.7	53.84	0.3889	51.62	3017.2
21	67583.	3.7574	1.5970	687.2	1029.6	53.38	0.3913	51.59	3013.7
22	68034.	3.7619	1.5971	687.6	1041.4	53.06	0.3939	51.56	3014.9
23	68607.	3.7601	1.5973	686.0	1033.7	52.49	0.3974	51.50	3011.3
24	68916.	3.7544	1.5977	684.3	1035.2	52.13	0.3992	51.47	3009.0
25	69272.	3.7634	1.5977	685.3	1041.5	51.94	0.4013	51.43	3013.4
26	69216.	3.7593	1.5979	683.9	1031.9	51.87	0.4012	51.43	3007.0
27	69187.	3.7585	1.5975	683.3	1036.3	51.85	0.4011	51.43	3006.3
28	69134.	3.7490	1.5975	680.8	1030.9	51.70	0.4011	51.43	2993.8
29	69106.	3.7128	1.5977	673.8	1015.9	51.19	0.4010	51.43	2963.2
30	68957.	3.6806	1.5969	666.9	1014.7	50.75	0.4007	51.44	2935.8
31	69072.	3.6746	1.5971	665.9	1015.9	50.61	0.4011	51.43	2932.2
32	[illegible]61.	3.6738	1.5974	665.0	[illegible].7	50.48	0.4018	51.42	[illegible]28.1

PK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

TURBINE PARAMETERS (CONTINUED)

TIME SLICE NO	SPEED RPM	AVAIL. ENERGY(T-S) (BTU/LB)	GAMMA	CP (BTU/LBM-R)	SPEED PARA-METER	FLOW PARA-METER	TORQUE PARA-METER	TURB WHEEL EXH PRESS PSIA
1	30293.	192.91	1.3907	3.5502	216.4	3.5793	0.0213	352.4
2	29462.	189.41	1.3909	3.5482	210.1	3.5961	0.0213	352.5
5	30376.	191.71	1.3911	3.5489	216.5	3.5802	0.0212	374.6
6	68144.	255.34	1.3999	3.6370	490.6	3.4789	0.0163	1976.8
7	67860.	253.52	1.3999	3.6361	488.7	3.4834	0.0163	1944.4
8	67670.	252.61	1.3998	3.6369	489.3	3.4904	0.0162	1931.3
9	67554.	252.41	1.3998	3.6370	487.1	3.4909	0.0163	1929.6
10	67216.	252.22	1.3998	3.6373	484.7	3.4939	0.0164	1932.0
11	67096.	252.06	1.3998	3.6380	484.1	3.4939	0.0164	1936.3
12	66850.	251.65	1.3998	3.6383	482.5	3.4905	0.0165	1932.4
13	66887.	251.46	1.3998	3.6383	482.8	3.4981	0.0165	1927.9
14	67201.	251.47	1.3998	3.6388	485.3	3.4913	0.0164	1929.4
15	67328.	251.43	1.3998	3.6392	486.4	3.4888	0.0163	1927.3
16	67428.	251.39	1.3998	3.6395	487.2	3.4908	0.0163	1929.4
17	67462.	251.30	1.3997	3.6401	487.6	3.4933	0.0163	1929.6
18	67039.	250.94	1.3997	3.6404	484.7	3.4953	0.0164	1929.2
19	66960.	250.70	1.3997	3.6407	484.3	3.4947	0.0164	1929.4
20	67196.	250.71	1.3997	3.6410	486.1	3.4943	0.0164	1925.9
21	67563.	250.52	1.3997	3.6417	489.2	3.4908	0.0163	1923.3
22	68034.	250.53	1.3997	3.6418	492.5	3.4934	0.0161	1923.3
23	68607.	250.32	1.3997	3.6425	497.0	3.4937	0.0160	1920.8
24	68516.	250.25	1.3997	3.6430	499.4	3.4894	0.0159	1919.9
25	69212.	250.22	1.3997	3.6432	502.1	3.4923	0.0158	1921.3
26	69216.	249.97	1.3997	3.6440	502.0	3.4935	0.0158	1918.0
27	69187.	249.81	1.3997	3.6441	501.9	3.4932	0.0158	1918.0
28	69134.	249.50	1.3996	3.6447	501.8	3.4967	0.0158	1909.9
29	69106.	249.35	1.3995	3.6445	501.8	3.4974	0.0158	1891.3
30	68557.	248.93	1.3995	3.6441	501.1	3.4988	0.0159	1873.9
31	69072.	248.98	1.3995	3.6441	501.6	3.4972	0.0158	1870.9
32	[illegible]61.	248.77	1.3995	3.64[illegible]	502.6	3.4988	0.0158	[illegible]7.7

