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Orbital Transfer Rocket Engine Technology

High Velocity Ratio Diffusing Crossover

Contract NAS3-23773-Task B.2

FINAL REPORT

B. W. Lariviere
ROCKWELL INTERNATIONAL
Rocketdyne Division

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G. P. Richter, Program Manager

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FOREWORD

The work represented by this final report was completed from December 1983 to December 1988 by personnel from engineering functional units at Rocketdyne, a division of Rockwell International, under Contract NAS3-23773. Mr. Dean Scheer, Lewis Research Center, was the NASA Project Manager. At Rocketdyne, Messrs. Ronald Pauckert, Project Manager, Timothy Harmon , Project Engineer, and Brian Larivìere, Development Engineer were responsible for the technical progress and administration of the program.

Important contributions to the completion of this program, and to the preparation of this report were made by the following Rocketdyne personnel:

Advanced Rotating Machinery:

Mr. Robert Sutton
Mr. Tim Irvin
Mr. Hal Buddenbohm
Mr. Al Little

Fluid Dynamics:

Dr. Eugene Jackson
Mr. Anthony Eastland
Dr. Sen Meng
Mr. Louis Rojas
Mr. Dave Wiltz
Mr. George Prueger
Ms. Laura Browzowski

Mechanical Elements:

Mr. Myles Butner

Structure Analysis:

Mr. Linsey Orr

Rotordynamics:

Mr. David Becht

Engineering Development Lab:

Mr. Carl Brown
Mr. Alex Tsosie
Mr. Bill Bubel
Mr. Sukjun Ko
Mr. Gene Bodel
Mr. Steve Rodgers
Mr. Jim Perry
Mr. Dale Styles

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SUMMARY

The effort conducted herein was sponsored by the Space Propulsion Technology Division, NASA Lewis Research Center, Cleveland, Ohio, under Contract NAS3-23773, "Orbit Transfer Rocket Engine Technology Program." The technical effort of this contract was completed from December 1983 through December 1988.

The overall objective of this task was to experimentally evaluate the performance of the high velocity ratio diffusing crossover used in the first and second stages of the MK49-F high pressure fuel turbopump, which is used on the RS-44 Orbital Transfer Vehicle rocket engine. With the diffuser inlet conditions generated by a scaled up model of the MK49-F inducer and impeller, the performance of these pumping elements and the high velocity ratio diffusing crossover were determined using water and air as the pumped fluids. The air tests were included to obtain performance data over a wide range of Reynolds number. These performance surveys were to be used to verify the design of the high velocity ratio diffusing crossover, and correct any design deficiencies that were found. Since the MK49-F was tested prior to the completion of this test program, the data from the MK49-F was used as a comparison for the water and air test data.

To complete the technical requirements of this program, a tester, utilizing a 2.85 times scale inducer, impeller, and diffuser crossover system, was designed, fabricated, and tested in both air and water.

The design of the high velocity ratio diffusing crossover was based on integrating the scaled up MK49-F first stage components with the existing SSME HPFTP tester. By using the existing tester hardware, design and fabrication costs were saved. Additional costs were saved by fabricating the new crossover tester components from common aluminum alloys to minimize the machining complexities and procurement costs.

A total of nine (9) tests were conducted on the north powerhead of the Pump Test Facility at the Engineering Development Laboratory from September 1988 to October 1988. The first two (2) tests of the diffusing crossover were conducted in air, while the remaining seven (7) tests were conducted in water. Both, the air and water tests were conducted at a shaft speed of 6322 rpm.

In air, the head versus flow (H-Q) test data determined that the upcomer diffuser in the crossover was stalled for all the flow conditions attempted. The stall was caused by increased boundary layer blockage due to the low Reynolds number resulting in the impeller discharge flow entering the diffuser inlet at an angle and velocity, which would produce a flow separation in the diffuser. Air test data compared well with the analytic predictions and MK49-F hydrogen data for the impeller and the inducer head performance, clearly showing that the stall was in the diffuser.

H-Q tests in water, from 65 to 140% of design flow, were conducted. The overall stage head measured these tests was only 4% lower than the prediction. Again, the performance of the inducer and impeller were compared with the available resources. During the H-Q tests, the upcomer diffuser stall point was determined to be at a slightly lower flow than predicted, and the hysteresis region was clearly evident. The head loss during stall was not severe which was indicative of a diffuser leading edge stall characteristic. Internal pressure distributions were also examined to evaluate the inducer, impeller, and various positions within the diffuser crossover system. Suction performance tests from 80% to 124% of design flow were conducted, which established the minimum inlet Net Positive Suction Head (NPSH). The performance was lower than the ideal potential, but a lower performance was expected with the design characteristics scaled from the smaller MK49-F. The performance of the tester, however, exceeded the minimum design requirements established for the MK49-F turbopump.

The test data showed 95% of the overall diffusion being accomplished by the upcomer portion of the crossover passage, as predicted. By calculating the required diffuser inlet boundary layer blockage to match the test data and using the Loss Isolation program to determine the vaneless area diffusion, the mean pressure recovery coefficient from the test data compared favorably with the predictions.

The technique generated to analyze the data will be beneficial for the design and analysis of future diffusing crossover passages. The data generated in this test program verified the methods used at Rocketdyne to design and predict the performance of pumping elements and high velocity ratio diffusing crossovers. The data generated in this program will also be of value in further anchoring the predictive codes of other designs.

INTRODUCTION

Multistage pumps require the use of crossover passages to convey the fluid from the exit of one impeller to the inlet of the next impeller. The MK49-F, which is used on the 15,000 lbf thrust Orbital Transfer Vehicle (OTV) engine, is a three stage centrifugal high-pressure liquid hydrogen turbopump. A cross-section of the MK49-F turbopump is presented in Figure 1 showing the location of the two interstage crossovers. The MK49-F uses seventeen continuous passage crossovers between each centrifugal impeller stage. Each passage consists a radially out diffuser called the "upcomer", followed by a radially inward diffuser called the "downcomer". A low turning loss section, called the transition, connects the two diffuser sections.

To develop the 4600 psia discharge pressure required by the advanced expander cycle OTV engine, a high impeller exit velocity is required. However, relatively low velocity is required at the inlet of the next impeller for the best overall pump performance. The result is a large diffuser inlet velocity to exit velocity ratio through the crossover.

The MK49-F design uses a velocity ratio of 6.23, which approaches the diffusion limit for stable efficient design. Previous diffusing crossover designs, at Rocketdyne, used velocity ratios that were lower, for example, 5.46 for the MK48-F, and 3.0 for the SSME HPFTP (MK38-F). With these high diffusion rates, the boundary layer flows must be carefully controlled to preclude stall, while operating over the wide range of pump flows required by the engine system.

The design of the crossover passages was based on advanced analytical procedures anchored by tests of stationary two-dimensional diffusers with steady flow. In the case of centrifugal pumps, however, the flow leaving the rotating impeller appears to the stationary diffusion system as an unsteady non-uniform flow field with potential inlet boundary layers even larger than normally encountered in laboratory tests of static diffusers. To accurately assess the design of the high velocity ratio diffusing crossover, it was required that the impeller flow be accurately simulated. This could only be achieved by using a scaled-up version of the MK49-F impeller.

A highly instrumented tester was designed and fabricated which would simulate the MK49-F first stage pumping elements and crossover passages. To take advantage of existing test facility hardware, a scaled up model of the stage was chosen with a scale factor of 2.85. This scaled up model also served to increase the Reynolds number for

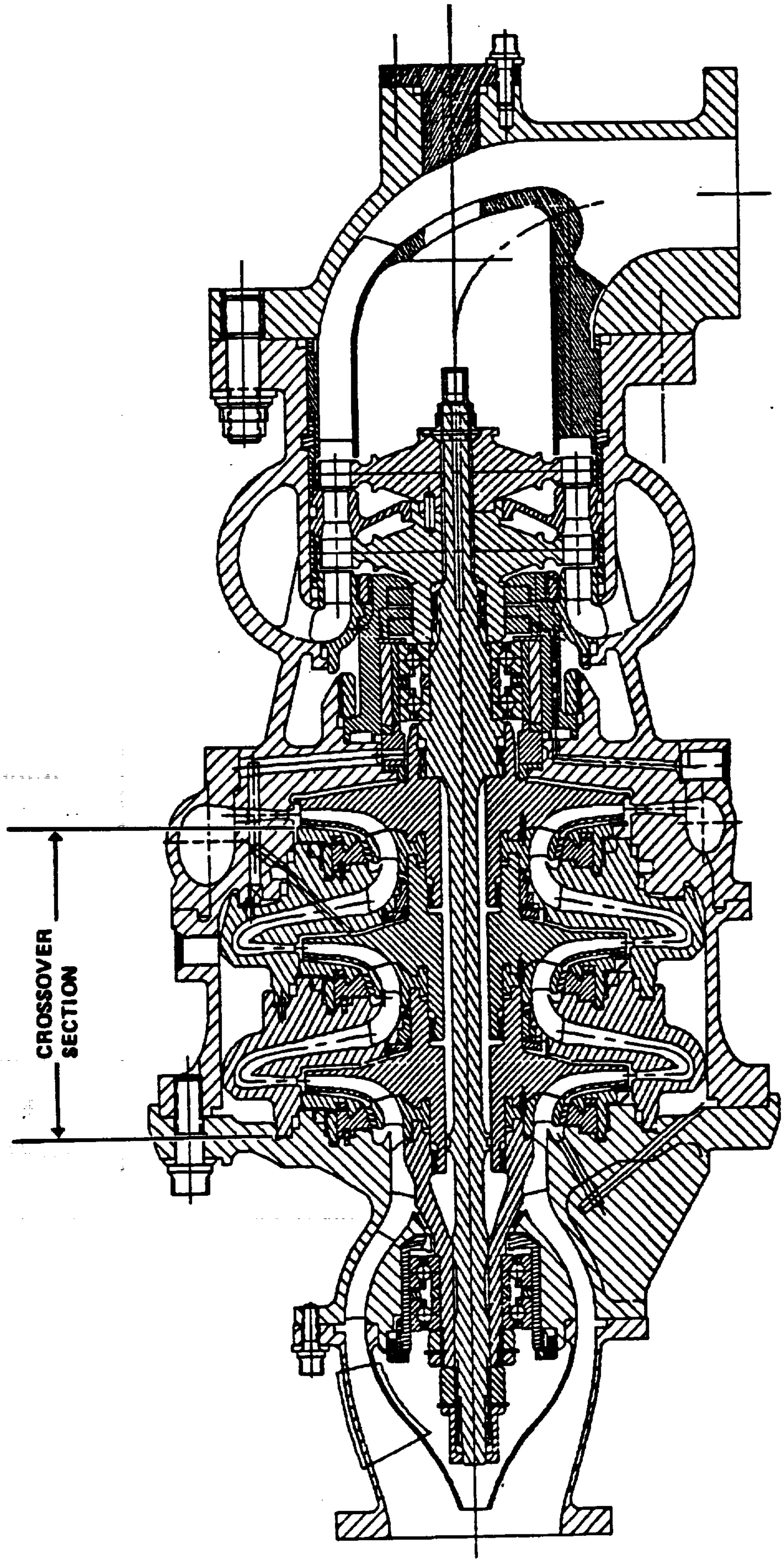


Figure 1 - MK49 Fuel Turbopump Cross-Section

the model test to bring it closer to the Reynolds number of operation in hydrogen of the full scale MK49-F.

Table 1 gives the basic dimensions and operating parameters of both the MK49-F pump for full speed operation in hydrogen and the scale up model for the subject test program.

Tests of the high velocity ratio diffusing crossover tester with unsteady whirling flow from the exit of the scaled up impeller, were conducted to evaluate the influences of the large-scale turbulence, non-uniform velocity profile, and non-steady velocity on the MK49-F stage performance and efficiency. Tests were conducted in two fluids, water and air, to determine the effects on performance over a wide range of Reynolds number.

Table 1 - Basic Parametric Information MK49-F Turbopump versus Crossover Test Rig

	MK49-F Turbopump	Crossover Tester	
Parameter	LH_2	Water	Air
Inducer Tip Diameter (inch)	1.95	5.56	5.56
Impeller Tip Diameter (inch)	3.90	11.124	11.124
Diffuser Inlet Diameter (inch)	4.30	12.25	12.25
Number of Blades:			
Inducer	4	4	4
Impeller	4+4	4+4	4+4
Diffuser	17	17	17
Inducer Flow Coeff. (ϕ=C_m/U_t) *	0.10	0.10	0.10
Design Speed (rpm)	110,000	6322	6322
Design Flow (gpm)	436	583	583
Reynolds Number **	7.6×10^7 ***	2.31×10^7	1.65×10^6

* Inlet Flow Coefficient, ϕ, where C_m is the meridional fluid velocity and U_t is the inducer tip speed.
** Reynolds number based on impeller diameter and speed.
*** At 33,400 rpm, Reynolds number drops to 2.31×10^7.

TECHNICAL DISCUSSION

DESIGN AND FABRICATION

Tester Configuration & Layout

Analytical and computer predictions determined that, for optimum performance of the RS-44 advanced expander cycle engine, an interstage diffusion of 6.23 for the MK49-F would result. However, there was little published data on multistage pump crossovers having high diffusion velocity ratios. Rocketdyne's experience was limited to a maximum diffusion velocity ratio of 5.46 used in the MK48-F turbopump. The high diffusion rate of the MK49-F was sufficiently beyond the current experience base that a test program to evaluate the performance of the high velocity ratio diffusing crossover was required. The overall objective was to design a tester and experimentally evaluate the performance of the high velocity ratio diffusing crossover used in the first and second stages of the MK49-F high pressure fuel turbopump.

The high velocity ratio diffusing crossover tester, shown in Figure 2, was designed with two major design requirements imposed. The first requirement was to design the crossover tester around the dimensions of the existing SSME HPFTP tester interfaces to minimize the tester design and fabrication costs. The second requirement was to incorporate as much internal instrumentation as possible to maximize the information obtained during testing of the diffusing crossover passage and MK49-F pumping elements.

A scale factor of 2.85 was determined from the SSME HPFTP impeller tester hardware. The crossover tester layout was then generated by maintaining these interface geometries and directly scaling the MK49-F turbopump pump elements. Figure 3 shows the cross-section of the HPFTP tester shaft, discharge manifold, bearing carrier, face seal, and bearing assembly which were used by the crossover tester. The hardware parts list for the High Velocity Ratio Diffusing Crossover tester are shown in Table 2.

The MK49-F inducer, impeller, and crossover housing, components were scaled up to mate with the HPFTP tester discharge manifold. A scale factor of 2.85 was used to increase the size of the MK49-F impeller from 3.900 inches in diameter to a size of 11.124 inches. With this scale factor established, the crossover, the impeller, and the inducer were designed.

Figure 2 - Crossover Tester Cross-Section

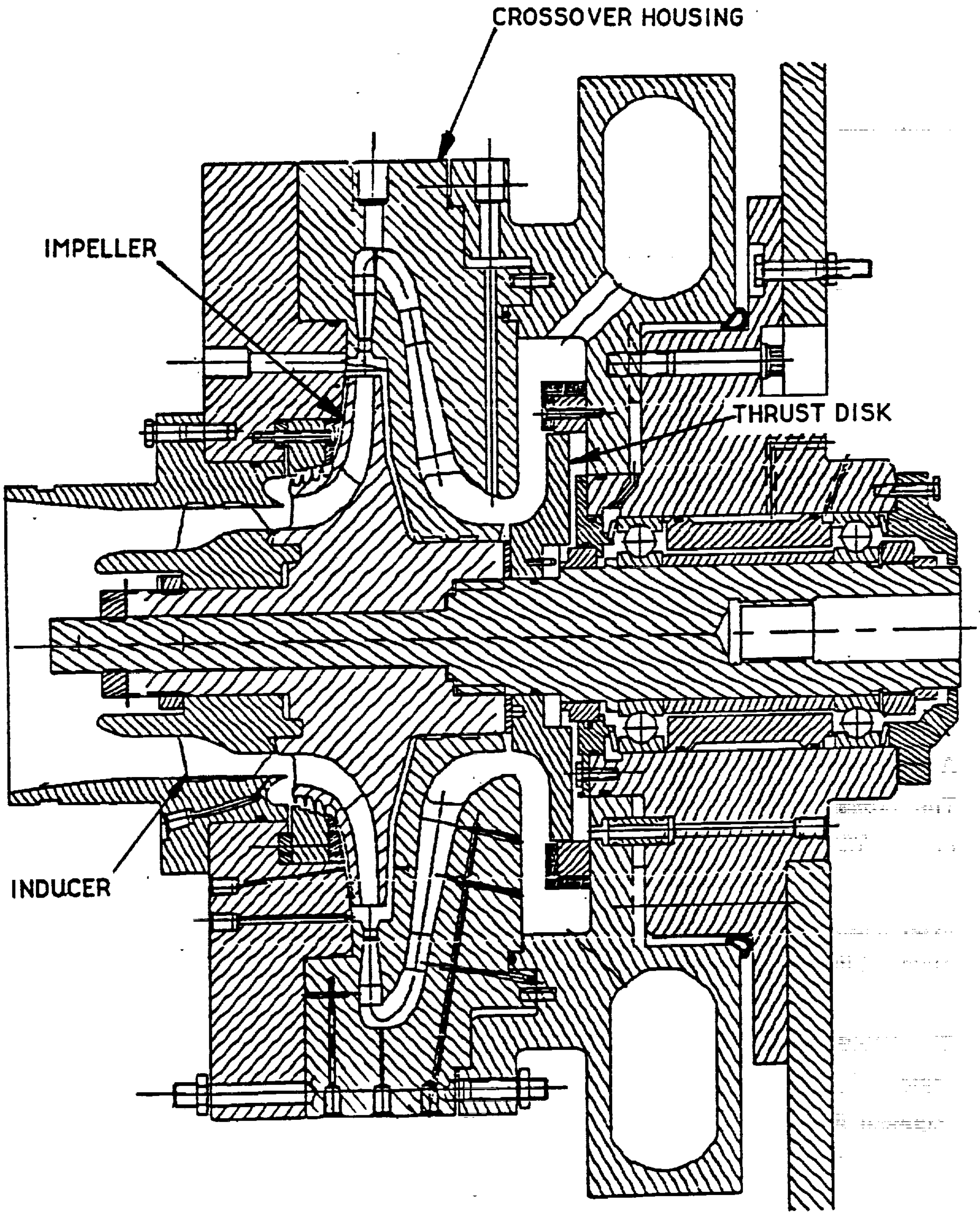


Figure 3 - Existing SSME HPFTP Tester Hardware

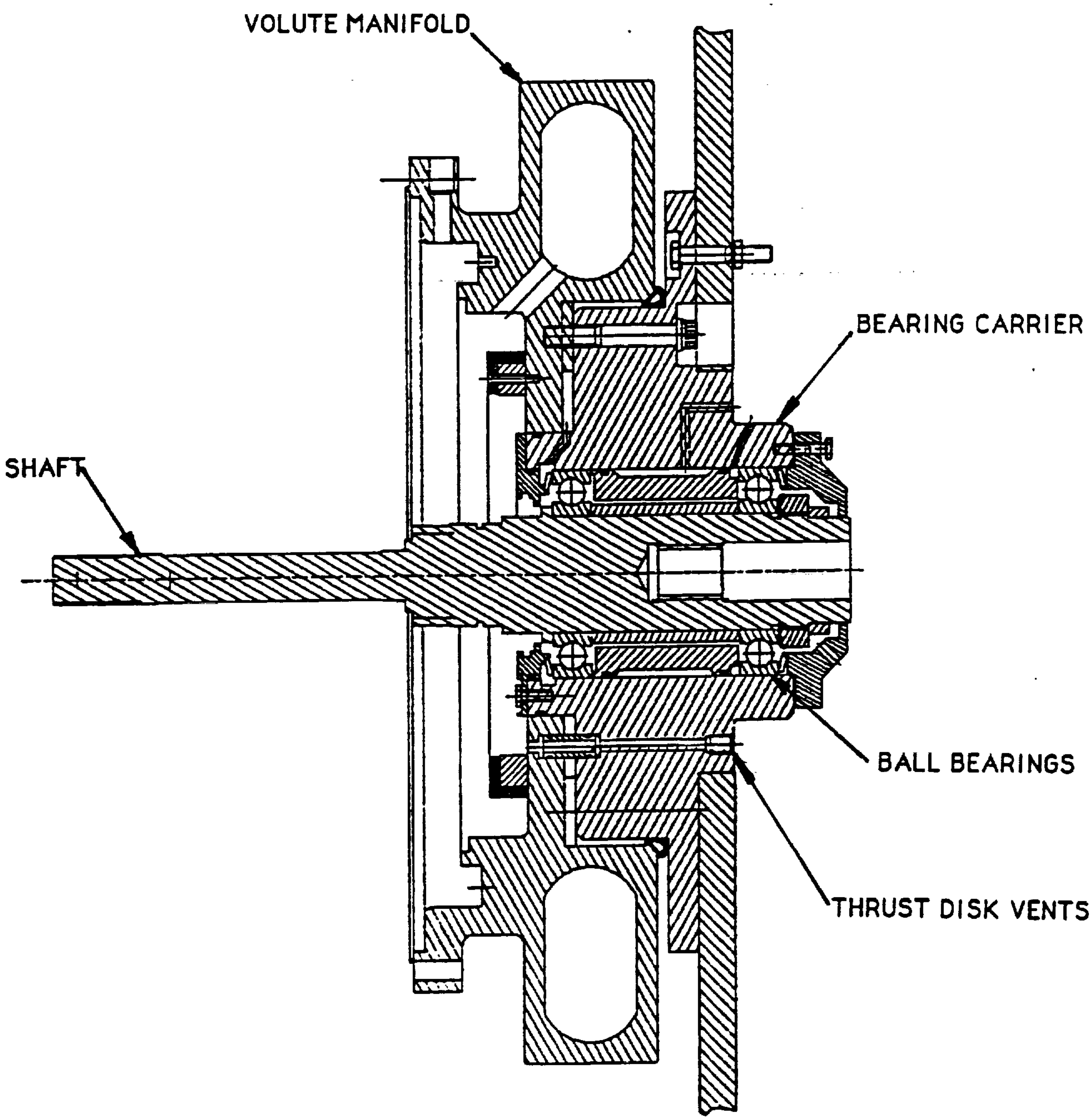


Table 2 - Crossover Tester Parts List

HIGH VELOCITY RATIO DIFFUSING CROSSOVER TESTER
PARTS LIST

PART NO.	DESCRIPTION	QNTY
7R0017922-5	TUBE	6
7R0017923-3	HOUSING, PUMP END	1
7R0017924-3	COVER PLATE, BEARING PRELOAD	1
7R0017925-3	CROSSOVER HOUSING	1
7R0017927-3	FACE SEAL MATING RING	1
7R0017927-5	THRUST DISK	1
7R0017928-3	THRUST DISK SEAL	1
7R0017928-5	RETAINER, THRUST DISK SEAL	1
7R0017930-1	IMPELLER	1
7R0017931-1	INDUCER	1
7R0017932-3	NUT (INDUCER)	1
7R0017933-3	LOCK (INDUCER)	1
7R0017934-3	SPACER	1
7R0017935-3	LOCK (IMPELLER)	1
7R0017936-3	SPACER	1
7R0017938-3	RETAINER	1
7R0017940-3	SEAL, LABY	1
7R0017940-5	RETAINER, LABY SEAL	1
7R0017941-3	NUT (IMPELLER)	1
7R0017942-3	SPACER	1
7R0017943-3	SCREEN	1
7R0017944-1	INLET	1
7R0017945-3	SPACER	1
7R0017950-3	TUBES	2
7R0033904-3	SPACER	1
MS 9390-580	PIN	3
T-5100073-120	FACE SEAL, SEALOL:3-3-B002B0-44	1
T-5100073-108	SPACER	1
T-5100073-104	NUT	
T-5100073-501	SLEEVE	1
T-5100073-801	COLLAR	1
T-5100073-104	SCREW, SET	2
SKF 7214 BEA	BEARING	2
EWR307280-007	MAINFOLD	1
EWR306802-003	SHAFT	1
EWR306803-003	BEARING CARRIER	1

High Velocity Ratio Diffusing Crossover

A pair of straight channel type vaned diffusers, with square cross-section separated by a variable cross-section turning channel, were chosen for the MK49-F. The same concept was chosen for the lower area ratio SSME HPFTP diffusion system which had demonstrated an outstanding efficiency.

For a straight channel diffuser design, maximum performance requires a uniform flow field at the diffuser inlet, or throat. To improve the inlet flow field and reduce the perturbations produced by the passing impeller blades, a vaneless entrance region, just upstream of the diffuser throat, was included in the design. A detailed vane leading edge geometry and flow pattern relationship was investigated, using available analytical codes, to determine the diffuser inlet flow angle and velocity from the impeller. From this information, the inlet vane angle, throat area, and number of crossover passages were determined. Once the inlet geometries were satisfied and the throat flow field established, the diffuser geometry was produced.

At the exit of the upcomer diffuser, a three-dimensional transition section turns the flow radially inward to the inlet of the downcomer diffuser, forming a continuous crossover passage, as seen in Figure 4. The turning channel cross-section changes continuously through the turn to minimize the static pressure gradient across the passage. These pressure gradients, created by the centrifugal force of the fluid in the turn would induce secondary flows which would reduce the overall crossover performance. The design of the turning channel required the use of computer-aided design (CAD) to produce the three dimensional lay out.

Figure 5 shows the ceramic casting core assembly of the seventeen crossover passages of the MK49-F turbopump. The High Velocity Ratio Diffusing Crossover tester passages were scaled up directly from the coordinates generated on CAD for the MK49-F crossover.

Initial bids for casting the aluminum crossover housing resulted in only one bidder response at a cost three times greater than the estimated costs based on the MK49-F crossover cores. It was decided that casting the crossover from a high strength plastic would save both cost and schedule. By casting with a plastic, costs would be saved in raw materials and "hard" tooling which are required for metal castings. A plastic, FR-40/5481C epoxy, crossover housing was designed, with an aluminum reinforcing ring.

Figure 4 - Crossover Passage Layout and Nomenclature

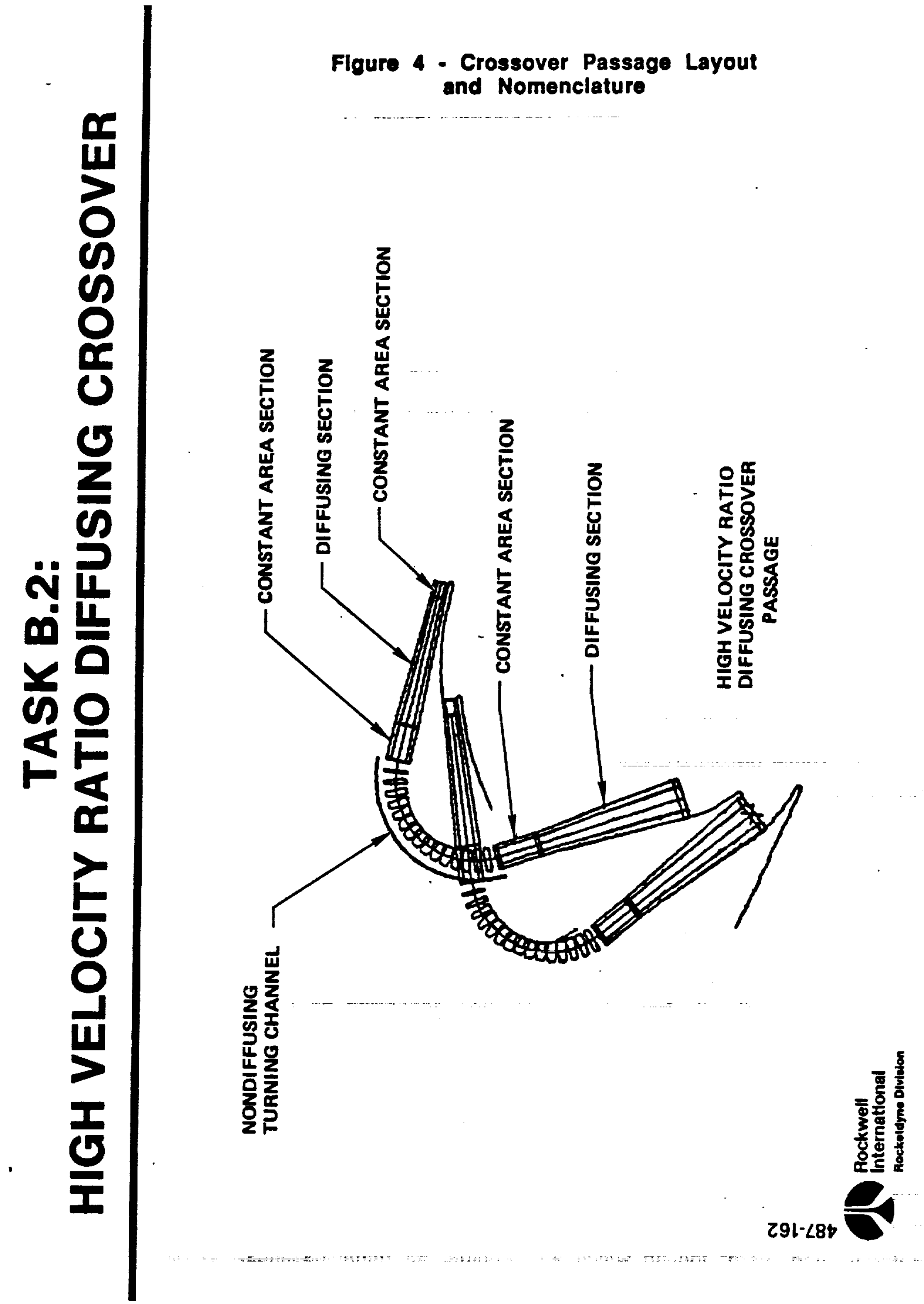
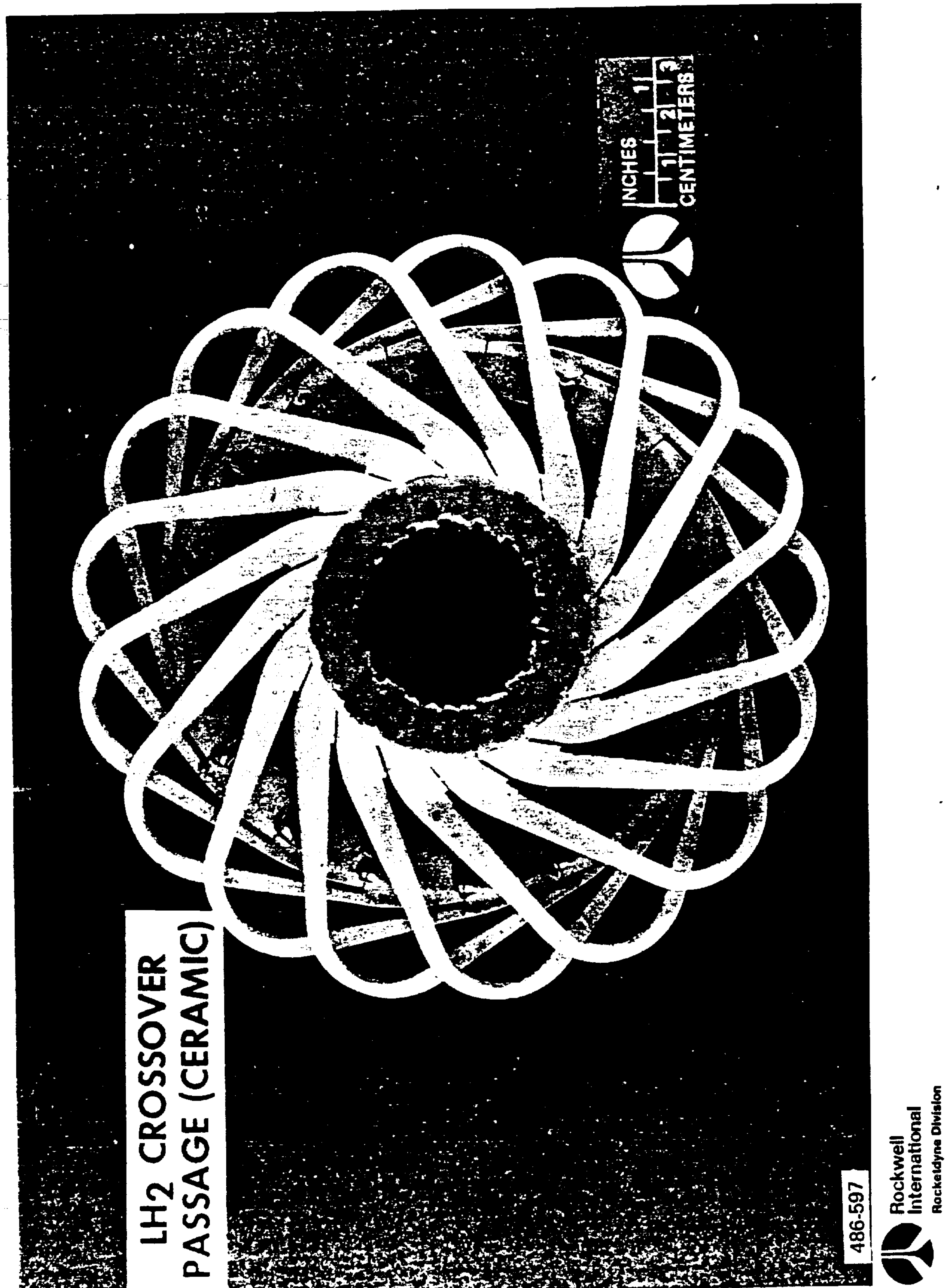


Figure 5 - MK49-F Turbopump Crossover Casting Core



Tri-Models was placed under contract to construct the core and tooling required to produce the plastic crossover housing, while the actual pouring of the part would be conducted at Rocketdyne. However, when Tri-Models completed the core box, their costs exceeded the purchase agreement. As a result, Rocketdyne took delivery of the core box only.

Using the core box and FR-40/5481C epoxy provided by Rocketdyne, A & M Model Makers was contracted to cast the crossover housing. Wax cores were successfully made and assembled into a "negative" of the crossover. The plan was to pour the plastic into the mold surrounding the cores, and then return the crossover to Rocketdyne for elevated temperature curing, which would promote the greatest strength of the epoxy. The pouring technique was designed to slowly cure the casting at an elevated temperature to reduce risk of cracking the crossover housing. However, when the pour of the plastic proceeded, cracks began to appear almost immediately. By the completion of the pour, the housing was riddled with cracks. The cracking was caused by normal shrinkage of the plastic, the aluminum reinforcement ring restricting any movement by the shrinking plastic.

The crossover housing drawing, 7R0017925, was modified to fabricate the part from aluminum alloy 356. Burrows Pattern Works was contracted to fabricate a set of ceramic cores from the existing core box . The cores were dimensionally inspected and found to be within the tolerance of the drawing. Enough cores were fabricated by Burrows Pattern Works to produce four crossover housings. The ceramic cores and the core box were delivered to Wellman Dynamics for casting. Figure 6 shows one of seventeen crossover cores which were assembled for each crossover housing pour.

Upon the attempt to cast the crossover housing, Wellman found that the Burrows Pattern Works cores were unusable. The long thin crossover inlet necessitated a high percentage of core binder. During the pour, the binder vaporized at the temperatures of molten aluminum, causing blows and cold shuts, ruining the casting. Wellman was forced to make their own cores using alumina sand and glass reinforcing rods running through the center of each core. Figure 7 shows the completed Wellman core assembly. Prior to the first pour by Wellman, the passage cores were dimensionally inspected and were found to meet the tolerance requirements of the drawing. In seven attempts to cast the crossover, only one good crossover housing was produced. Figure 8 shows the diffuser inlet vanes of this crossover housing. Rocketdyne released Wellman of the requirement for two castings, because of the excessive costs required to achieve a useable product.