PK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

SEAL AND BEARING DATA

TIME SLICE NO	PRIM LOX SEAL DR PR (PSIA)	PRIM LOX SEAL DR TEMP (DEG R)	I/S PURGE PR (PSIA)	I/S PURGE TEMP (DEG R)	PRIM HG SEAL ORIF U/S PR (PSIA)	PRIM HG SEAL ORIF U/S TEMP (DEG R)	PRIM HG SEAL DR FLOW (LB/SEC)	SEC HG SEAL DR PR (PSIA)	SEC HG SEAL DR TEMP (DEG R)	SEC HG SEAL ORIF U/S PR (PSIA)	SEC HG SEAL ORI U/S TEMP (DEG R)
1	14.39	264.55	217.50	557.18	18.97	345.18	0.0560	18.5	390.14	14.06	414.28
2	14.38	287.13	216.12	557.24	18.97	274.37	0.0625	18.0	342.84	14.08	341.54
5	14.45	302.99	213.12	557.98	18.85	220.18	0.0688	18.3	309.00	14.08	300.97
6	14.48	316.73	219.15	557.99	25.75	301.36	0.0846	44.4	385.53	16.02	351.91
7	14.44	337.39	217.41	557.73	29.18	375.15	0.0865	38.9	412.60	15.35	397.57
8	14.45	352.59	217.83	557.47	28.68	390.91	0.0834	37.7	418.44	15.23	406.54
9	14.45	355.31	217.74	557.47	28.58	392.28	0.0830	36.9	419.37	15.17	407.57
10	14.43	357.35	217.98	557.47	27.81	393.59	0.0806	37.5	419.55	15.23	407.57
11	14.40	359.63	218.07	557.51	27.37	394.16	0.0793	37.1	419.37	15.19	407.57
12	14.37	361.90	217.92	557.63	27.02	394.64	0.0782	35.4	420.05	15.07	407.95
13	14.36	364.34	218.47	557.68	26.68	396.00	0.0771	36.9	420.51	15.16	409.04
14	14.35	366.80	218.05	557.65	27.06	396.77	0.0782	34.0	421.87	14.92	409.87
15	14.33	368.89	218.36	557.68	26.96	397.23	0.0778	35.3	422.36	15.02	410.81
16	14.34	371.02	218.52	557.66	26.85	398.17	0.0774	35.0	422.61	15.02	410.86
17	14.35	373.22	218.81	557.61	26.46	398.77	0.0762	35.4	422.47	15.05	410.61
18	14.37	375.04	218.99	557.49	26.71	399.80	0.0769	35.4	422.99	15.06	410.91
19	14.40	376.67	219.06	557.50	26.71	400.36	0.0768	35.0	423.71	15.02	411.74
20	14.45	378.51	219.32	557.56	26.92	401.18	0.0774	35.4	424.01	15.07	411.89
21	14.45	380.22	219.32	557.59	27.37	401.20	0.0787	33.6	423.78	14.95	412.33
22	14.46	381.60	219.56	557.62	27.29	403.23	0.0785	33.6	422.67	14.92	412.16
23	14.47	383.09	219.83	557.63	27.06	398.86	0.0780	32.8	422.45	14.86	412.01
24	14.49	384.38	219.98	557.65	27.06	397.14	0.0781	32.3	421.81	14.82	411.62
25	14.50	385.60	220.06	557.65	27.06	395.90	0.0782	31.8	421.85	14.78	411.70
26	14.51	386.71	220.04	557.67	27.06	394.77	0.0783	31.7	422.33	14.79	411.80
27	14.48	387.67	220.10	557.77	27.06	394.61	0.0784	31.3	422.35	14.76	411.92
28	14.50	388.94	220.15	557.92	27.06	394.35	0.0784	31.1	422.52	14.75	412.17
29	14.45	390.30	220.20	557.98	26.99	394.06	0.0782	30.4	422.62	14.70	412.62
30	14.49	391.72	220.28	558.01	27.00	393.46	0.0783	30.2	422.35	14.68	412.62
31	[illegible]	393.08	220.55	558.15	27.06	[illegible]	0.0785	30.7	422.38	14.70	[illegible]
32	14.53	394.19	220.58	558.33	27.06	393.13	0.0785	30.5	423.02	14.68	412.62

ORIGINAL PAGE IS
OF POOR QUALITY

PK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

SEAL AND BEARING DATA (CONTINUED)