Figure 6 - Individual Casting Core for Crossover Tester

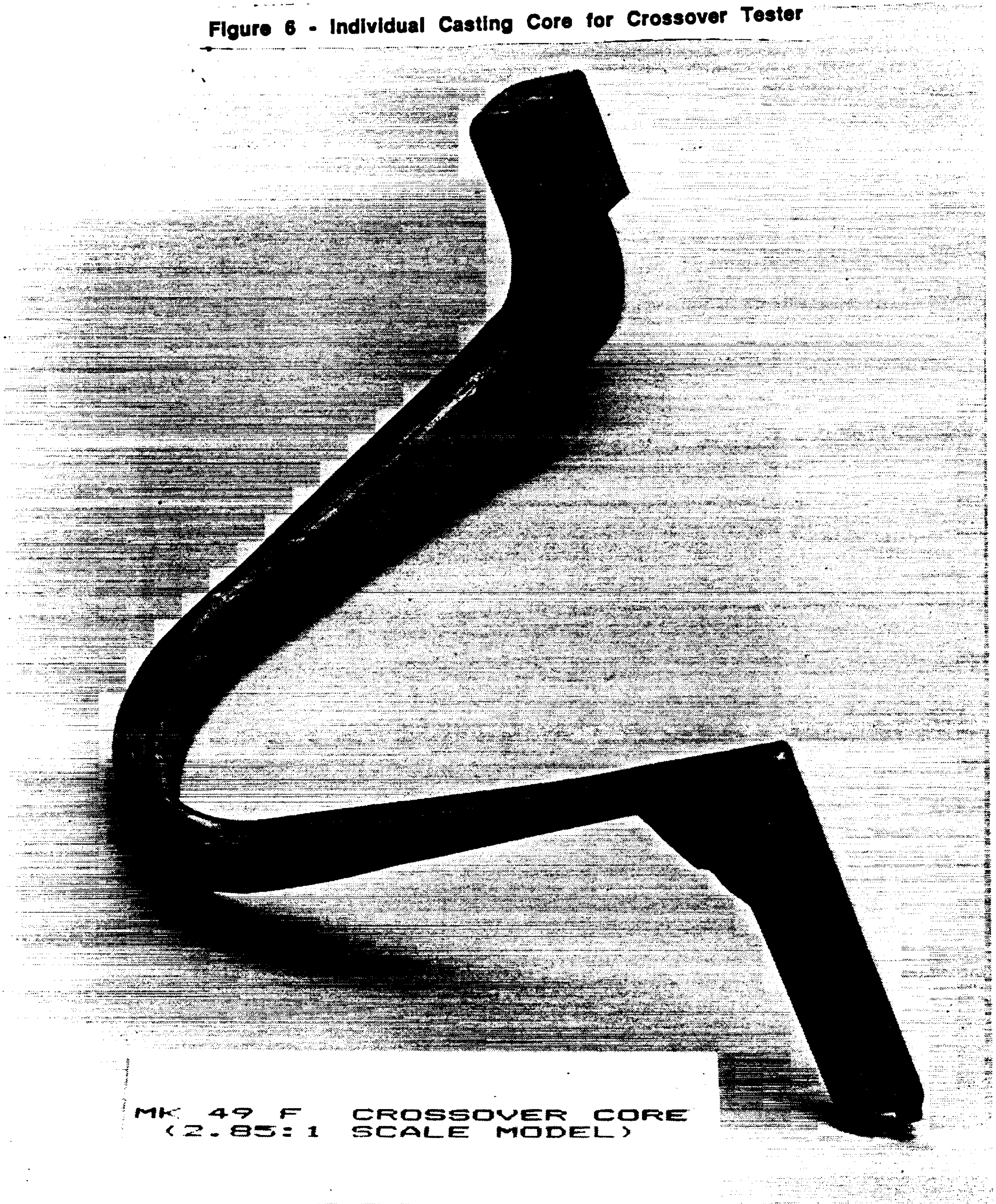


Figure 7 - Assembled Casting Cores for Crossover Tester by Wellman

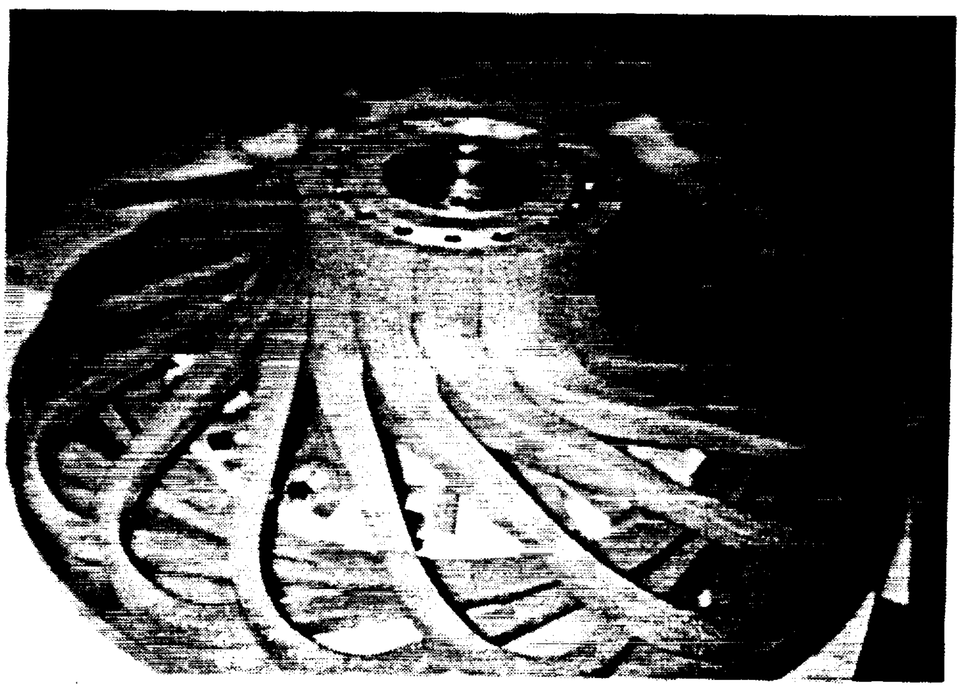
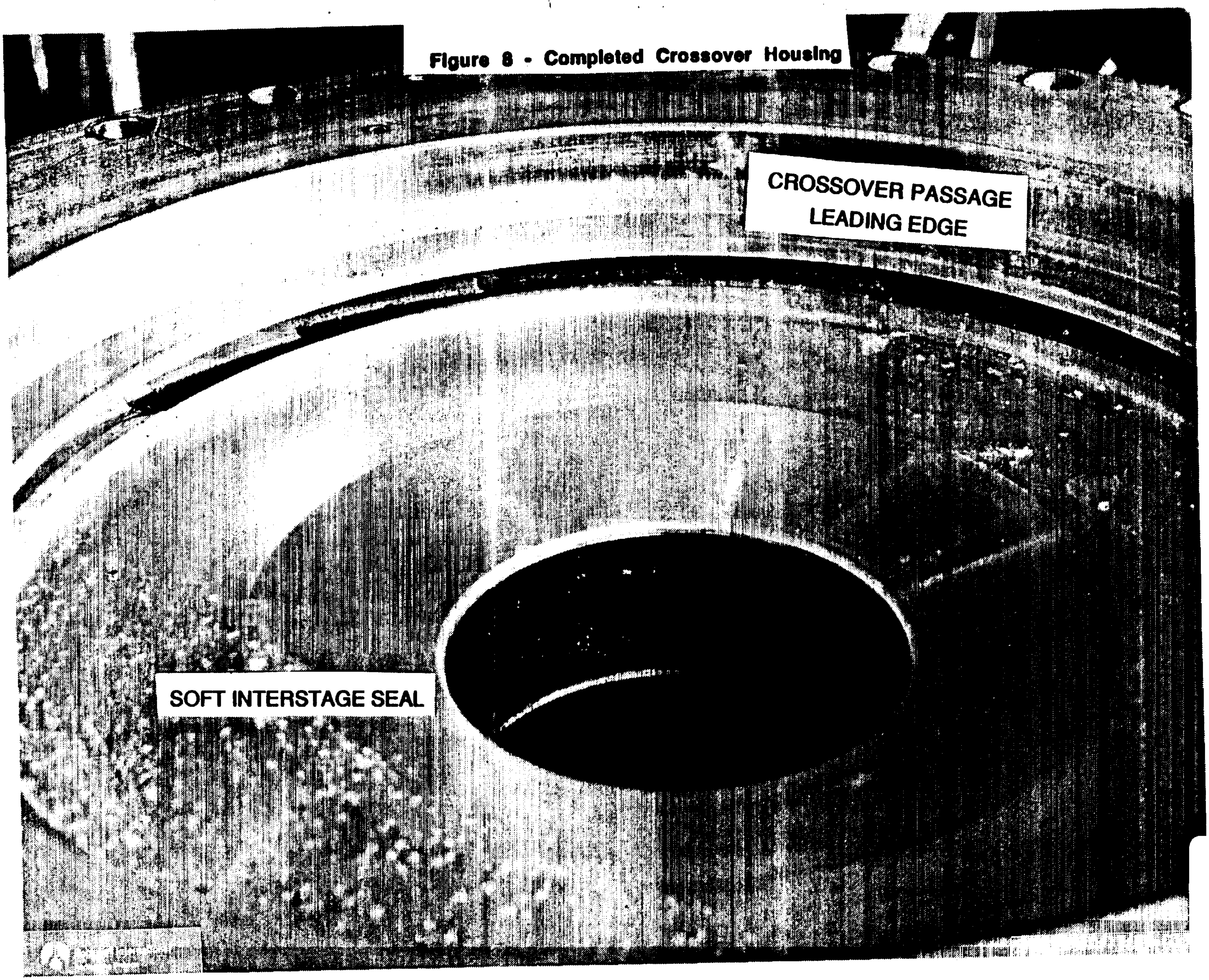


Figure 8 - Completed Crossover Housing



Impeller

The crossover tester impeller design, 7R0017930, maintained the critical dimensions of the MK49-F, such as blade geometry, inlet area, exit area, tip width, and shroud contours. However, the MK49-F impeller was machined in two pieces from titanium in the form of a pre-impeller and main impeller. The aluminum alloy 6061-T6 impeller was also designed and fabricated in two pieces, but in the form of a shroudless impeller and a front shroud. The impeller blades and face were numerical control (NC) machined to produce the complicated flow passage. The scaled-up impeller with the front shroud removed can be seen in Figure 9. Once the impeller blades were machined and dimensionally inspected, the front shroud was bonded to the impeller face using a furnace braze process. At the completion of the furnace braze operation, the impeller was machined to final dimensions and is shown in Figure 10.

Inducer

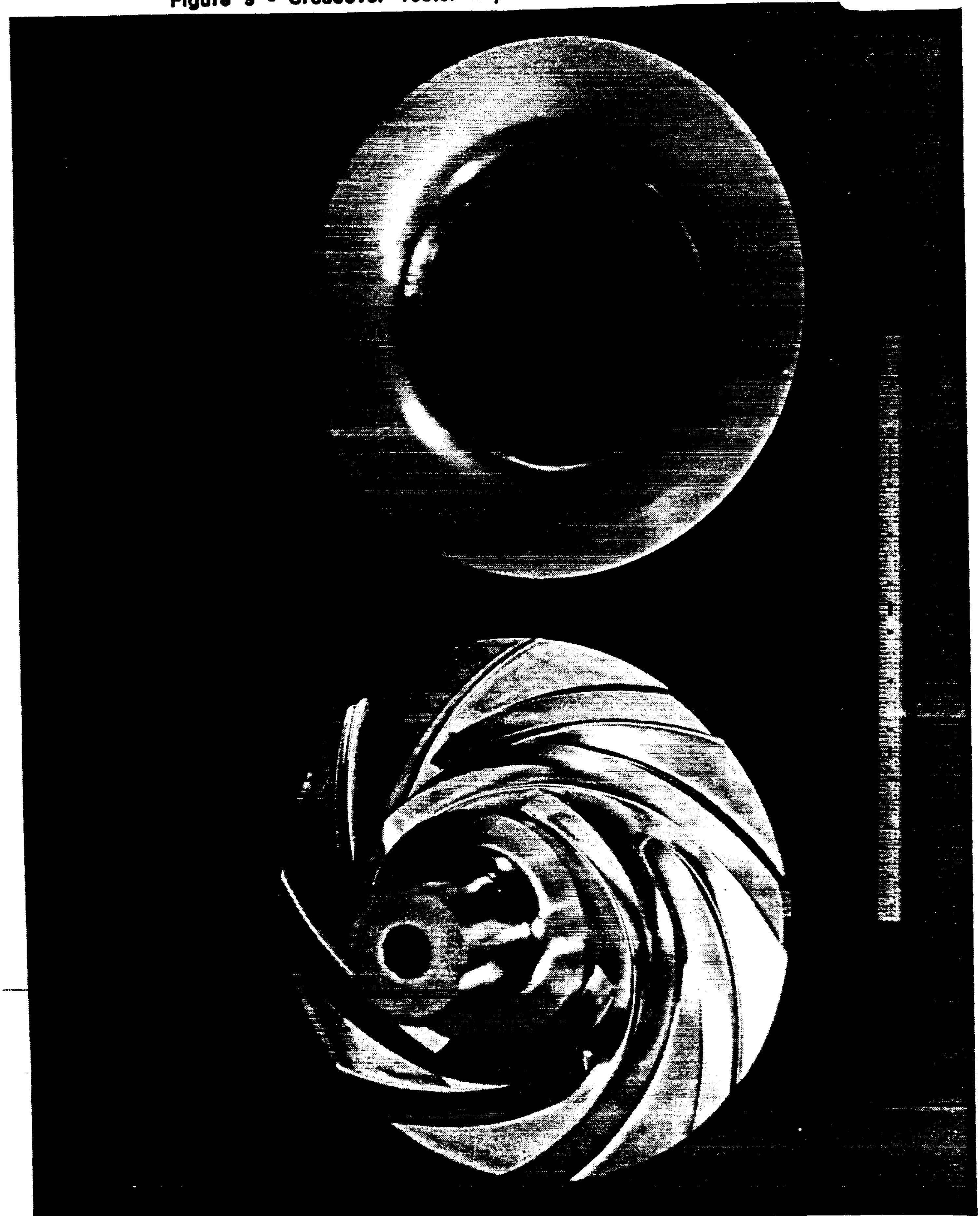
The crossover tester inducer, 7R0017931, was NC machined from aluminum alloy 7075-T73. The inducer blade coordinates, hub contour, and leading edge contours were also scaled directly from the MK49-F inducer using CAD. The crossover tester inducer is shown in Figure 11.

Dynamic Soft Wear Ring Seals

To gain some experience with the soft seal technology, being developed concurrently in task B.5 of this contract, cast in place polyurethane seals were incorporated in the inducer tunnel and the impeller interstage seal. The inducer seal was centrifugally cast by pouring the seal material, Hexcel 3125, in the inducer tunnel, while rotating the part on a lathe for several hours. A similar technique was used to cast the interstage seal in the inner diameter of the crossover housing. The seals were then machined to final bore dimensions after the casting and curing processes were completed. The casting and subsequent machining techniques were very successful. A photograph of the soft seal material in the inducer tunnel, 7R0017944, is shown in Figure 12.

The impeller front wear ring labyrinth seal and thrust disk seal also used soft seal technology and were machined from Kel-F stock. These seals went through several curing cycles before they were machined to their final dimensions. The clearances for the inducer tunnel, interstage seal, and the front wear ring labyrinth seal were also scaled by 2.85 from the MK49-F design, as shown in Table 3.