TIME SLICE NO	SEC HG SEAL PR FLOW (LB/SEC)	RR BRG COOLANT SUPPL.PR (PSIA)	RR BRG COOLANT SUPPL.TEMP (DEG R)	RR BRG DRAIN PR (PSIA)	RR BRG DRAIN TEMP (DEG R)	RR BRG COOL.ORIF U/S PR (PSIA)	RR BRG COOL.ORIF U/S TEMP (DEG R)	RR BRG COOL.ORIF D/S PR (PSIA)	RR BRG COOLANT FLOW (LB/SEC)
1	0.C	3488.1	0.0	247.1	105.37	247.1	99.26	112.6	0.1406
2	C.0	3488.1	0.0	246.1	102.24	246.1	96.68	111.6	0.1430
5	C.C	3487.4	0.0	240.2	97.14	240.2	91.24	108.4	0.1456
6	0.C	3506.6	0.0	234.4	100.87	234.4	97.88	104.9	0.1354
7	0.0	3506.4	0.0	234.0	100.96	234.0	97.41	104.7	0.1356
8	C.C	3508.2	0.0	233.6	100.48	233.6	97.10	104.2	0.1359
9	C.C	3508.8	0.0	233.9	100.54	233.9	97.05	104.4	0.1360
10	C.0	3505.3	0.0	234.3	100.34	234.3	97.06	104.6	0.1363
11	0.C	3510.8	0.0	234.7	100.57	234.7	97.53	104.6	0.1361
12	C.C	3511.2	0.0	235.6	100.72	235.6	97.90	104.8	0.1364
13	C.C	3511.1	0.0	236.2	101.30	236.2	98.56	105.1	0.1362
14	C.0	3511.4	0.0	234.4	101.07	234.4	97.36	104.6	0.1360
15	C.C	3512.2	0.0	233.9	100.53	233.9	96.67	104.2	0.1365
16	0.0	3512.7	0.0	234.2	100.46	234.2	97.12	104.2	0.1363
17	0.0	3512.7	0.0	234.2	100.38	234.2	96.95	104.1	0.1365
18	0.C	3512.6	0.0	234.4	100.22	234.4	96.74	104.3	0.1368
19	0.C	3513.5	0.0	234.3	100.36	234.3	96.63	104.5	0.1367
20	0.0	3514.4	0.0	234.8	100.59	234.8	97.27	104.6	0.1364
21	0.C	3515.2	0.0	234.5	100.89	234.5	97.64	104.5	0.1359
22	0.0	3515.6	0.0	232.3	100.46	232.3	96.06	103.7	0.1360
23	C.C	3516.0	0.0	231.8	100.62	231.8	96.49	103.3	0.1354
24	0.C	3516.5	0.0	232.0	100.42	232.0	96.16	103.5	0.1357
25	C.0	3516.2	0.0	231.9	100.06	231.9	96.01	103.5	0.1358
26	0.C	3515.2	0.0	233.9	100.66	233.9	97.88	103.9	0.1355
27	C.0	3506.9	0.0	233.6	100.98	233.6	97.70	104.0	0.1353
28	0.0	3485.0	0.C	232.9	100.89	232.9	97.72	103.6	0.1350
29	C.C	3462.7	0.0	231.3	100.60	231.3	96.76	103.1	0.1348
30	0.0	3440.8	0.0	229.3	99.80	229.3	95.68	102.2	0.1346
31	[illegible]C	3420.1	0.0	228.5	[illegible]9.55	228.5	95.51	101.9	[illegible]1343
32	0.0	3400.0	0.0	228.0	99.75	228.0	95.89	101.4	0.1336

MK46-0
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

S E A L   A N D   B E A R I N G   D A T A (CONTINUED)

TIME SLICE NO	PRIMARY LOX SEAL DRAIN: ORIF U/S PR (PSIA)	PRIMARY LOX SEAL DRAIN: ORIF U/S TEMP (DEG R)	PRIMARY LOX SEAL DRAIN: FLOWRATE (LB/SEC)	PUMP BRG OVBD DRAIN: ORIF U/S PR (PSIA)	PUMP BRG OVBD DRAIN: ORIF U/S TEMP (DEG R)	PUMP BRG OVBD DRAIN: BRG FLOWRATE (LB/SEC)
1	14.4	264.55	0.0	33.3	390.95	0.3842
2	14.4	287.13	0.0	38.1	327.58	0.4639
5	14.5	302.99	0.0	43.5	317.10	0.5153
6	14.5	316.73	0.0	59.9	261.07	0.6889
7	14.4	337.19	0.0	80.9	212.82	0.8950
8	14.4	352.59	0.0	68.6	261.93	0.7607
9	14.4	355.31	0.0	66.4	265.97	0.7225
10	14.4	357.35	0.0	64.3	269.39	0.7054
11	14.4	359.63	0.0	62.0	272.74	0.6873
12	14.4	361.50	0.0	59.6	275.88	0.6683
13	14.4	364.34	0.0	56.7	279.40	0.6455
14	14.4	366.80	0.0	54.6	282.78	0.6279
15	14.3	368.89	0.0	52.8	286.37	0.6116
16	14.3	371.02	0.0	51.5	289.60	0.5998
17	14.4	373.22	0.0	50.3	292.95	0.5876
18	14.4	375.04	0.0	50.2	295.90	0.5843
19	14.4	376.67	0.0	50.0	298.64	0.5801
20	14.4	378.51	0.0	51.3	300.88	0.5868
21	14.4	380.22	0.0	54.2	302.44	0.6048
22	14.5	381.60	0.0	57.0	303.43	0.6217
23	14.5	383.09	0.0	61.0	303.83	0.6455
24	14.5	384.38	0.0	64.9	303.57	0.6678
25	14.5	385.60	0.0	67.1	302.49	0.6812
26	14.5	386.71	0.0	69.8	301.24	0.6973
27	14.5	387.67	0.0	71.2	299.46	0.7064
28	14.5	388.94	0.0	71.3	297.83	0.7089
29	14.5	390.30	0.0	71.9	296.38	0.7137
30	14.5	391.72	0.0	71.7	295.05	0.7143
31	14.5	393.08	0.0	71.6	294.08	0.71[illegible]
32	14.5	394.19	0.0	71.2	293.59	0.7134