Figure 9 - Crossover Tester Impeller with Shroud Removed



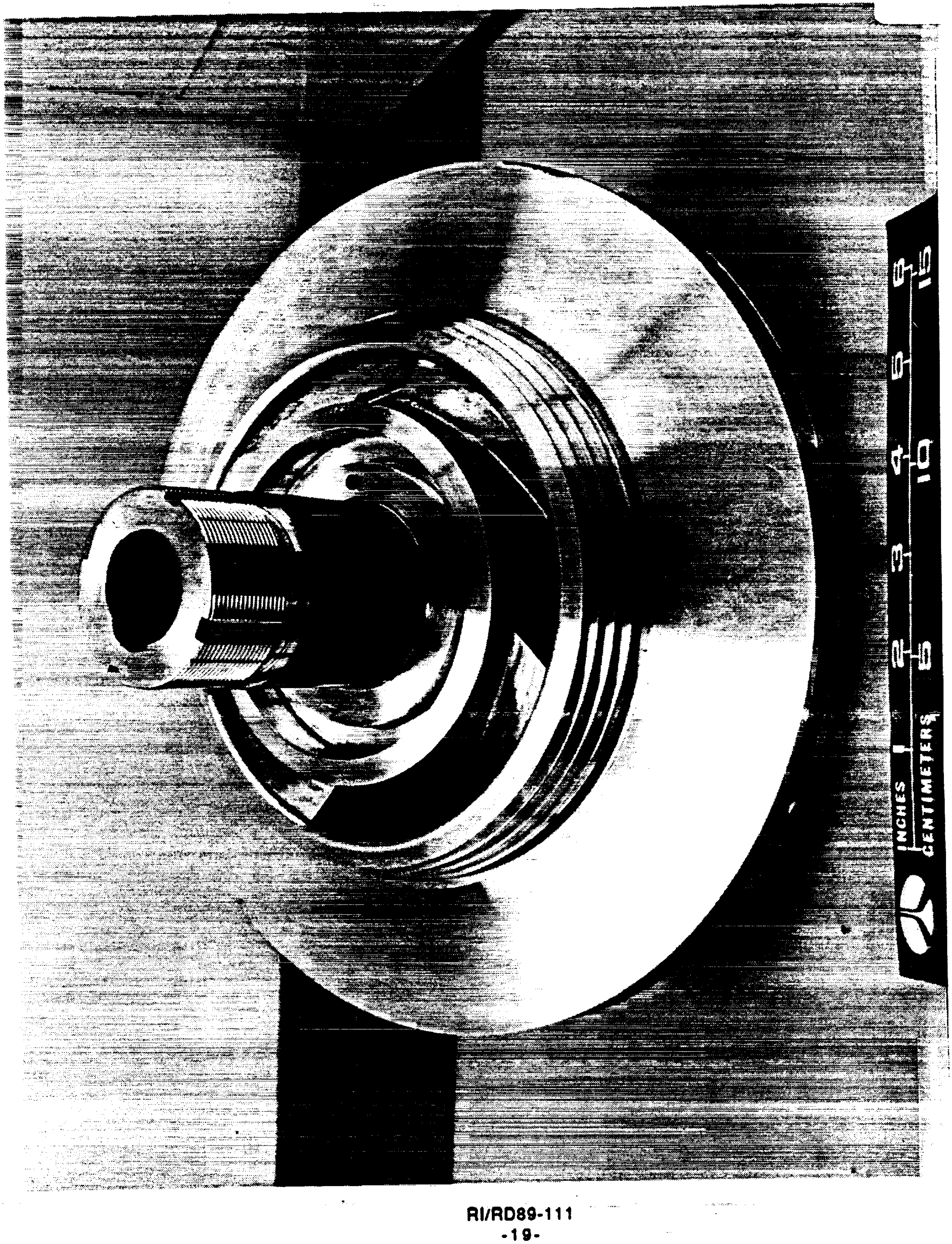


Figure 10 - Final Machined Crossover Tester Impeller

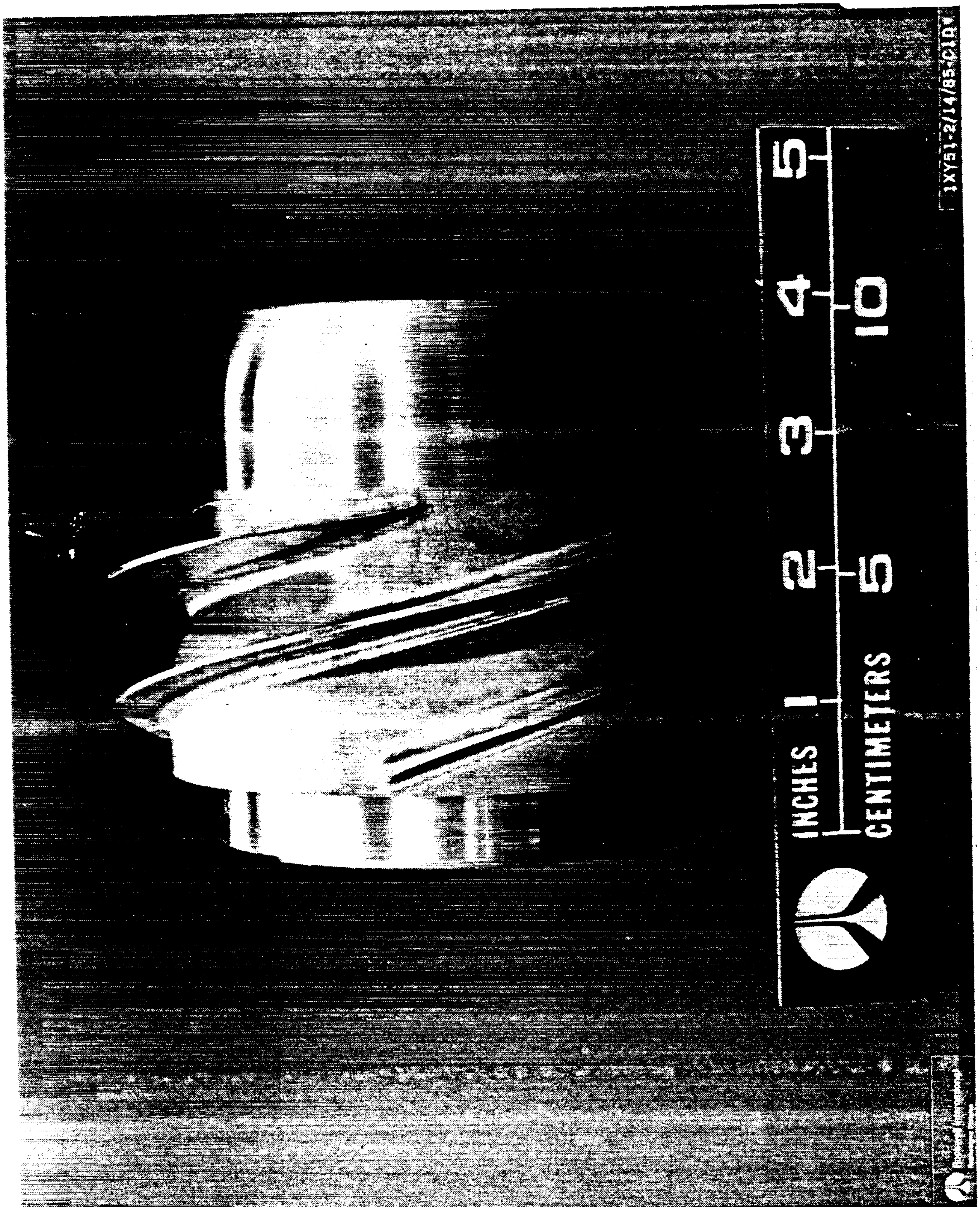


Figure 11- Crossover Tester Inducer

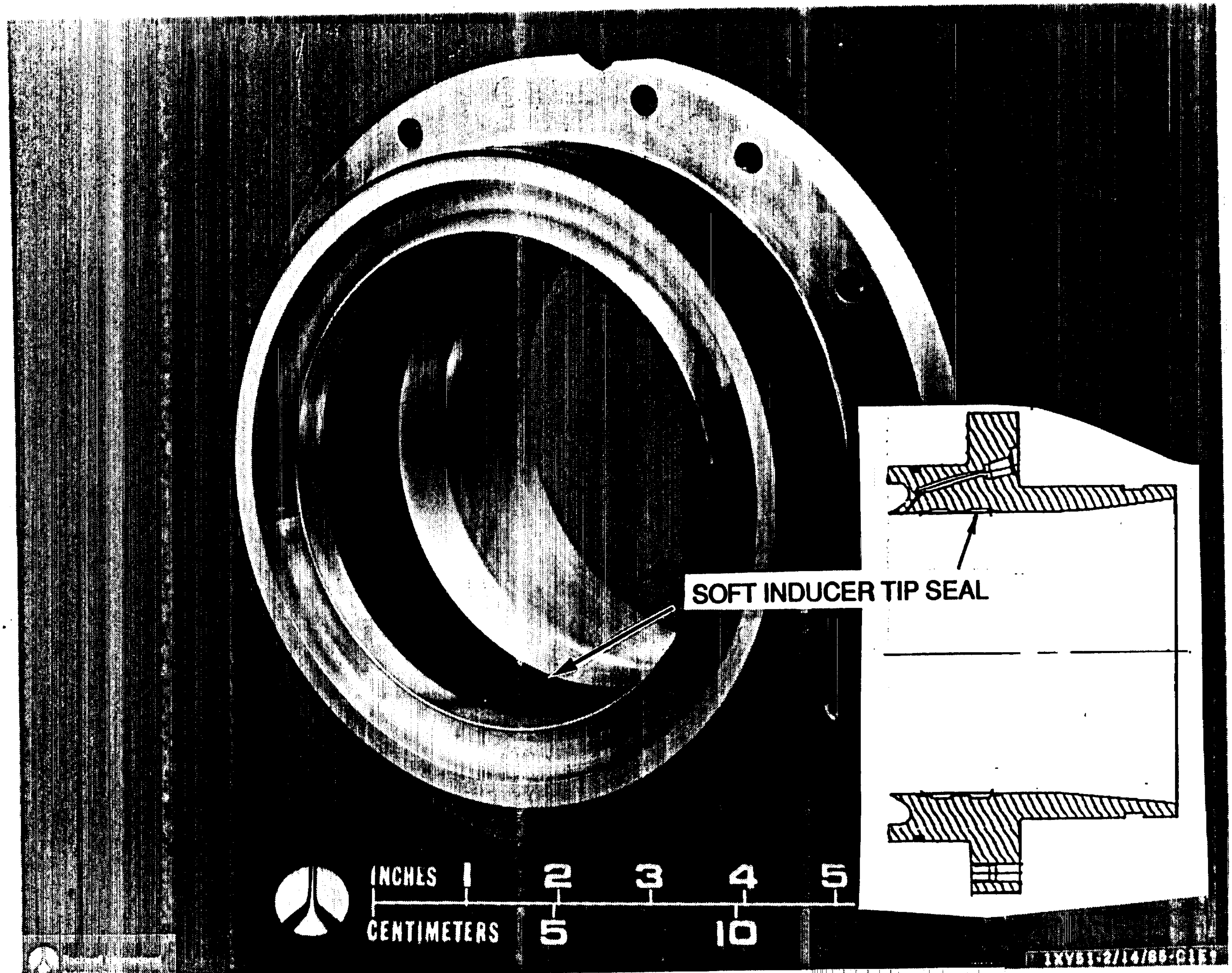


Figure 12 - Crossover Tester Inlet Housing with Soft Inducer Tip Seal

Table 3 - Operating Clearance Comparison
Crossover Tester vs. MK49-F

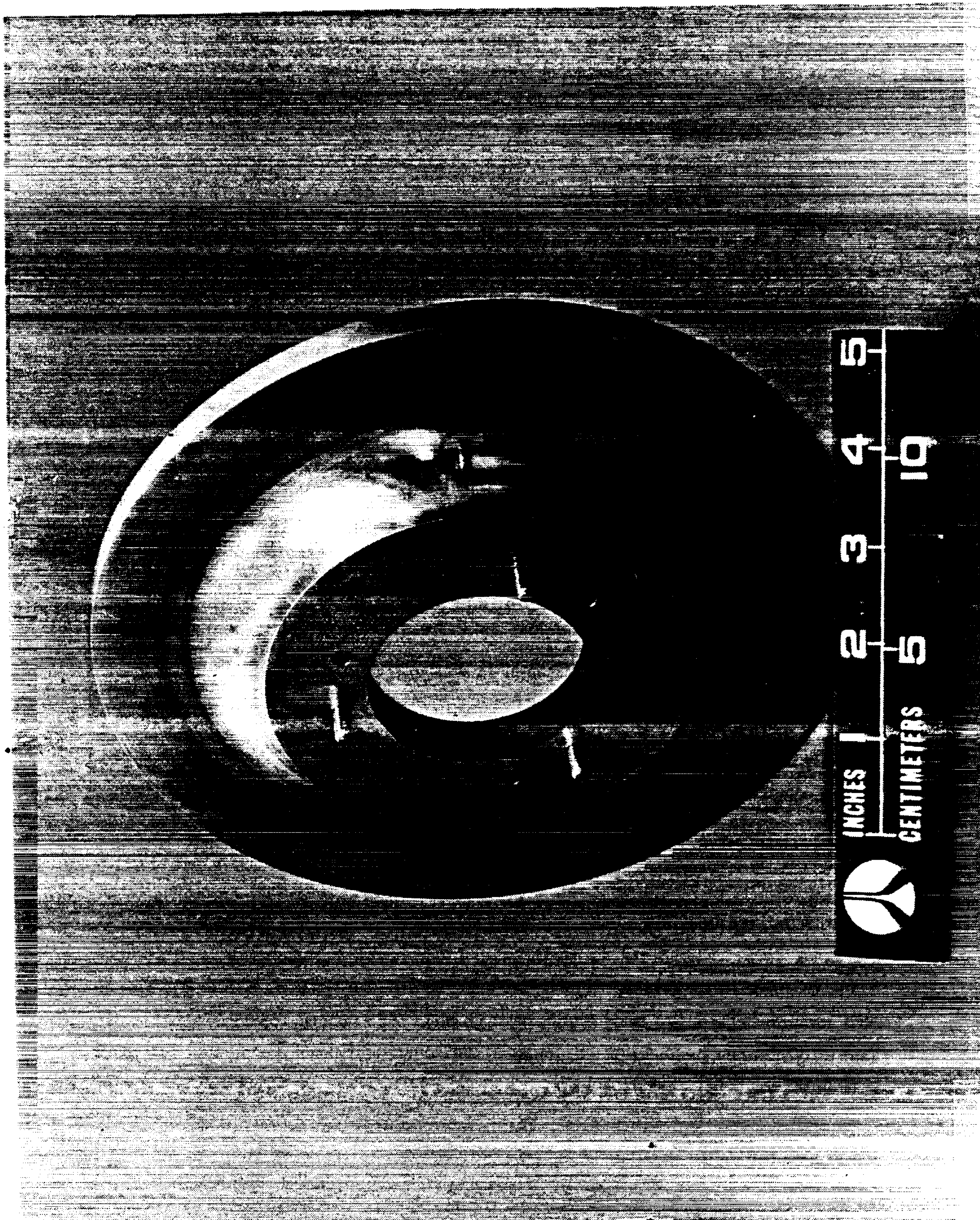
Diametral Clearance (inch)

Clearance Location	Crossover Tester	MK49-F Turbopump
Impeller Tip	0.710	0.250
Impeller Front Hub Labyrinth	0.023	0.008
Inducer Tip	0.029	0.010
Interstage Seal	0.023	0.008

Thrust Disk

Hydrodynamic analysis of the test pump showed the potential of large loads with some uncertainty of the load direction due to the lack of definitive pressure profiles around the impeller shrouds. With moderate changes in the effective vortex strengths in these shroud areas, the total net axial force could change direction and magnitude. To better handle this potential load variation the drive end bearing stop was replaced with a belleville spring to accommodate the thrust without unloading. Also, a thrust compensating disk, 7R0017927, as seen in Figure 13, was added to the design. To cross the gap between the volute manifold and the bearing carrier, transfer tubes, 7R0017922, were designed to allow the thrust disk back pressure to be vented through a control valve overboard. By allowing some of the crossover discharge flow to leak past the thrust disk tip seal into the thrust disk drain cavity, the pressure behind the disk could be regulated to produce the desired resultant axial thrust. Blank transfer tubes (no through holes) were also designed to return the manifold to its SSME test condition.

A thermodynamic computer model of the pump was developed to predict the axial load over the anticipated test range. The pressure of 461 psia in the thrust disk drain cavity was selected to preclude the direction of the axial thrust at the 80% design flow towards the drive end. This pressure yields a uniform thrust direction with a maximum amplitude of 3555 lb. toward the pump inlet at 120% design flow as shown in Table 4. Also seen in Table 4, the loads produced at 60 and 70 percent of design flow are larger than at 80 percent because of the predicted stall characteristic of the pump. The axial load in air was considered negligible.



[illegible] Tester Thrust Balance Disk

Table 4 - Hydrodynamic Performance and Axial Load Predictions
Crossover Tester Internal Static Pressures (psia) in Water

Tester Location	% of Design Flow Q_d (583 gpm)					
	60%	70%	80%	100%	110%	120%
Inducer Inlet Pr	94.3	94.3	94.3	94.4	94.3	94.3
Inducer Discharge Pr	163	160	156	141	129	114
Impeller Discharge Pr	558	556	553	541	528	509
Imp Front Shroud Hub Pr	365	362	360	347	335	315
Imp Rear Shroud Hub Pr	529	527	523	512	499	480
Crossover Disch Pr	711	708	741	710	685	649
Thrust Disk Front Pr	724	720	751	718	693	658
Thrust Disk Rear Pr	461	461	461	461	461	461
Axial Thrust (lbf) *	1336	1474	43	1333	2273	3555

* Positive Load towards the Pump Inlet.

Ball Bearings and Shaft Support System

In addition to adding the thrust disk, a redesign of the pump bearing system was also required. The original 70mm bore conrad ball bearings, used in the SSME HPFTP tester, could not be used due to the high variations in axial load for the flow ranges to be tested. The maximum axial load capacity calculated for these bearings was 2500 lb. It was therefore necessary to increase the ball bearing axial load capacity. As a result, a pair of 70mm J type angular contact ball bearings were procured to replace the original conrad bearings. Mechanical preloading was used to obtain the appropriate radial stiffness and accommodate axial translation.

DESIGN SUPPORT ANALYSIS

Rotordynamics

In early 1984, the preliminary MK49-F crossover tester design, without the thrust disk, was analyzed to predict the critical speeds, shaft mode shapes, and shaft deflection. The rotating assembly consisted of a single stage inducer and impeller subassembly cantilevered on a shaft supported by two ball bearings. The finite element model of the rotor is shown in Figure 14. The rotor was segmented into 10 weight groups and 25 finite elements. The bearings were represented as translational springs to ground (rigid casing), and the assembly drive coupling shaft was assumed to add weight but no radial stiffness to the system.

MK-49F CROSSOVER TESTER

ROTATING ASSEMBLY MODEL

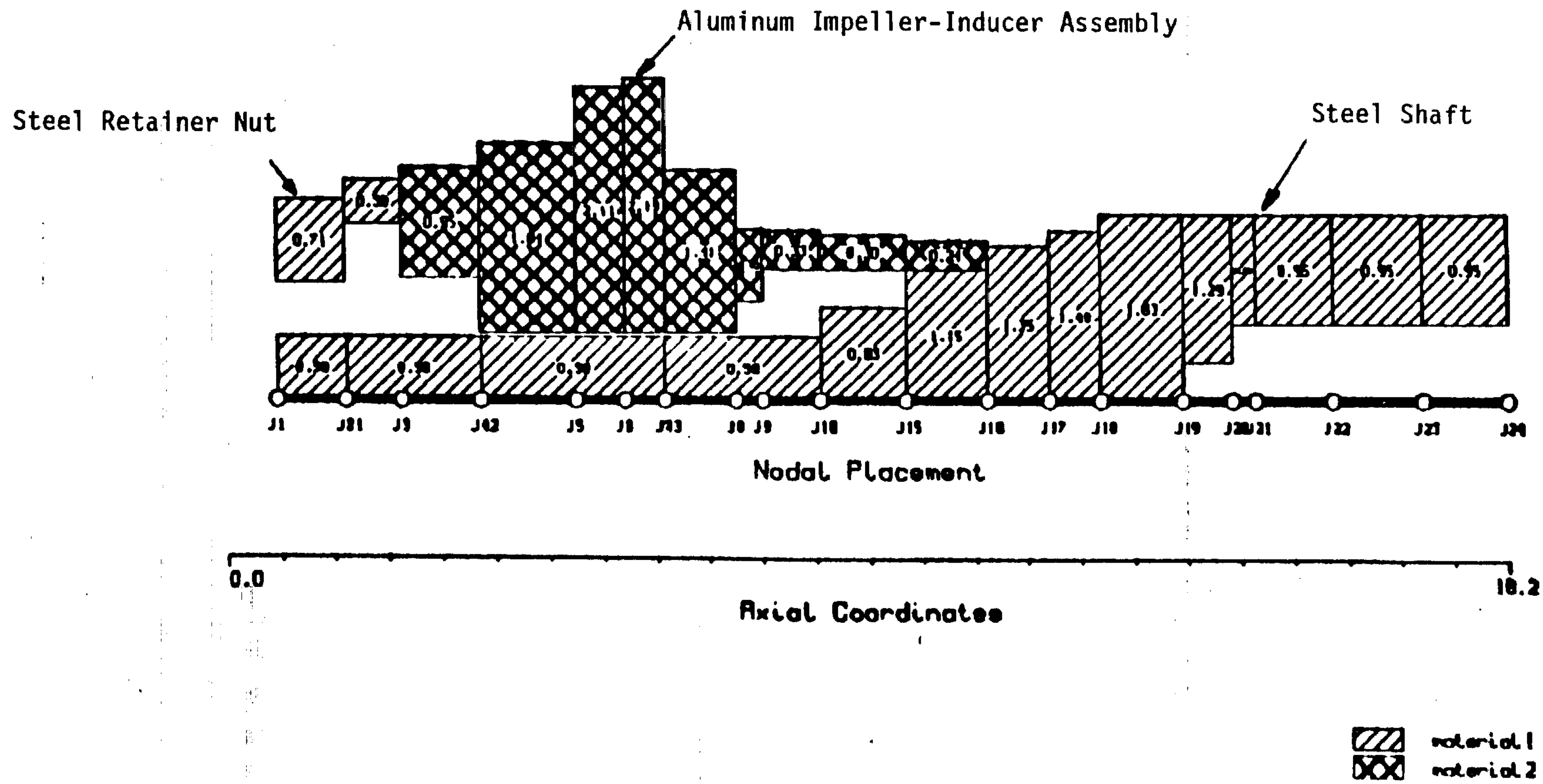


Figure 14 - Crossover Tester Rotordynamic Finite Element Model

The first three critical speeds of the rotor, pumping water and air respectively, are shown in Figures 15 and 16 as a function of bearing stiffness. The mode shapes corresponding to these critical speeds, for a bearing stiffness of 500,000 lb/in., are given in Figure 17. For the tester running in water, the operating speed is 6,322 rpm. Observing the normal rotordynamic practice of not operating within 20% of a critical speed, a first critical speed of at least 7590 rpm is required. According to Figure 15, if the bearings have a minimum stiffness of approximately 440,000 lb/in., the first critical speed would be over 7590 RPM, and the machine could operate safely at 6,322 RPM. The preloaded angular contact ball bearings easily met these radial stiffness requirements.

With air as the pumped fluid, a similar critical speed analysis was conducted with proposed operating speeds of 6,322 rpm and 14,000 rpm. This analysis was required because in the previous analysis, water being pumped adds mass and damping to the rotor system, while air, due to its low density and compressibility, provides less mass and virtually no damping. Again, a 20% margin on critical speeds was maintained and no critical speeds were found between 5,000 and 7,500 rpm and between 11,670 and 17,500 rpm for the predicted bearing stiffnesses, as seen in Figure 16. It was noted for the 14,000 rpm case, that the tester would run between the first and second critical speeds and below twice the first critical speed eliminating the requirement for a rotor stability analysis. The critical speed analysis showed that this machine could operate safely at either of the desired shaft speeds.

Due to the overhung nature of the crossover tester design, an unbalance response analysis was performed to determine the potential rubbing due to rotor deflection. Figure 18 and 19 show the predicted inducer and impeller deflections, respectively, as a function of rotor speed with 500,000 lb/in bearing stiffnesses. At 6,322 rpm, the predicted deflections were significantly less than the radial clearances built into the tester as shown earlier in Table 2. Figures 20 and 21 show similar inducer and impeller deflections, respectively, with air as the pumped fluid, as a function of shaft speed for bearing stiffnesses of 500,000 lb/in. As shown in these figures, large deflections would be incurred if the tester speed dwelled around the first critical speed of 8,000 rpm.

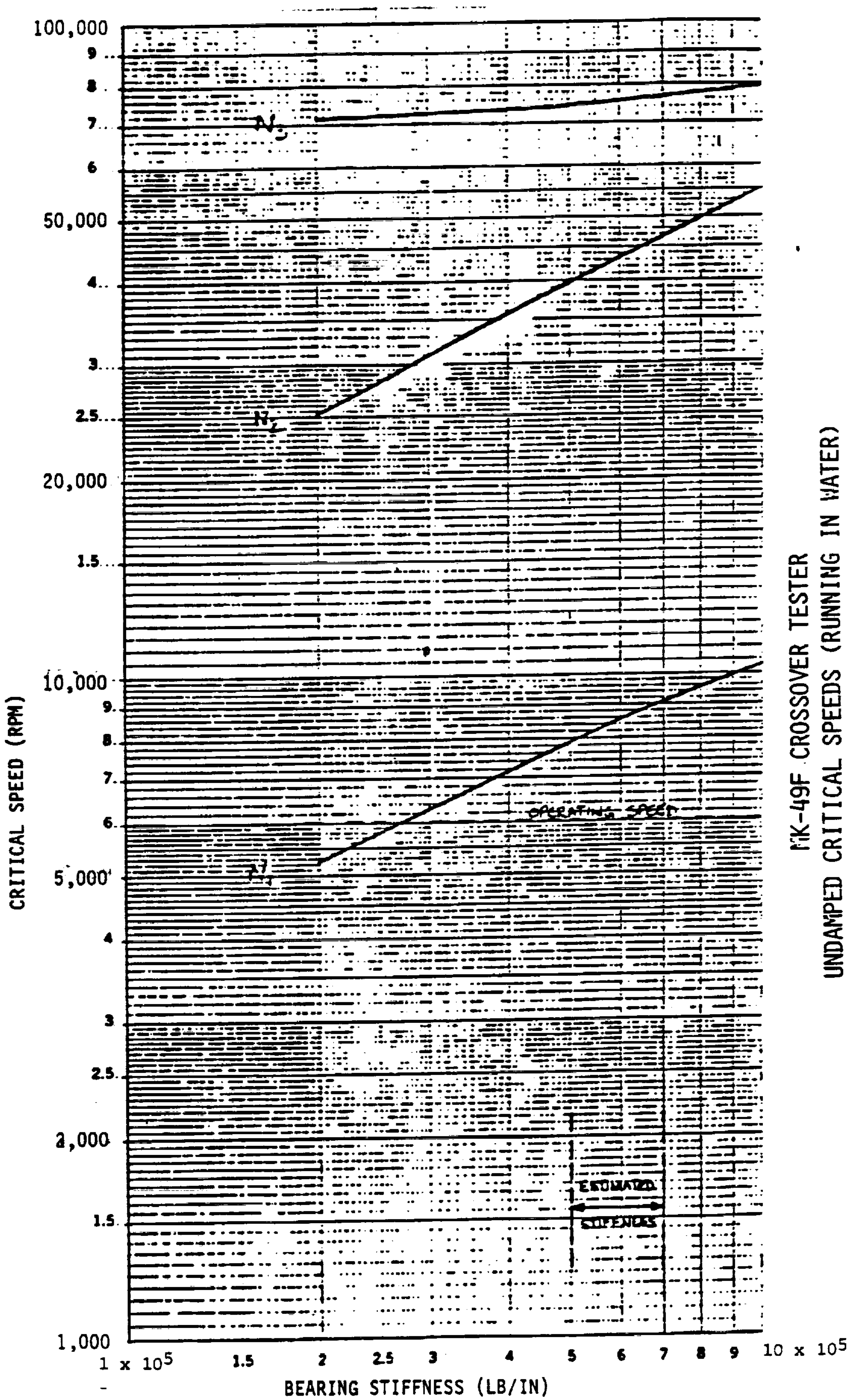


Figure 15 - Critical Speed vs. Bearing Stiffness (Water)

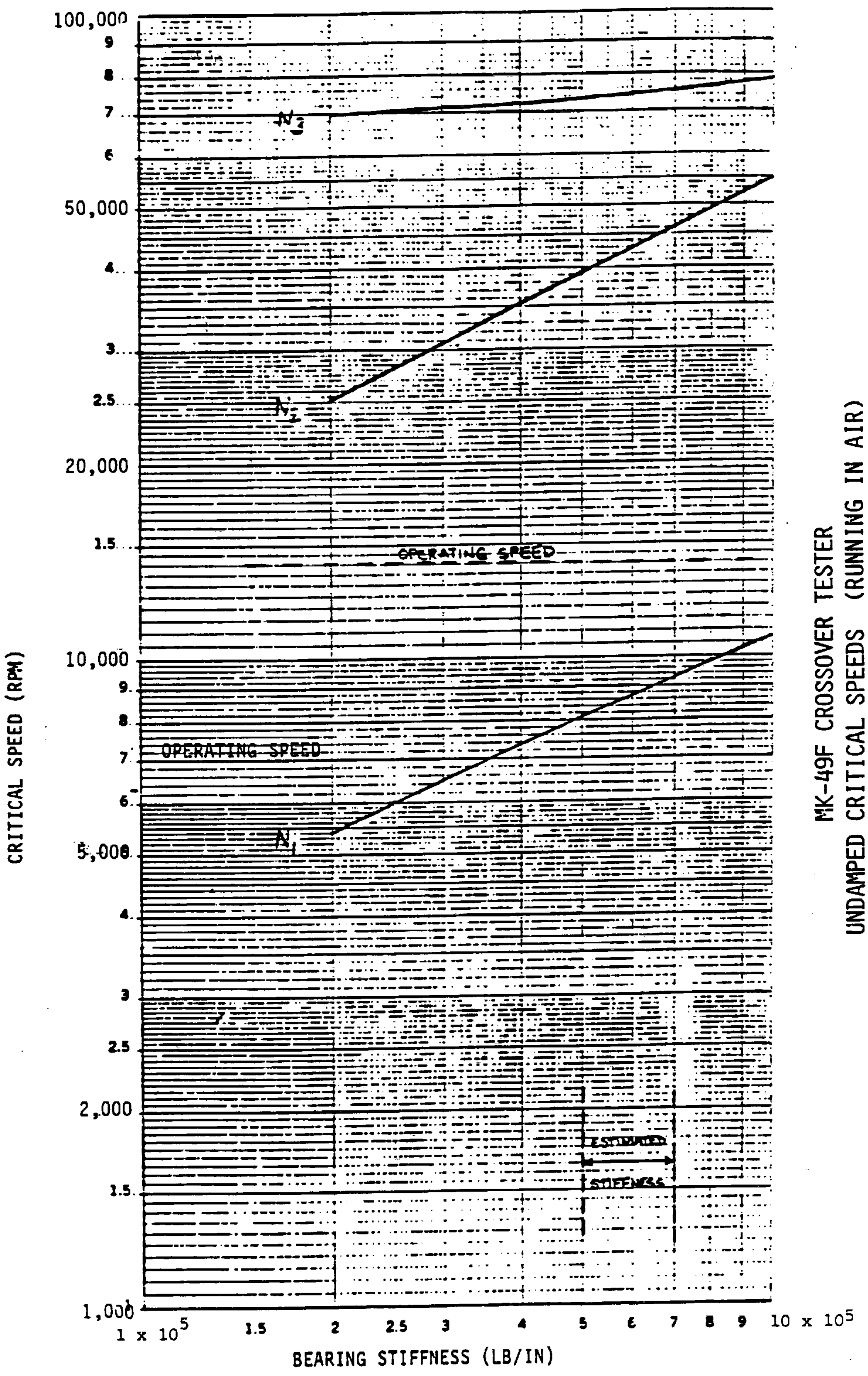


Figure 16 - Critical Speed vs. Bearing Stiffness (Air)