PK48-G
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

P U M P   P R E S S U R E S

TIME SLICE NO	SUPPLY TANK PR (PSIA)	PUMP INLET PR (PSIA)	IMPELLER DISCH PR (PSIA)	BAL PIST CAV PR #2 (PSIA)	PUMP DISCH PR (PSIA)	BAL PIST CAV PR #1 (PSIA)	BAL PIST SUMP PR (PSIA)	BAL PIST RETURN PR (PSIA)	IMPELLER FRONT SHROUD PR (PSIA)
1	260.2	240.9	883.1	571.8	1046.5	585.7	341.5	397.0	800.2
2	260.2	238.3	828.8	538.4	943.0	546.6	316.2	377.4	752.2
5	260.0	236.0	863.4	555.5	986.2	566.7	322.0	387.9	782.8
6	257.7	154.8	3428.2	1743.5	4340.9	1825.6	778.8	1035.9	3036.5
7	257.3	154.3	3400.3	1736.6	4307.3	1812.0	770.2	1057.0	3011.0
8	257.3	154.2	3389.5	1728.8	4305.5	1806.4	773.7	1026.7	3001.2
9	257.3	149.6	3304.0	1670.7	4133.4	1744.0	724.4	975.5	2919.6
10	257.1	143.8	3131.2	1539.5	3808.6	1597.0	635.4	873.8	2753.3
11	256.9	137.6	2968.6	1420.4	3515.4	1464.6	534.8	766.5	2588.1
12	256.8	135.6	2863.2	1341.3	3337.3	1392.8	491.0	715.9	2488.9
13	256.6	133.9	2771.8	1282.0	3195.9	1331.3	464.3	682.5	2408.7
14	256.4	132.1	2707.8	1232.3	3083.3	1280.2	445.8	656.0	2336.5
15	256.2	131.3	2656.8	1199.5	2996.8	1245.6	433.5	637.4	2279.2
16	256.2	130.3	2656.7	1203.9	3003.4	1244.7	434.2	638.4	2278.5
17	256.2	130.1	2686.3	1214.6	3057.4	1263.0	439.0	646.5	2308.6
18	256.2	133.6	2834.5	1313.6	3316.2	1373.9	481.6	706.9	2464.1
19	256.2	138.9	2991.8	1426.9	3594.9	1492.4	553.1	787.9	2609.1
20	256.3	143.5	3140.1	1538.7	3860.1	1613.9	632.4	874.1	2756.3
21	256.5	148.9	3298.5	1657.1	4154.0	1741.9	734.2	977.8	2908.2
22	256.7	154.8	3405.5	1735.0	4356.9	1820.2	786.6	1040.5	3009.6
23	257.0	161.4	3520.9	1811.2	4596.6	1902.9	843.9	1102.6	3108.8
24	257.7	165.6	3579.5	1851.1	4724.6	1951.8	877.8	1137.4	3163.3
25	258.4	170.4	3642.7	1895.7	4861.7	1998.2	911.7	1175.2	3224.9
26	259.2	172.7	3640.0	1894.8	4855.2	1998.9	912.5	1175.0	3223.6
27	259.7	171.8	3635.3	1891.1	4850.4	1997.2	908.2	1171.2	3219.6
28	260.1	173.4	3635.3	1894.3	4859.2	2001.8	914.8	1178.2	3221.6
29	260.6	177.1	3651.5	1911.7	4909.3	2018.5	929.0	1192.7	3237.5
30	261.1	178.4	3645.3	1911.6	4918.9	2021.7	933.0	1196.2	3244.0
31	261.5	179.7	3662.3	1924.0	4955.2	2034.9	942.6	1206.3	3251.0
32	261.7	182.4	3678.8	1936.7	4991.1	2051.3	953.9	1221.0	3268.0

ORIGINAL PAGE IS
OF POOR QUALITY

PK48-0
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

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PUMP PRESSURES AND TEMPERATURES