MK-49F CROSSOVER TESTER (WATER)
MODE SHAPES FOR K_B = 500,000 LB/IN

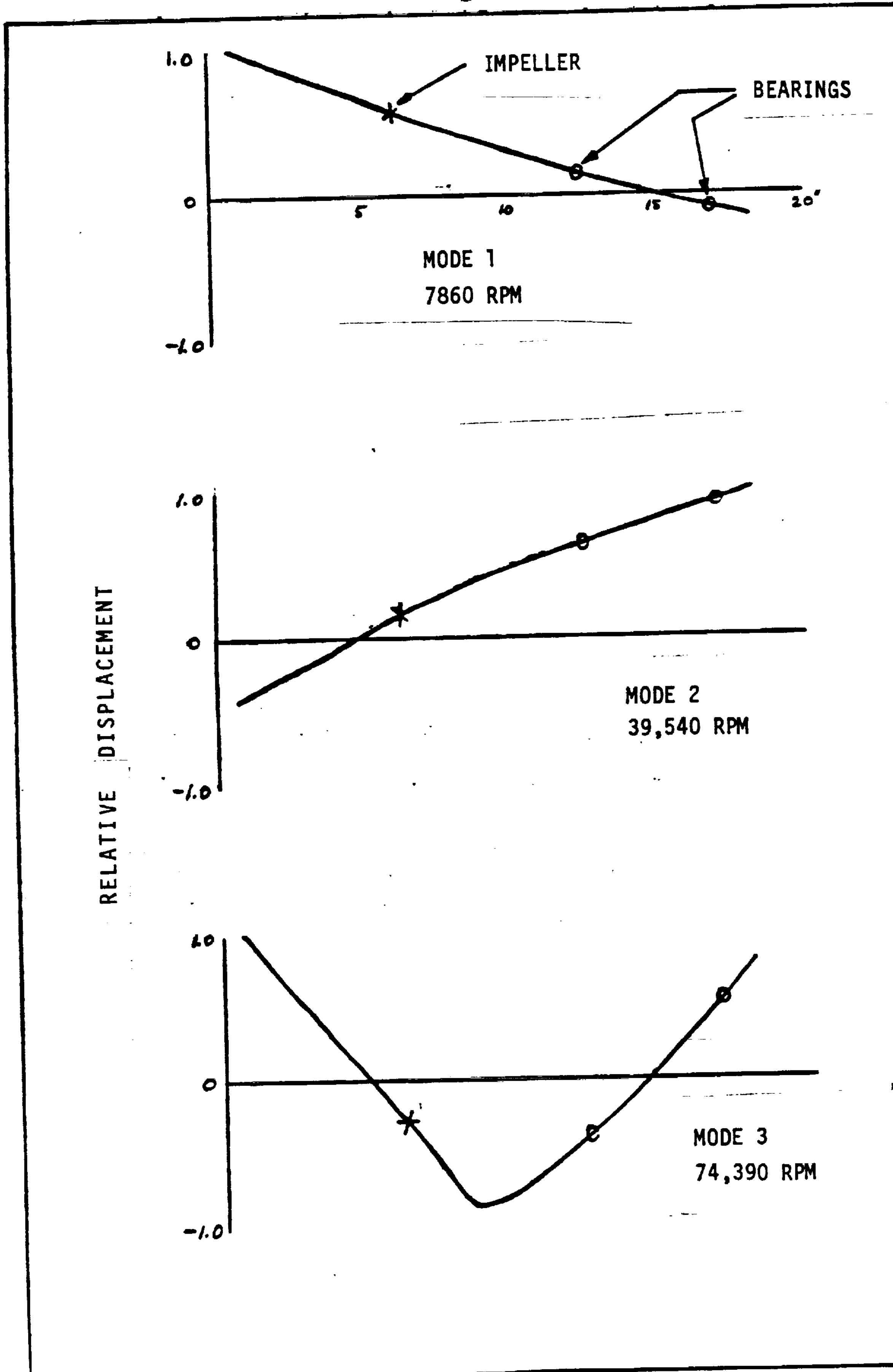


Figure 17 - Crossover Tester Rotor Mode Shapes for 500 Klb/In

Figure 18 - Inducer Deflections in Water

K_B = 500,000 LB/IN

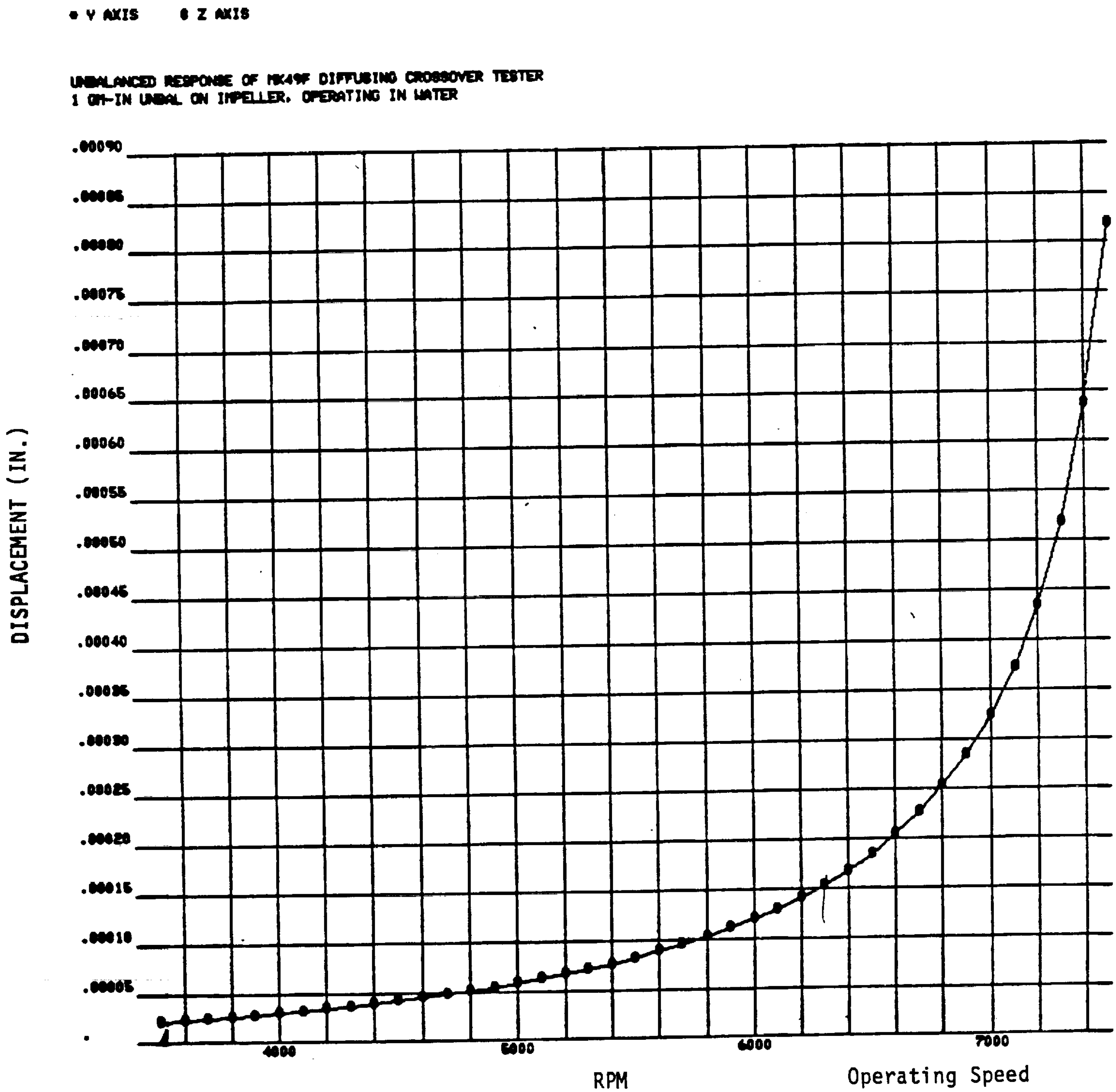


Figure 19 - Impeller Tip Deflections in Water

$K_B = 500{,}000$ LB/IN

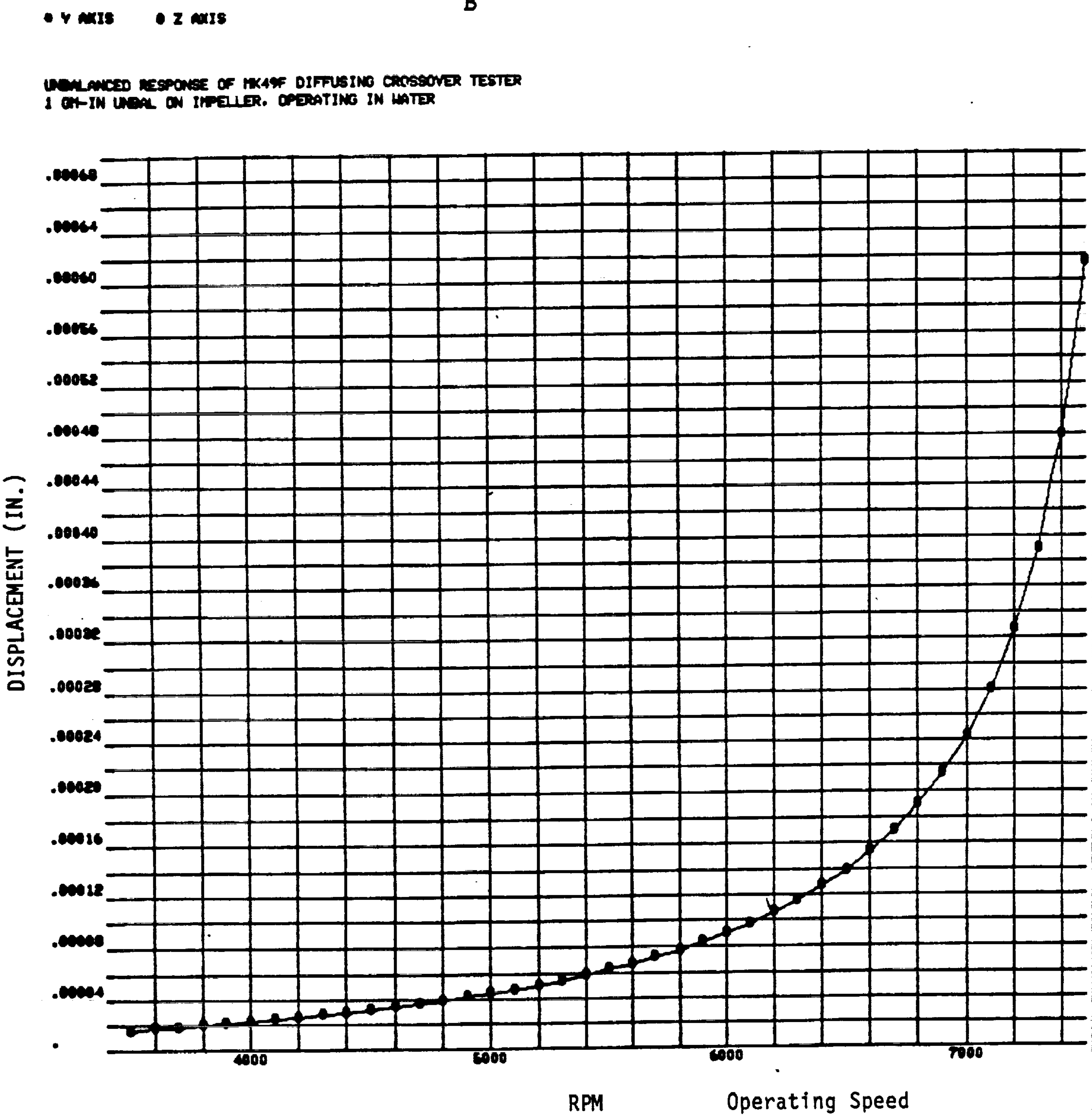


Figure 20 - Inducer Deflections in Air

$K_B = 500{,}000$ LB/IN

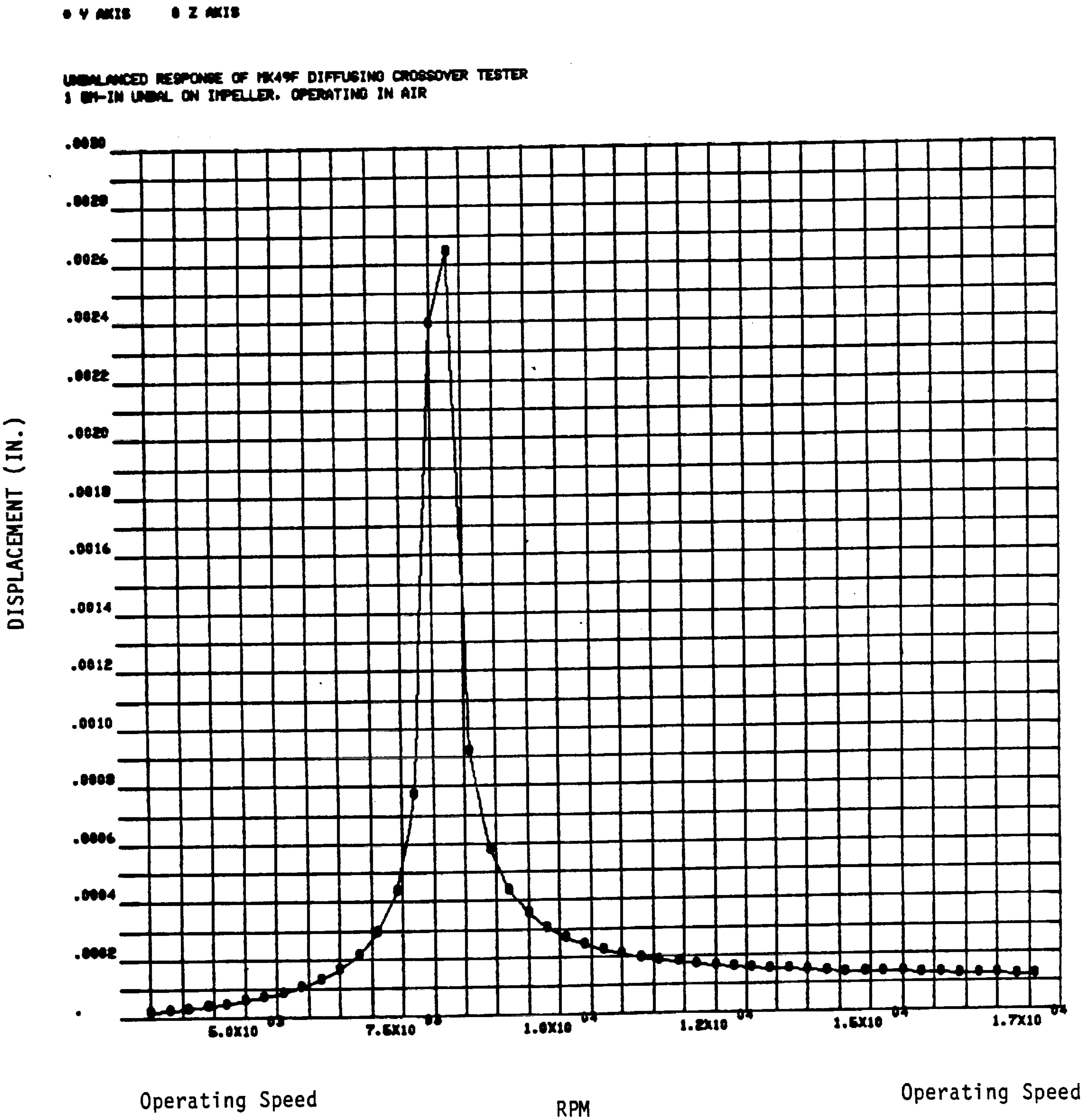
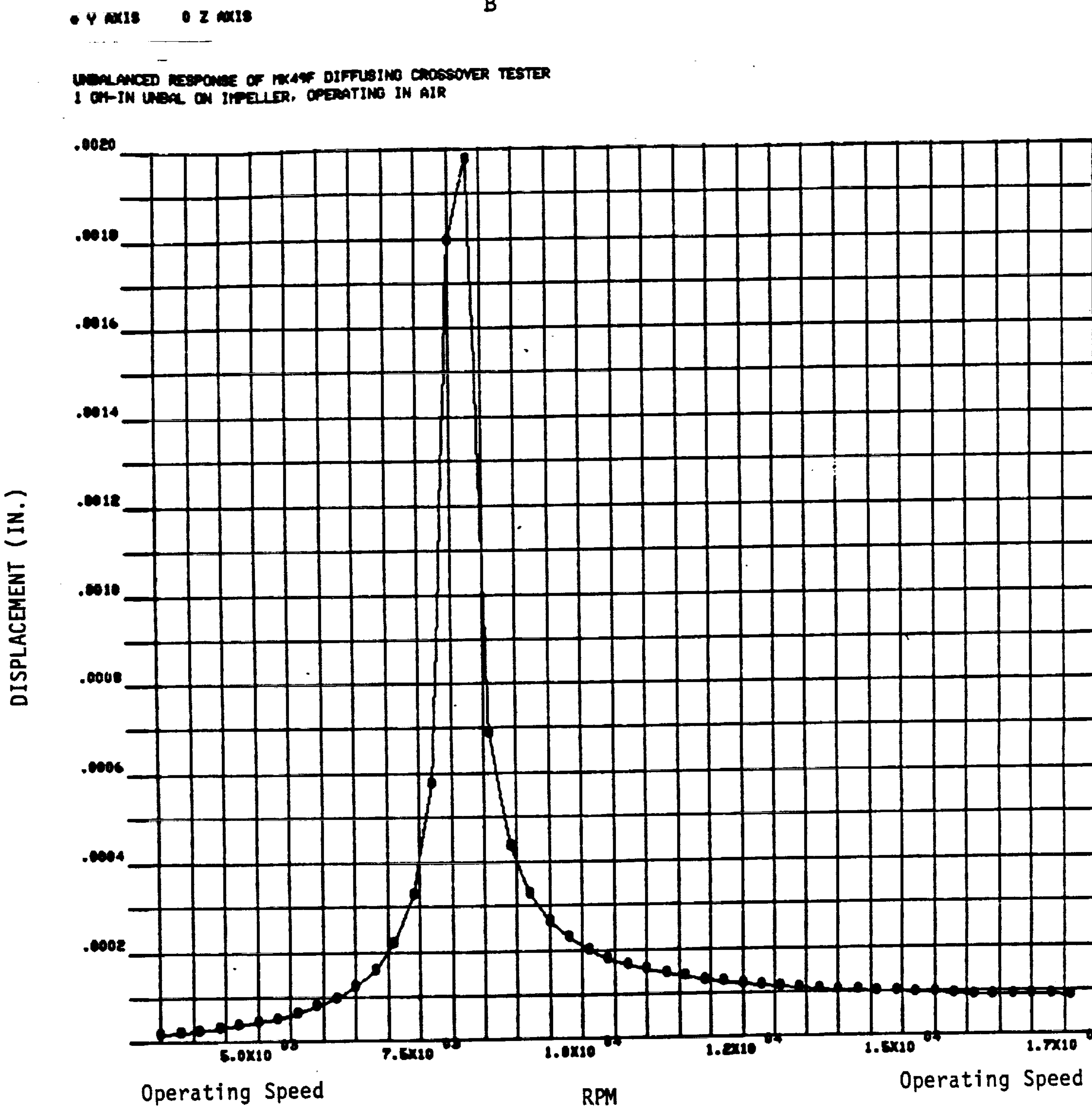


Figure 21 - Impeller Tip Deflections in Air

K_B = 500,000 LB/IN



As discussed earlier, the design for the High Velocity Ratio Diffusing Crossover tester was modified to incorporate the thrust disk, however, this was accomplished after the initial rotordynamic analyses were completed. To determine if this modification would significantly alter the rotordynamic characteristics of the tester, the finite element model of the rotor was updated and its critical speeds, operating in water, were recalculated. Close comparison of this critical speed map with that of the old design showed that the first critical speed was virtually unaffected by the addition of the thrust disk because of its close proximity to the pump end bearing.

Structural Analysis

An analysis of the Crossover Tester assembly was performed for operating conditions of 6322 rpm for water testing and 14500 rpm for air testing, and for a maximum discharge pressure of 1111 psia in water. The analysis covered the major hydrodynamic test components, including the inducer, impeller, inlet, and crossover. In addition, new hardware required by the bearing support system redesign effort, including bearing preload belleville spring sizing and face seal retainer deflections, were analyzed.

Because of the geometric similarity between the tester inducer, impeller and crossover and their counterparts from the MK49-F turbopump, stresses in these tester parts were determined by applying scaling factors to the MK49-F part stresses. Scale factors accounting for differences in tester and turbopump tip speeds, fluid densities, material densities, and static pressures were used as appropriate. Centrifugal stresses in the inducer and impeller were less than 10% of those in the turbopump. Fluid pressure stresses on the inducer and impeller blades and on the crossover were 38% of those occurring in the turbopump. Although the aluminum alloy, 6061-T6, used on the tester components, had significantly lower strength than the Inconel 718 (inducer), titanium (impeller) and Inconel 625 (crossover) used on the turbopump, the tester parts were shown to have higher factors of safety because of the lower loading.

TEST PLAN

Test Matrix

The planned high velocity ratio diffusing crossover tests were divided into four parts; H-Q tests in water, crossover stall mapping in water, suction performance tests in water, and H-Q tests in air. These tests were run to establish the diffusion capability of the crossover passage, as well as, verify the performance and efficiency of the scaled up model of the MK49-F first stage pumping elements. The planned test matrix is shown in Table 5. The yaw probe survey tests described in Table 5 were later deleted from the test matrix due to cost and schedule constraints coupled with the fact that these results were not critical to accomplishing the basic objectives of the program. Only in the event of a serious stall in the downcomer would the yaw data become critical.

Test Instrumentation

Instrumentation for the High Velocity Ratio Diffusing Crossover tests consisted of those parameters necessary to determine pressure, temperature, flowrate, speed, torque, and acceleration. In addition, adequate instrumentation was required of the facility to safely conduct the proposed tests and provide the information required for facility diagnostics. The low and high frequency data recorded provided the information necessary to investigate the performance and efficiency of the MK49-F turbopump high velocity ratio diffusing crossover and its pumping elements.

The instrumentation used, including parameter nomenclature, transducer ranges, redline limits, recording device, and parameter displays, for the water test series are shown in Table 6. Redundancy on all critical parameter systems were maintained. Figure 22 shows the locations of the various instrumentation types available on the crossover hardware. The three Kiel probes at the discharge of the crossover are located at three different radial heights: 1/4 passage, mid-height, 3/4 passage, from hub to tip.

The instrumentation used for the air test series are shown in Table 7. The air tests required less instrumentation to obtain the necessary performance information.

All low frequency data was recorded on a Digital Data Acquisition System (DDAS). The DDAS also provides test sequence control and redline monitoring, in addition to recording the low frequency data and facility events.

Some selected parameters were recorded in real-time on strip charts, as seen on the instrumentation lists in Tables 6 and 7, shown previously. During suction performance (cavitation) tests, monitoring of inlet pressure decay rate and pump differential pressure, ΔP, were essential to successfully and safely control the test.

Provision was also made in the hardware design for laser velocimeter measurements at the impeller discharge (diffuser inlet). The measurements would have been able to define the blade-to-blade flowfield leaving the impeller at different planes from the tip

Table 5 - Crossover Planned Test Matrix

TEST NO.	TEST TYPE	TEST FLUID	FLOW (GPM)	TEST DESCRIPTION	SPEED (RPM)	DATA SAMPLING	PROBE TYPE
1	CHECK OUT	H2O	582	ESTAB AXIAL LOAD	6322	20 SCANS	KIEL
2	HEAD vs. FLOW	H2O	408-694	H-Q W/ PROBE	6322	20 SCANS	KIEL
3	H-Q STALL MAPPING	H2O	233-408	HQ 60-90%Q	6322	20 SCANS	KIEL
4	CAVITATION	H2O	582	NPSH @ 100%Q	6322	CONTINUOUS	KIEL
5	CAVITATION	H2O	640	NPSH @ 110%Q	6322	CONTINUOUS	KIEL
6	CAVITATION	H2O	698	NPSH @ 120%Q	6322	CONTINUOUS	KIEL
7	CAVITATION	H2O	523	NPSH @ 90%Q	6322	CONTINUOUS	KIEL
8	CAVITATION	H2O	465	NPSH @ 80%Q	6322	CONTINUOUS	KIEL
9	CAVITATION	H2O	407	NPSH @ 70%Q	6322	CONTINUOUS	KIEL
10	CAVITATION	H2O	349	NPSH @ 60%Q	6322	CONTINUOUS	KIEL
* 11	PROBE SURVEY POS#1	H2O	408-694	HQ 70-120%Q	6322	20 SCANS	YAW
* 12	PROBE SURVEY POS#2	H2O	408-694	HQ 70-120%Q	6322	20 SCANS	YAW
* 13	PROBE SURVEY POS#3	H2O	408-694	HQ 70-120%Q	6322	20 SCANS	YAW
TEST NO.	**TEST TYPE**	**TEST FLUID**	**FLOW (CFS)**	**TEST DESCRIPTION**	**SPEED (RPM)**	**DATA SAMPLING**	**PROBE TYPE**
14	HEAD vs. FLOW	AIR	0.91-1.56	H-Q W/ PROBE	6322	20 SCANS	KIEL

* These tests were later deleted

Table 6 - Water Test Instrumentation List

PARAMETER NUMBER	PARAMETER NAME	RANGE PSIG	REDLINE MIN/MAX	DATA RECORDING AND DISPLAY DIGITAL	STRP CHRT	CRT	HF DIGITAL
1	INLET STATIC PRESS #1	100 PSIA		X	X		
2	INLET STATIC PRESS #2	100 PSIA		X			
3	INDUCER DISCH PRESS #1	0-500		X		X	
4	INDUCER DISCH PRESS #2	0-500		X			
5	IMP FRNT SHRD PR #1	0-2000		X			
6	IMP FRNT SHRD PR #2	0-1000		X			
7	REAR SHRD PR #1	0-1000		X			
8	REAR SHRD PR #2	0-2000		X			
9	IMP DISCH PR 0	0-1000		X		X	
10	IMP DISCH PR 45	0-2000		X			
12	UPC CONST SEC PR #2	0-2000		X			
13	UPC CONST SEC PR #3	0-2000		X			
14	UPC CONST SEC PR #4	0-2000		X			
15	TRANSITION PR #1	0-2000		X		X	
18	DWN DIFF DISCH PR #2	0-3000		X			
19	DWN MID-DIFFUSR PR #1	0-2000		X			
20	DWN MID-DIFFUSR PR #1	0-2000		X			
21	XOVR DISCH STATIC	0-2000		X		X	
24	BAL PSTN SMP DRN PR	0-500		X			
25	IMP DISCH TOTAL PR	0-2000		X			
26	TRANSITION TOTAL PR	0-2000		X			
27	XOVR EXIT TOTAL PR #1	0-2000		X	X		
28	XOVR EXIT TOTAL PR #2	0-2000		X			
29	XOVR EXIT TOTAL PR #3	0-2000		X			
* 30	PUMP DELTA-PR	0-3000		X	X	X	
31	WATER INLET TEMP F	0-100		X			
34	LUBE OIL OUT TEMP F	0-200		X		X	
35	THRUST DISK FLOW	0-200		X		X	
36	WATER FLOW GPM	0-1284		X	X	X	
37	LUBE OIL FLOWRATE GPM	0-4		X		X	
38	SHAFT SPEED - RPM	0-10,000		X	X		X
39	TORQUE - IN-LBS	0-20000		X			
40	RADIAL 0 ACCEL	0-10 GRMS	5				X
41	RADIAL 90 ACCEL	0-10 GRMS	5				X
42	AXIAL ACCEL	0-10 GRMS	5				X

* USE XOVR DISCH TOTAL PR #1 TO INLET STATIC #2 PR FOR DELTA-P

Figure 22 - Crossover Tester Instrumentation Locations

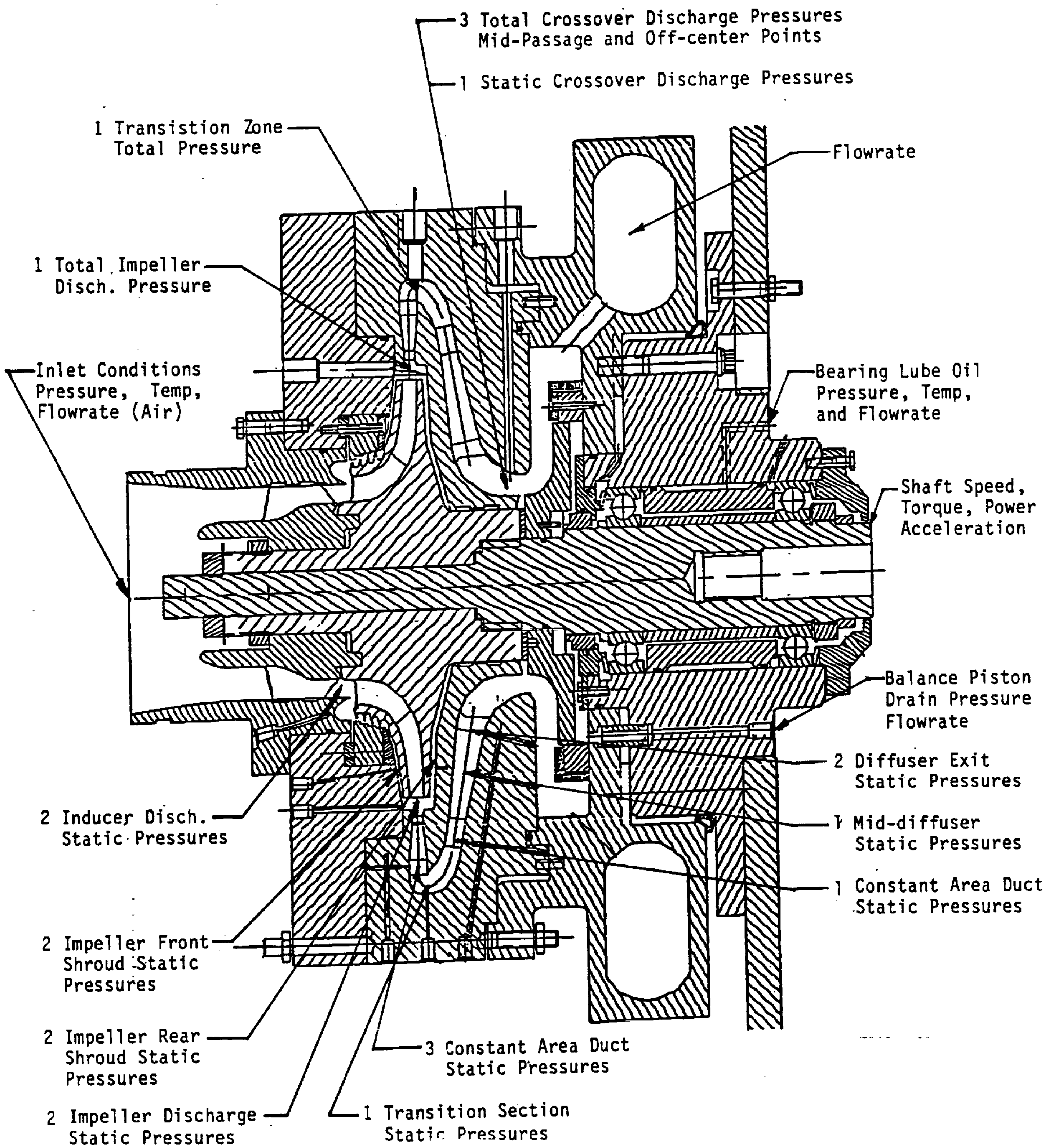


Table 7 - Air Test Instrumentation List

PARAMETER NUMBER	PARAMETER NAME	RANGE PSIG	REDLINE MIN / MAX	DATA RECORDING AND DISPLAY: DIGITAL	STRP CHRT	CRT	HF DIGITAL
1	INLET STATIC PRESS #1	0-1		X			
2	INLET STATIC PRESS #2	0-1		X			
3	INDUCER DISCH PRESS #1	0-5		X			
4	INDUCER DISCH PRESS #2	0-5		X			
5	IMP FRNT SHRD PR #1	0-5		X			
6	REAR SHRD PR #1	0-5		X			
8	IMP DISCH PR 0	0-5		X		X	
9	UPC CONST SEC PR #2	0-5		X		X	
10	UPC CONST SEC PR #3	0-5		X			
11	TRANSITION PR #1	0-5		X		X	
12	DWN DIFF DISCH PR #2	0-5		X		X	
13	DWN CONST SEC PR #2	0-5		X		X	
14	DWN MID-DIFF PR #1	0-5		X		X	
15	XOVR DISCH #1	0-5		X	X	X	
17	INLT ORF U/S PR	0-1		X	X	X	
18	INLT ORF D/S PR	0-1		X	X	X	
19	IMP DISCH TOTAL PR	0-5		X			
20	TRANSITION TOTAL PR	0-5		X			
21	XOVR EXIT TOTAL PR#1	0-5		X			
22	XOVR EXIT TOTAL PR#2	0-5		X			
23	XOVR EXIT TOTAL PR#3	0-5		X			
* 24	PUMP DELTA-PR	0-5		X	X		
18	INLT ORF DELTA-PR	0-1		X	X	X	
25	AIR INLET TEMP F	0-100		X			
26	INLT ORF U/S TEMP	0-100		X			
30	LUBE OIL OUT TEMP F	0-200	- / 150	X			
31	LUBE OIL FLOWRATE GPM	0-10	1 / -	X			
32	SHAFT SPEED - RPM	0-10,000		X	X		X
33	TORQUE - IN-LBS	0-5000		X			
34	RADIAL 0 ACCEL	0-10 GRMS	5				X
35	RADIAL 90 ACCEL	0-10 GRMS	5				X
36	AXIAL ACCEL	0-10 GRMS	5				X

* USE XOVR DISCH TOTAL PR #1 TO INLET STATIC PR #2 FOR PUMP DELTA-P

shroud to the rear shroud. Had the diffuser-crossover system shown poor performance, this would permit valuable diagnostic data to be obtained relative to the uniformity of the fluid entering the diffuser. For example, such measurements could potentially differentiate between an impeller stall problem and a diffuser stall problem. A second laser window was designed for the transition section of the diffuser between the upcomer and downcomer diffusers. This too could be valuable for diagnostics to differentiate between stall in the various parts of the diffusing system.

Test Procedures

The first test scheduled for the high velocity ratio diffusing crossover tester was a system check out at 6322 rpm and 100% of design flow (582 gpm). This test, in water, was designed to verify the soundness of the tester assembly, to verify the instrumentation systems, and to determine the pump pressure distributions and axial loads. One major goal of this test was to establish the hydrodynamically produced axial loads, compare them to the current prediction, and modify the thrust disk back pressure to accommodate these loads. A secondary goal was to rotate the total pressure Kiel probes within the flow passages, to align the sensor with the fluid velocity vector. (Kiel probes will measure the total pressure accurately within ±40 degrees of the mean streamline for velocities ranging from 4 ft/sec to Ma 1 in air)

Following the check out test, the performance tests were to evaluate the diffusing crossover tester by mapping the delivered head as a function of flow. Tests were to be run from 70% to 120% of design flow in 10% increments, while maintaining a constant thrust disk back pressure to ensure the net axial thrust direction would always be towards the inlet. To establish the H-Q map, the tester is brought to the proper inlet conditions and ramped to speed, as stated in the program test plan. By adjusting the pump discharge throttle valve, the tester flowrate was changed to the various set points described by the test plan, and the resulting pump pressure distribution recorded. At each H-Q set point, the data system was allowed to take twenty (20) scans and average the results before continuing to the next point. This method reduced the opportunity for erroneous data.

Once the H-Q map had been determined, the stall region of the crossover was explored. Starting at a nominal flow condition, as determined by the previous test, the flow would be decreased in 2% to 5% flow increments until diffuser stall was clearly defined. Again, the data was recorded at the steady state set points. The flow was then increased in similar increments until the diffuser performance returned to the nominal H-Q map.

Determining the diffuser stall point, in the decreasing flow direction, and the diffuser reattachment point, in the increasing flow direction, is important for the engine system operating conditions.

The final test series in water were the suction performance tests used to determine the inlet head at which pump discharge head breaks down. These tests were to be run at the 60% to 120%Q_d conditions, in 10% flow increments, in the order described by the test matrix. The suction performance tests were initiated when the desired flow conditions were met. At this point, the inlet pressure was slowly reduced until a minimum 10% breakdown in discharge pressure was observed. Immediately thereafter, the inlet to the tester would be pressurized to the initial conditions. The thrust disk drain valve, during these tests, was to be maintained in a constant position. Data were recorded continuously during the cavitation tests.

The H-Q test in air was designed to verify the tester assembly function, set the total pressure Kiel probe angular positions, verify all instrumentation was operational, and obtain an H-Q curve for the pump from 70% to 120% of design flow, in 10% increments. The H-Q tests in air were conducted similarly to the H-Q tests in water.

Test Facility Description

The test program for the high velocity ratio diffusing crossover was conducted at the Pump Test Facility in Rocketdyne's Canoga Main Building. Both water and air tests were conducted at this facility on the north powerhead. The tester was driven by a 4000 hp reversible, synchronous electric motor. The 1200 rpm output of the motor was increased through a oil lubricated gearbox to 6322 rpm. . The water and air tests were remotely conducted from the control center, shown in Figure 23.

The water and air tests were conducted at the 6322 rpm speed to stay well below the first undamped critical speed for this rotating assembly which lies between 8000 and 9400 rpm for the predicted bearing stiffnesses, as shown in the rotordynamic analysis. The air tests were originally going to be run at 14,000 rpm in a separate air test rig, but it was more economical to run the tests on the same rig as the water test. Also, at the lower speed in air the Reynolds number is even further reduced from that in water yielding a stronger contrast to characterize Reynolds number effects.

The water test facility and hardware interface schematic for the high velocity ratio diffusing crossover was configured as shown in Figure 24. The water flowed from the

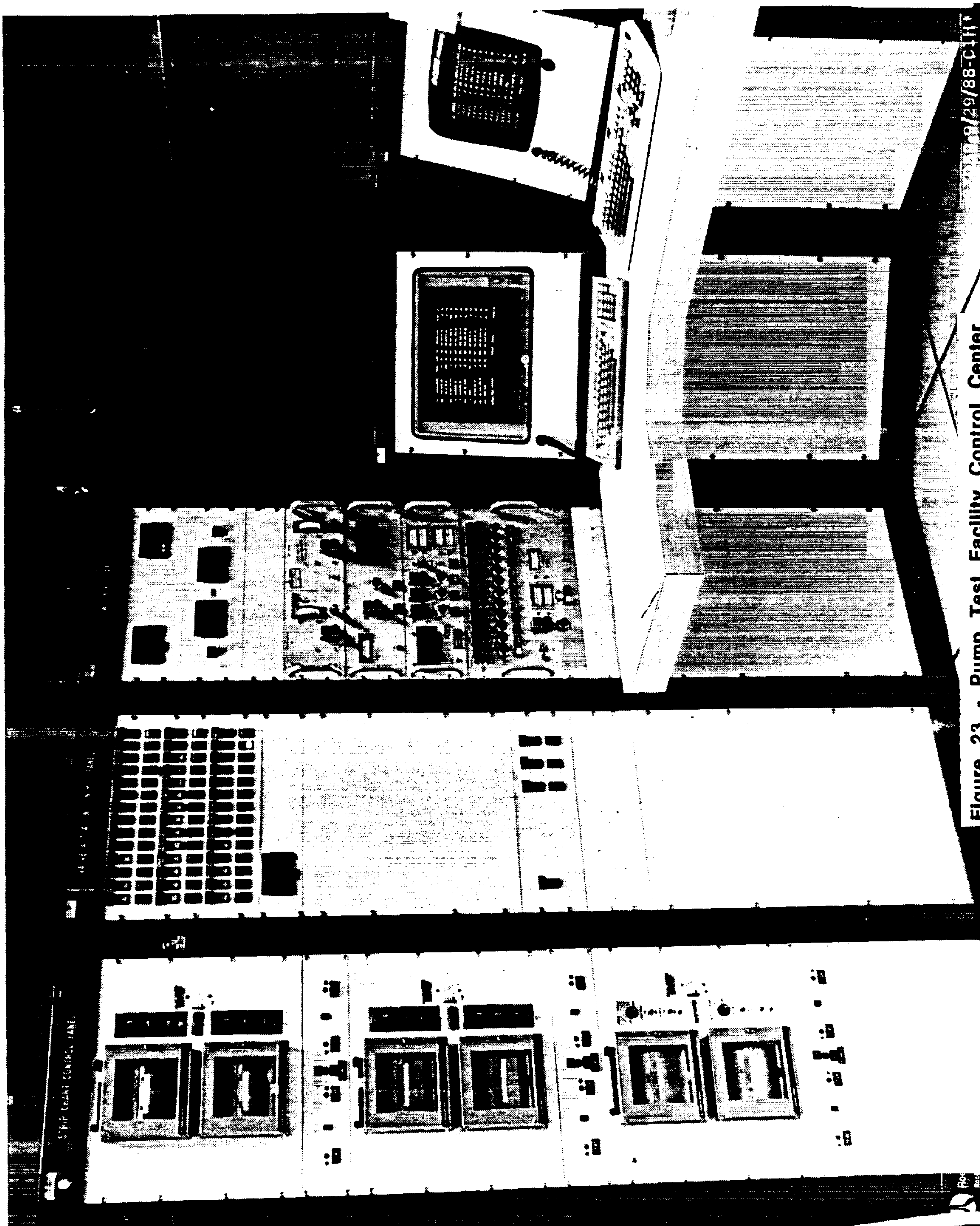
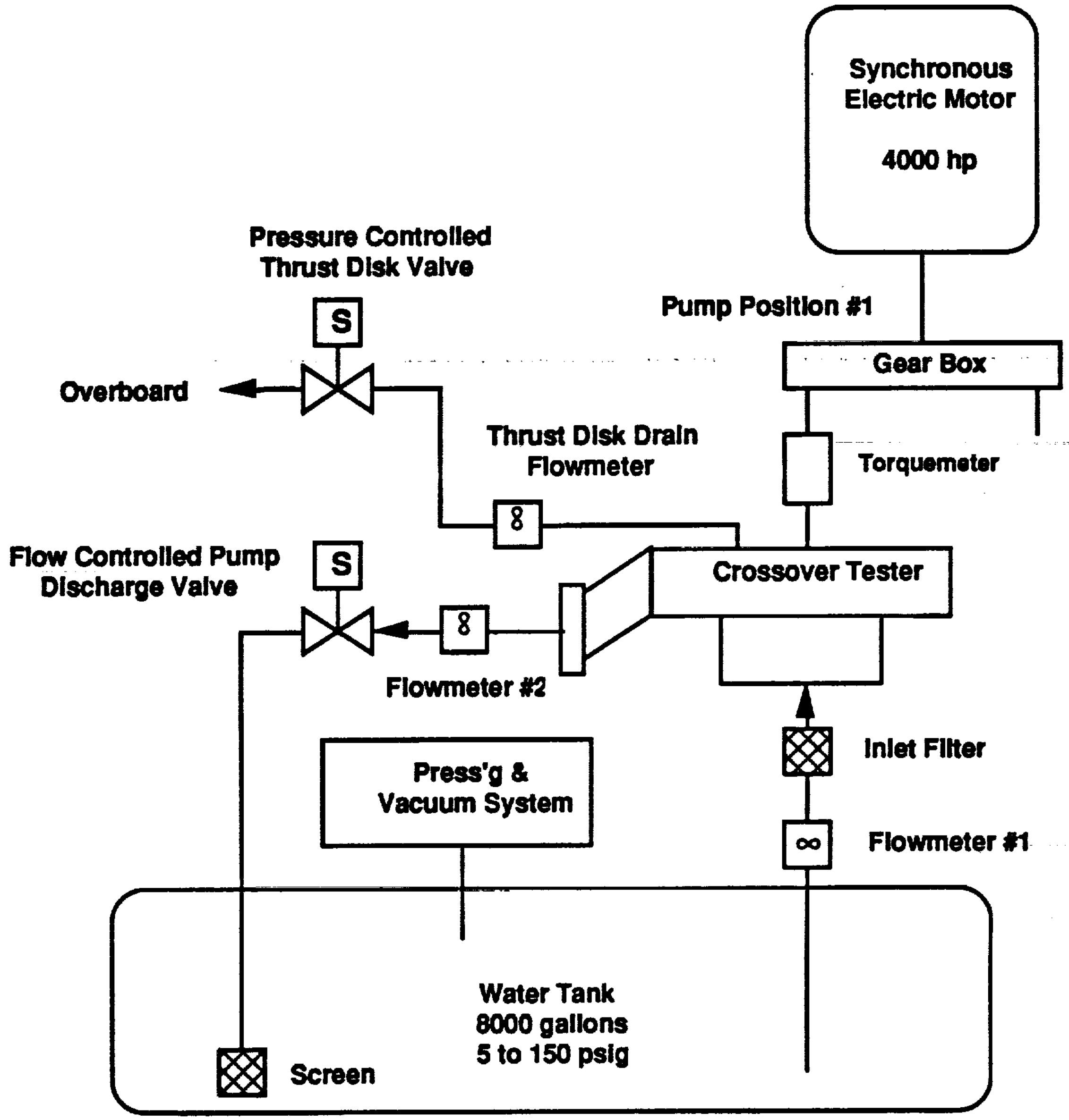