TIME SLICE NO	SPEED RPM	INDUCER DISCH PRESS PSIA	PUMP BRG U/S PRESS PSIA	PUMP BRG D/S PRESS PSIA	PUMP BRG DELTA P PSID	PUMP BRG OVBD TEMP DEG R	PUMP BRG OVBD PRESS PSIA	PUMP BRG SLINGER SUMP TEMP DEG R	PUMP BRG SLINGER SUMP PR PSIA
1	30253.	331.9	397.0	403.4	-6.417	180.71	42.8	184.62	43.9
2	29462.	303.6	377.4	385.6	-8.219	185.87	50.6	187.49	50.5
5	30376.	307.9	387.9	396.8	-8.846	189.24	58.4	189.48	58.1
6	68144.	778.5	1035.9	1048.4	-12.462	197.68	89.7	205.99	133.7
7	67860.	778.2	1057.0	1077.7	-20.660	206.00	109.9	214.11	148.1
8	67870.	776.1	1026.7	1038.0	-11.322	202.75	96.4	213.68	142.1
9	67554.	714.8	975.5	986.5	-10.985	201.88	93.7	213.10	137.6
10	67216.	564.9	873.8	885.3	-11.475	201.29	90.9	212.37	130.4
11	67056.	417.6	766.5	784.0	-17.469	200.41	87.8	211.19	123.8
12	66850.	361.2	715.9	734.4	-18.513	199.25	84.0	209.96	118.6
13	66887.	334.8	682.5	699.8	-17.282	198.06	80.3	208.87	115.6
14	67201.	317.0	656.0	674.6	-18.652	197.04	77.5	207.88	111.9
15	67328.	309.5	637.4	657.4	-20.040	196.16	75.1	207.27	110.2
16	67428.	310.7	638.4	659.7	-21.302	195.52	73.1	206.73	110.1
17	67462.	316.7	646.5	666.6	-20.096	194.81	71.7	206.40	110.1
18	67039.	357.6	706.9	725.7	-18.871	194.39	71.3	206.43	111.5
19	66960.	457.0	787.9	807.4	-19.493	194.24	71.2	206.84	116.2
20	67156.	601.6	874.1	888.7	-14.611	194.67	73.1	207.82	123.5
21	67583.	734.2	977.8	990.0	-12.167	195.70	76.3	208.94	129.8
22	68034.	798.1	1040.5	1050.8	-10.252	196.84	80.3	210.35	136.0
23	68607.	858.3	1102.6	1112.5	-9.855	198.03	84.9	211.62	142.5
24	68916.	891.4	1137.4	1147.6	-10.178	199.47	89.1	212.73	145.7
25	69272.	929.3	1175.2	1185.6	-10.349	200.60	92.6	213.73	151.3
26	69216.	929.4	1175.0	1185.3	-10.303	201.56	95.9	214.52	151.8
27	69187.	928.5	1171.2	1181.8	-10.600	202.34	97.9	214.94	152.6
28	69134.	934.2	1178.2	1189.0	-10.795	202.75	99.0	215.33	153.1
29	69106.	952.7	1192.7	1202.8	-10.135	202.95	99.4	215.43	153.0
30	68957.	958.8	1196.2	1206.9	-10.709	202.95	99.6	215.75	156.1
31	69072.	968.6	1206.3	1216.7	-10.371	202.95	100.0	215.79	156.5
32	69161.	979.3	1221.0	1230.6	-9.576	202.95	99.5	215.82	156.8

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

P U M P P R E S S U R E S A N D T E M P E R A T U R E S (CONTINUED)

TIME SLICE NO	BAL PIST RECIRC U/S ORIF PR PSIA	BAL PIST RECIRC U/S ORIF TEMP DEG F	BAL PIST RECICR DELTA P PSI	BAL PIST FLOW LB/SEC	BAL PIST FLOW TEMP RISE DEG R
1	225.1	179.8	34.97	1.756	-6.70
2	207.3	179.3	29.35	1.609	-6.39
5	210.6	179.8	30.15	1.630	-6.98
6	535.6	211.8	122.67	3.146	-38.76
7	531.7	211.8	120.76	3.121	-39.08
8	533.4	212.0	121.07	3.124	-39.24
9	496.2	211.5	110.09	2.980	-38.74
10	401.0	210.9	80.94	2.554	-38.06
11	322.6	210.0	58.14	2.166	-37.06
12	293.3	209.6	50.03	2.009	-36.67
13	276.5	209.4	45.32	1.912	-36.56
14	266.1	209.4	42.32	1.848	-36.59
15	259.8	209.4	40.59	1.809	-36.52
16	260.1	209.5	40.96	1.817	-36.65
17	263.4	209.6	41.76	1.835	-36.69
18	287.3	209.6	48.30	1.974	-36.72
19	339.8	209.8	63.46	2.264	-36.96
20	418.8	210.8	87.20	2.652	-37.93
21	504.1	211.5	112.76	3.016	-38.72
22	542.8	212.2	124.28	3.165	-39.41
23	585.1	213.3	136.90	3.318	-40.55
24	608.1	213.9	144.05	3.401	-41.13
25	633.2	214.7	151.55	3.485	-41.92
26	633.5	214.8	151.40	3.483	-42.00
27	632.1	214.7	150.82	3.476	-41.97
28	636.6	214.7	152.12	3.492	-41.91
29	648.1	214.9	155.50	3.530	-42.03
30	651.1	214.9	[illegible]	3.562	[illegible]
31	658.1	215.0	158.57	3.564	-42.18
32	665.4	215.2	160.75	3.588	-42.34

ORIGINAL PAGE IS
OF POOR QUALITY

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

UN NUMBER 6
EST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

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PUMP PRESSURES AND TEMPERATURES

TIME SLICE NO	PUMP INLET TEMP (DEG R)	PUMP DISCH TEMP (DEG R)	BAL PIST RETURN TEMP (DEG R)	PUMP DISCH VENT U/S TEMP (DEG R)	PUMP DISCH VENT U/S PR (PSIA)	PUMP DISCH VENT DELTA PR (PSI)	HP (TEMP)
1	173.11	177.68	0.0	178.23	1029.6	8.46	73.24
2	172.91	177.27	0.0	177.73	922.3	8.75	68.13
5	172.82	177.44	0.0	177.75	965.5	8.99	73.29
6	173.03	195.23	0.0	194.17	4265.7	48.44	854.55
7	172.76	195.00	0.0	194.45	4227.6	46.99	840.27
8	172.77	195.11	0.0	194.75	4225.6	45.88	832.64
9	172.80	195.11	0.0	194.45	4048.0	47.33	825.57
10	172.83	195.58	0.0	194.81	3716.1	50.30	819.41
11	172.91	196.38	0.0	195.39	3419.6	52.20	814.15
12	172.90	196.48	0.0	195.85	3238.4	52.81	801.19
13	172.88	196.76	0.0	196.09	3095.4	53.63	798.81
14	172.86	197.18	0.0	196.53	2981.7	54.36	801.69
15	172.88	197.33	0.0	196.89	2893.4	54.68	797.89
16	172.86	197.39	0.0	196.98	2900.4	54.97	802.45
17	172.89	197.48	0.0	197.21	2954.8	54.57	806.18
18	172.87	196.82	0.0	196.91	3220.3	53.16	808.45
19	172.86	196.32	0.0	196.54	3504.5	51.73	818.95
20	172.86	195.62	0.0	195.88	3775.6	50.42	826.30
21	172.78	195.19	0.0	195.61	4075.0	47.77	833.26
22	172.79	195.23	0.0	195.28	4280.8	45.97	840.74
23	172.78	195.61	0.0	195.60	4525.6	43.70	853.95
24	172.77	195.78	0.0	195.64	4657.2	40.99	846.02
25	172.78	196.02	0.0	195.95	4796.6	37.60	851.07
26	172.75	196.02	0.0	195.95	4789.8	38.73	842.11
27	172.77	196.01	0.0	195.92	4784.6	38.16	835.38
28	172.78	195.98	0.0	195.98	4793.5	37.78	831.91
29	172.86	196.03	0.0	196.09	4846.9	36.52	823.40
30	172.85	196.02	0.0	196.09	4857.2	35.67	[illegible]16.00
31	172.81	196.08	0.0	196.09	4894.0	35.96	824.20
32	172.81	196.18	0.0	196.11	4931.5	35.49	824.59

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

C A L C U L A T E D   P U M P   P A R A M E T E R S

TIME SLICE NO	TEST SPEED (RPM)	PUMP FLOW GPM	PUMP FLOW (LB/SEC)	HEAD FT	PRESS RISE (PSI)	FLUID HP (HP)	TURB HP (HP)	EFF (%)	ISEN EFF (%)	SPECIFIC SPEED
1	30253.	97.36	15.0819	1684.3	805.6	46.2	67.89	68.05	63.06	1137.
2	29462.	99.08	15.3418	1476.3	704.7	41.2	65.52	62.88	60.44	1231.
5	30376.	100.38	15.5524	1570.7	750.3	44.4	71.44	62.19	60.60	1220.
6	68144.	232.27	36.3137	8736.6	4186.1	576.8	714.91	80.72	67.50	1149.
7	67860.	228.91	35.7505	8662.2	4153.0	563.1	698.73	80.61	67.01	1143.
8	67870.	226.25	35.3134	8657.7	4151.3	555.9	693.52	80.18	66.76	1137.
9	67554.	229.98	35.8357	8325.0	3983.8	542.4	692.46	78.36	65.70	1175.
10	67216.	237.71	36.8490	7694.0	3664.8	515.5	693.48	74.36	62.91	1261.
11	67096.	242.82	37.4410	7125.4	3377.8	485.1	695.05	69.81	59.58	1348.
12	66650.	244.67	37.5919	6770.4	3201.6	462.7	691.60	66.94	57.74	1401.
13	66887.	246.90	37.8346	6490.4	3062.0	446.5	691.01	64.64	55.89	1453.
14	67201.	248.90	38.0398	6269.5	2951.2	433.6	690.45	62.83	54.09	1505.
15	67328.	249.91	38.1113	6096.9	2865.6	422.5	689.48	61.30	52.95	1543.
16	67428.	250.59	38.2118	6113.1	2873.0	424.7	690.58	61.52	52.93	1544.
17	67462.	249.65	38.0809	6223.9	2927.3	430.9	691.17	62.37	53.45	1521.
18	67039.	245.82	37.6709	6735.3	3182.6	461.3	690.53	66.83	57.06	1414.
19	66560.	241.91	37.2532	7282.1	3456.0	493.2	690.00	71.51	60.23	1321.
20	67156.	238.19	36.8715	7799.7	3716.7	522.9	689.08	75.91	63.26	1250.
21	67583.	231.33	35.9724	8369.7	4005.1	547.4	687.18	79.69	65.70	1173.
22	68034.	226.53	35.3445	8760.9	4202.1	563.0	687.59	81.91	66.97	1131.
23	68607.	220.60	34.5041	9225.8	4435.3	578.8	685.96	84.41	67.78	1082.
24	68916.	213.50	33.4458	9468.7	4559.1	575.8	684.27	84.18	68.06	1049.
25	69272.	209.75	32.8948	9731.6	4691.3	582.0	685.28	84.97	68.39	1024.
26	69216.	207.44	32.5302	9711.6	4682.5	574.4	683.88	84.02	68.21	1019.
27	69187.	205.89	32.2873	9702.9	4678.6	569.6	683.32	83.39	68.18	1015.
28	69134.	204.86	32.1261	9716.0	4685.8	567.5	680.76	83.40	68.22	1011.
29	69106.	201.38	31.5945	9807.1	4732.2	563.4	673.79	83.64	68.42	995.
30	68957.	199.03	31.2286	9821.4	4740.5	557.7	666.91	83.65	68.34	987.
31	65072.	199.78	31.3614	9892.0	4775.5	564.0	668.85	84.74	68.44	[illegible]
32	65161.	198.42	31.1612	9957.9	4808.8	564.2	664.96	84.88	68.42	977.

PK48-0
LIQUID CXYGEN TURBCPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

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CALCULATEC PUMP PARAMETERS

TIME SLICE NO	TEST SPEED (RPM)	NPSH (FT)	SUCTION SPECIFIC SPEED	INLET FLOW COEFF	HEAD COEFF	PUMP DELTA T (DEG R)	(Q/N) OVER (Q/N)DES	BAL PIST K	FR SHRD K
1	30293.	447.22	3073.53	0.08169	0.47701	4.57	0.9697	0.1668	0.5950
2	29462.	441.69	3043.76	0.08548	0.44202	4.37	1.0147	0.1310	0.5879
5	30376.	436.82	3185.12	0.08399	0.44239	4.63	0.9970	0.1494	0.5849
6	68144.	283.24	15042.37	0.08664	0.48896	22.20	1.0285	0.1801	0.5752
7	67860	281.65	14933.51	0.08574	0.48887	22.24	1.0178	0.1733	0.5756
8	67870.	281.04	14872.96	0.08473	0.48847	22.34	1.0058	0.1757	0.5749
9	67554.	271.92	15299.08	0.08653	0.47411	22.31	1.0272	0.1716	0.5746
10	67216.	260.70	15973.37	0.08989	0.44258	22.76	1.0670	0.1528	0.5727
11	67096.	248.33	16713.14	0.09198	0.41135	23.48	1.0919	0.1342	0.5757
12	66650.	244.31	16921.30	0.09303	0.39373	23.59	1.1043	0.1454	0.5731
13	66887.	240.90	17187.77	0.09382	0.37704	23.89	1.1137	0.1423	0.5641
14	67201.	237.37	17531.68	0.09414	0.36080	24.32	1.1175	0.1395	0.5678
15	67328.	235.83	17686.24	0.09434	0.34955	24.45	1.1199	0.1366	0.5715
16	67428.	233.98	17841.88	0.09446	0.34944	24.53	1.1213	0.1283	0.5711
17	67462.	233.47	17846.43	0.09406	0.35541	24.59	1.1166	0.1397	0.5705
18	67039.	240.23	17225.17	0.09320	0.38948	23.95	1.1064	0.1569	0.5685
19	66560.	250.80	16574.98	0.09182	0.42209	23.47	1.0900	0.1637	0.5785
20	67156.	260.15	16009.83	0.09010	0.44893	22.76	1.0695	0.1748	0.5773
21	67583.	270.73	15400.86	0.08700	0.47624	22.41	1.0328	0.1845	0.5788
22	68034.	282.41	14863.71	0.08463	0.49192	22.44	1.0047	0.1836	0.5834
23	68607.	295.32	14303.61	0.08173	0.50939	22.83	0.9702	0.1890	0.5857
24	68916.	303.10	13862.17	0.07874	0.51813	23.01	0.9347	0.1971	0.5860
25	69272.	312.77	13489.30	0.07696	0.52706	23.25	0.9136	0.1979	0.5841
26	69216.	317.15	13264.91	0.07617	0.52683	23.26	0.9043	0.1995	0.5836
27	69187.	315.16	13272.18	0.07564	0.52679	23.24	0.8979	0.2016	0.5833
28	69134.	318.38	13128.30	0.07532	0.52832	23.20	0.8941	0.2031	0.5824
29	69106.	325.64	12792.99	0.07407	0.53370	23.17	0.8793	0.2025	0.5829
30	68957.	328.11	12626.04	0.07332	0.53618	23.18	0.8703	0.2059	0.5818
31	69072.	330.69	12589.77	0.07352	0.53885	23.27	0.8727	0.2064	0.5811
32	69161.	336.12	12410.35	0.07292	0.54106	23.37	0.8657	0.2096	0.5817

PK48-C
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.0(

SCALED TO TARGET SPEED = 70000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	224.98	34.85107	8993.61	4301.61	903.72	2388.05
2	235.41	36.45154	8333.94	3978.23	913.83	2493.42
5	231.32	35.63930	8340.82	3984.13	896.83	2319.70
6	238.60	37.30271	9218.99	4417.27	926.30	298.88
7	236.13	36.87806	9217.20	4419.08	922.31	299.69
8	233.35	36.42179	9209.69	4416.01	913.53	298.96
9	238.31	37.13334	8938.88	4277.53	918.55	291.97
10	247.56	38.37525	8344.51	3974.70	925.50	282.74
11	253.33	39.06166	7755.62	3676.56	924.51	270.30
12	256.20	39.36332	7423.49	3510.47	919.87	267.88
13	258.39	39.59558	7108.67	3353.65	915.63	263.85
14	259.27	39.62414	6802.62	3202.18	906.09	257.55
15	259.82	39.62373	6590.42	3097.51	896.71	254.92
16	260.15	39.66911	6588.30	3096.34	897.81	252.17
17	259.04	39.51360	6701.00	3151.68	900.64	251.37
18	256.68	39.33479	7343.39	3469.98	920.38	261.92
19	252.89	38.94435	7958.22	3776.93	935.62	274.09
20	248.13	38.41013	8464.19	4033.32	934.34	282.32
21	239.60	37.25906	8979.08	4296.74	925.90	290.45
22	233.08	36.36611	9274.69	4448.51	915.77	298.97
23	225.08	35.20459	9604.19	4617.19	907.02	307.44
24	216.86	33.97167	9768.83	4703.56	886.56	312.71
25	211.95	33.24049	9937.21	4790.38	878.19	319.37
26	209.79	32.89884	9932.95	4789.19	871.06	324.37
27	208.31	32.66662	9932.16	4789.15	865.17	322.61
28	207.43	32.52868	9960.99	4803.93	863.58	326.41
29	203.99	32.00320	10062.46	4855.39	855.77	334.12
30	201.92	31.68274	10109.12	4879.33	852.12	337.72
31	202.47	31.78282	10159.5[illegible]	4904.71	857.87	339.6[illegible]
32	200.83	31.53945	10201.13	4926.23	854.99	344.33

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

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SCALED TO DESIGN SPEED = 70,000. RPM

TIME SLICE NO	FLOW (GPM)	FLOW (#/SEC)	HEAD (FT)	PRESS RISE (PSI)	HORSE POWER (BHP)	NPSH (FT)
1	224.98	34.85107	8993.61	4301.61	903.72	2388.05
2	235.41	36.45154	8333.94	3978.23	913.83	2493.42
5	231.32	35.83930	8340.82	3984.13	896.83	2319.70
6	238.60	37.30271	9218.99	4417.27	926.30	298.88
7	236.13	36.87806	9217.20	4419.08	922.31	299.69
8	233.35	36.42179	9209.69	4416.01	913.53	298.96
9	238.31	37.13334	8938.88	4277.53	918.55	291.97
10	247.56	38.37525	8344.51	3974.70	925.50	282.74
11	253.33	39.06166	7755.62	3676.56	924.51	270.30
12	256.20	39.36332	7423.49	3510.47	919.87	267.88
13	258.39	39.59558	7108.67	3353.65	915.63	263.05
14	259.27	39.62414	6802.62	3202.18	906.09	257.55
15	259.82	39.62373	6590.42	3097.51	896.71	254.92
16	260.15	39.66911	6588.30	3096.34	897.81	252.17
17	259.04	39.51360	6701.00	3151.68	900.64	251.37
18	256.68	39.33479	7343.39	3469.98	920.38	261.92
19	252.89	38.94435	7958.22	3776.93	935.62	274.09
20	248.13	38.41013	8464.19	4033.32	934.34	282.32
21	239.60	37.25906	8979.08	4296.74	925.90	290.45
22	233.08	36.36611	9274.69	4448.51	915.77	298.97
23	225.08	35.20459	9604.19	4617.19	907.02	307.44
24	216.86	33.97167	9768.83	4703.56	886.56	312.71
25	211.95	33.24049	9937.21	4790.38	878.19	319.37
26	209.79	32.89884	9932.95	4789.19	871.06	324.37
27	208.31	32.66662	9932.16	4789.15	865.17	322.61
28	207.43	32.52868	9960.99	4803.93	863.58	326.41
29	203.99	32.00320	10062.46	4855.39	855.77	334.12
30	201.92	31.68274	10109.15	4879.33	852.12	337.72
31	202.47	31.78282	10159.58	4904.71	857.87	339.63
32	200.83	31.53945	10201.13	4926.23	854.99	344.33

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

SCALED TO TARGET SPEED = 70000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	485.74	0.0
2	368.46	0.0
5	381.73	0.0
6	658.13	0.0
7	663.86	0.0
8	661.54	0.0
9	606.94	0.0
10	456.71	0.0
11	304.69	0.0
12	247.35	0.0
13	220.08	0.0
14	200.64	0.0
15	192.67	0.0
16	194.34	0.0
17	200.88	0.0
18	244.23	0.0
19	347.69	0.0
20	497.19	0.0
21	627.90	0.0
22	681.07	0.0
23	725.52	0.0
24	748.82	0.0
25	774.88	0.0
26	773.97	0.0
27	774.57	0.0
28	779.91	0.0
29	795.84	0.0
30	803.23	0.0
31	810.34	0.0
32	816.42	0.0

ORIGINAL PAGE IS
OF POOR QUALITY

MK48-O
LIQUID OXYGEN TURBOPUMP ASSEMBLY

RUN NUMBER 6
TEST DATE 4-28-81

PROCESSING DATE 5-22-81
TEST DURATION, SEC 69.00

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SCALED TC DESIGN SPEED = 70,000. RPM

TIME SLICE NO	IND STAT PR RISE PSID	VOLUTE STAT PR RISE PSID
1	485.74	0.0
2	368.46	0.0
5	381.73	0.0
6	658.13	0.0
7	663.86	0.0
8	661.54	0.0
9	606.94	0.0
10	456.71	0.0
11	304.69	0.0
12	247.35	0.0
13	220.08	0.0
14	200.64	0.0
15	152.67	0.0
16	194.34	0.0
17	200.88	0.0
18	244.23	0.0
19	347.69	0.0
20	497.19	0.0
21	627.90	0.0
22	681.07	0.0
23	725.52	0.0
24	748.82	0.0
25	774.86	0.0
26	773.97	0.0
27	774.57	0.0
28	779.91	0.0
29	795.84	0.0
30	803.23	0.0
31	810.34	0.0
32	816.42	0.0