Figure 23 - Pump Test Facility Control Center

Figure 24 - Water Test Facility Schematic



8000 gallon tank through the tester and returned to the tank in a recirculation mode. The tank pressurizing and vacuum systems were capable of maintaining a constant pressure at the pump inlet during the head versus flow maps and could also ramp the inlet pressure to less than 5 psia during the suction performance runs.

A hydraulically operated pump discharge valve, using flowrate feedback, was installed downstream of the tester. This valve was used to vary the water flowrate during the H-Q tests and maintain a constant flowrate during the suction performance test series. This valve utilized the flowmeter downstream of the tester to react to the requested changes in the flow conditions. Since the flowmeter was located downstream of the pump, a flowmeter was added to the thrust disk drain system so the actual pumped flow could be measured. Later a flowmeter was placed in the inlet line reduce measurement error created by adding the output of two separate flowmeters (see Figure 24).

A 40 micron (minimum) mesh filter was installed in the inlet duct to protect the hardware from any debris in the facility lines. A 100 micron filter was installed downstream of the hardware to collect any debris which emanated from the tester. The tester bearings were lubricated by a pump-fed 2 gpm oil jet supply and drain system, also provided by the facility. A photograph of the lubrication system and hardware interface is shown in Figure 25.

The air tests were conducted at the same pump position as the water tests. The fluid supply system, however, was significantly different. A six inch diameter pipe, ten feet long, with an eight-inch to six-inch pipe reducer at the entrance was used as the inlet duct to channel the atmospheric air into the inducer. Within the inlet duct, a 2.000 inch diameter orifice was used, in coordination with the upstream pressure and temperature and orifice ΔP, to calculate mass flow. There were no appreciable axial loads predicted for these tests, so the thrust disk back pressure system was plugged. Like the water test, pump flow was controlled using throttling valve in the pump discharge line. A schematic of the air test facility is shown in Figure 26.

There are two digital data acquisition systems that were used to record and reduce test data at the Pump Test Facility. The system consists of two digital computers forming a multi-user display and data processing system. The test control and data acquisition system for the water test facility consists of an analog-to-digital conversion subsystem tied into the Data General MV4000 computer as seen in Figure 27. The analog subsystem can acquire 128 analog signals, such as pressure, delta pressure, temperature, torque,

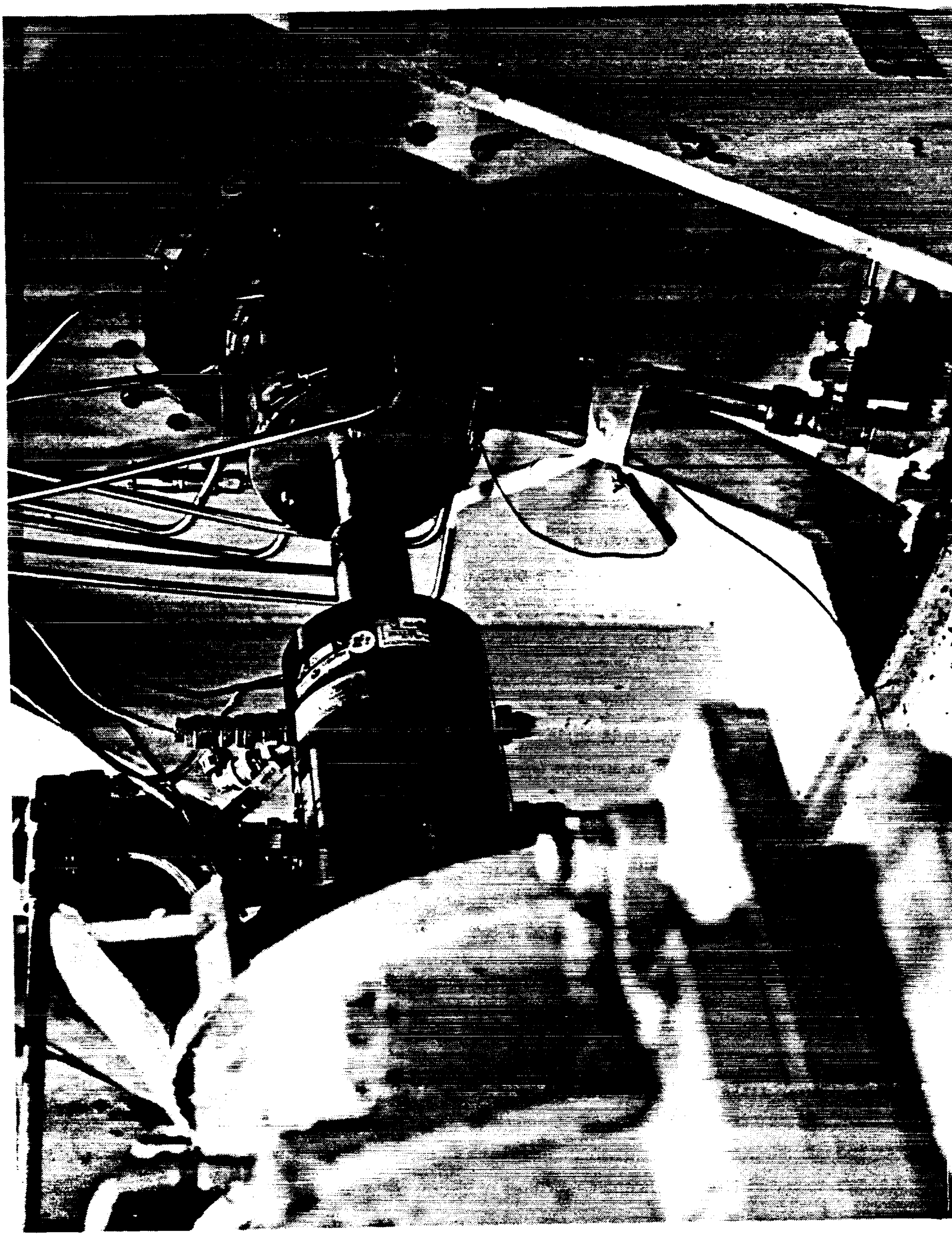
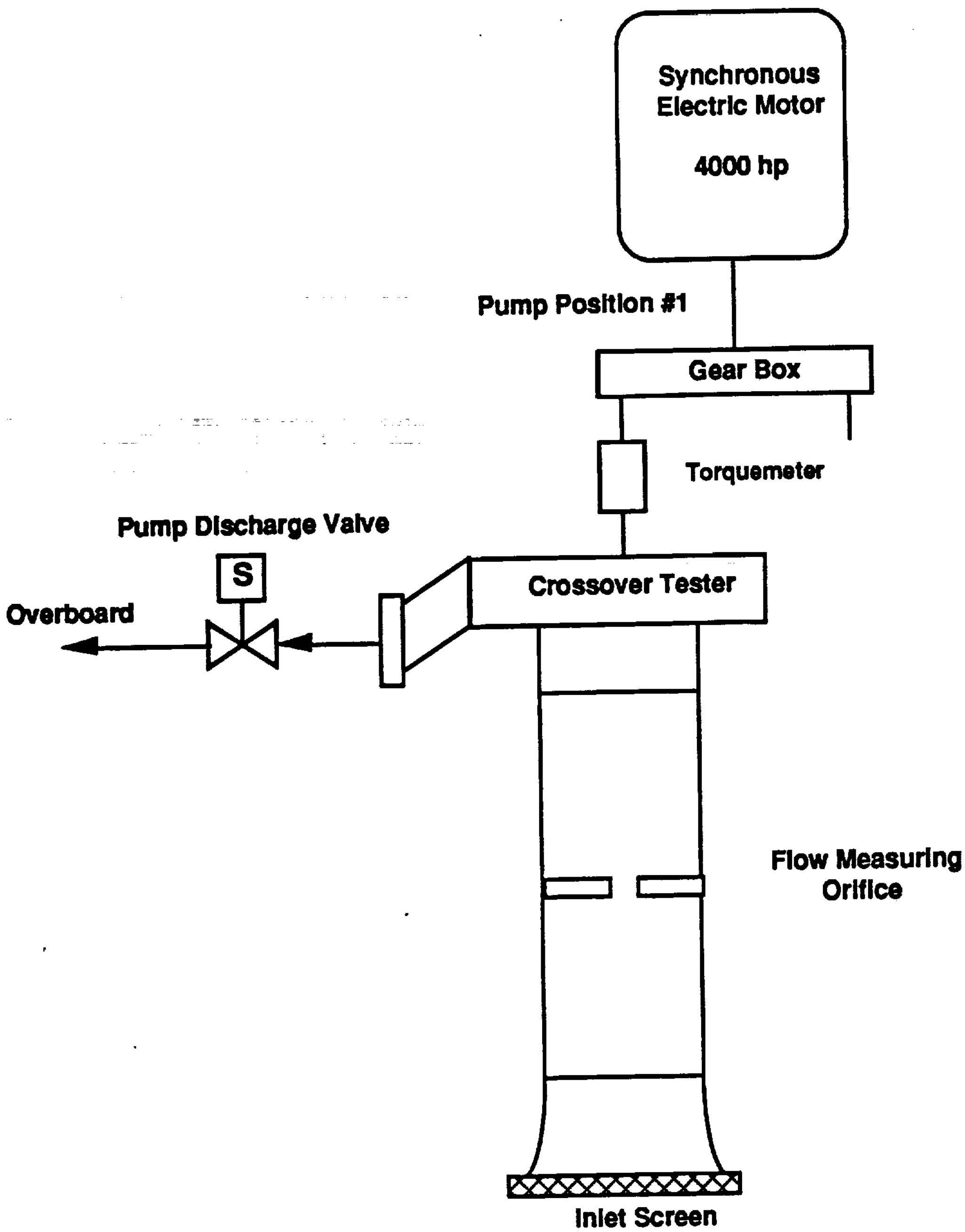


Figure 25 - Crossover Tester Lube Oil Interface

Figure 26 - Air Test Facility Schematic



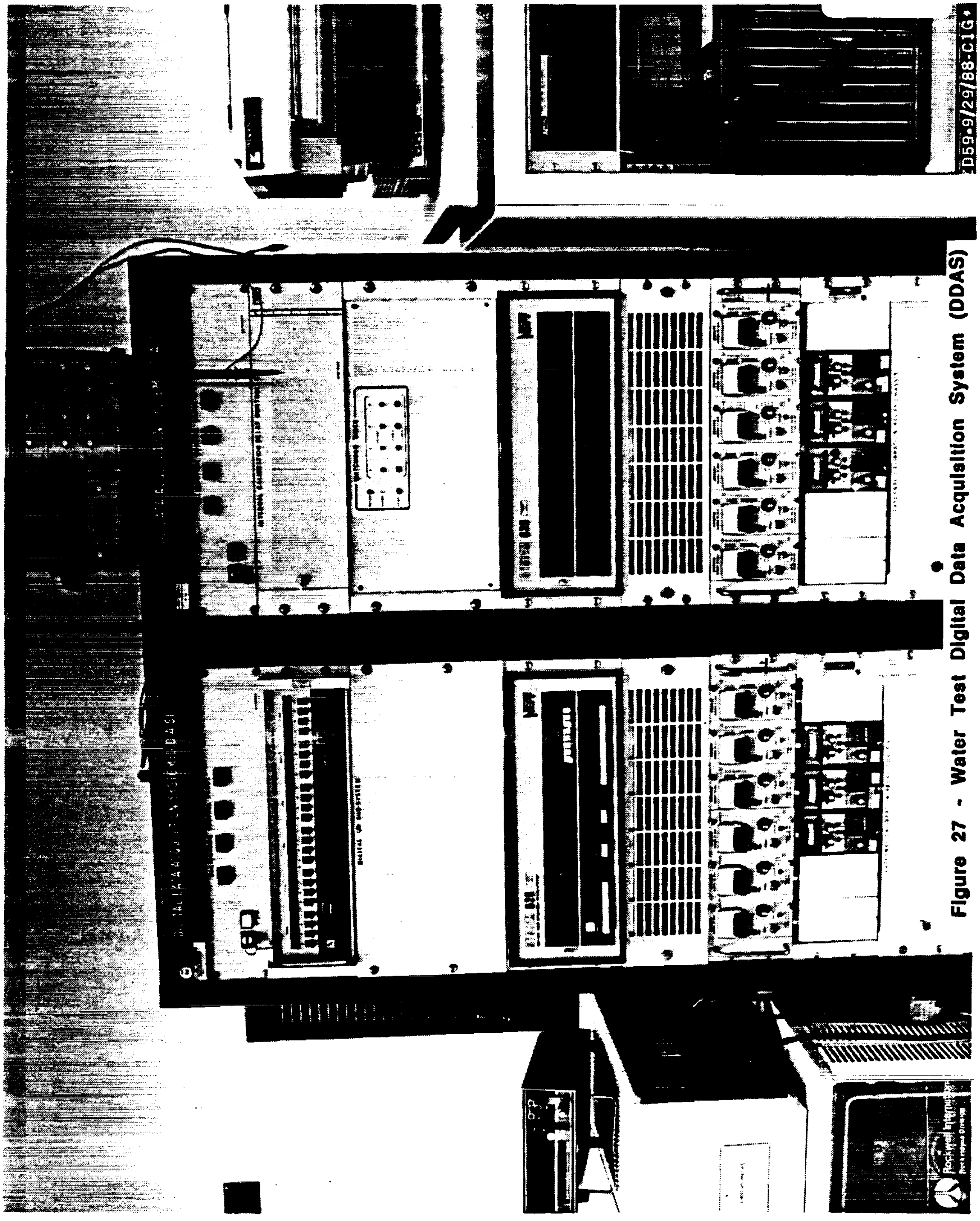


Figure 27 - Water Test Digital Data Acquisition System (DDAS)

speed, acceleration, flow, and displacement transducer outputs. All analog signals are filtered and sampled within 80 microseconds (1st sample to the 128th sample). While performing test control, the computer simultaneously accepts the digitized data from the analog subsystem and passes the data every 0.1 second to the hard disk storage for post test processing. After all data channels are acquired, the data is converted to specified engineering units and sent to the various display monitors. At the conclusion of the test, the data is transmitted to an Apollo computer format via BLAST software. The data is then further reduced and analyzed by the Rotating Machinery Analysis groups.

For the air test facility, the Pressure System Incorporated (PSI) system was used. The four major components of the PSI system are the Data Acquisition and Control Unit (DACU), Pressure Calibration Unit (PCU), pressure sensor modules, and the system controller. The DACU provides the control and data acquisition functions for the pressure sensor modules. An eight bit microprocessor executing firmware programs controls the DACU. The PCU consists of pneumatic valves and high accuracy quartz pressure transducers. The pressure transducers ranged from 1 psig to 15 psig, with accuracies to 0.5%. Under DACU control, the PCU switches the calibration value within the sensor to calibrate position and then applies a three point pressure calibration to all transducers. The calibration data is then reduced by the DACU. The main purpose of the system controller, an IBM PS/2 Model 80 computer, is to program the DACU and direct data flow within the acquisition system. Additional functions of the computer are data reduction, data display, and permanent data storage. A photograph of the Air test data controller and display are shown in Figure 28. When the test condition is met, the PSI system averages twenty scans of data and stores the data in specified engineering units on a 3.5 inch floppy diskette. The test information is then transferred from the data file into a Lotus 1-2-3 spreadsheet where the data is further reduced.

TEST DESCRIPTION

Test Summary

Tests of the high velocity ratio diffusing crossover were conducted between September 1988 and October 1988. During that period, tests were conducted in air and water for the purpose of obtaining performance data at two Reynolds Numbers and determining the stall and cavitation characteristics of the crossover tester. Since the design of the crossover tester and the MK49-F are geometrically similar, this data can be easily scaled for comparison.

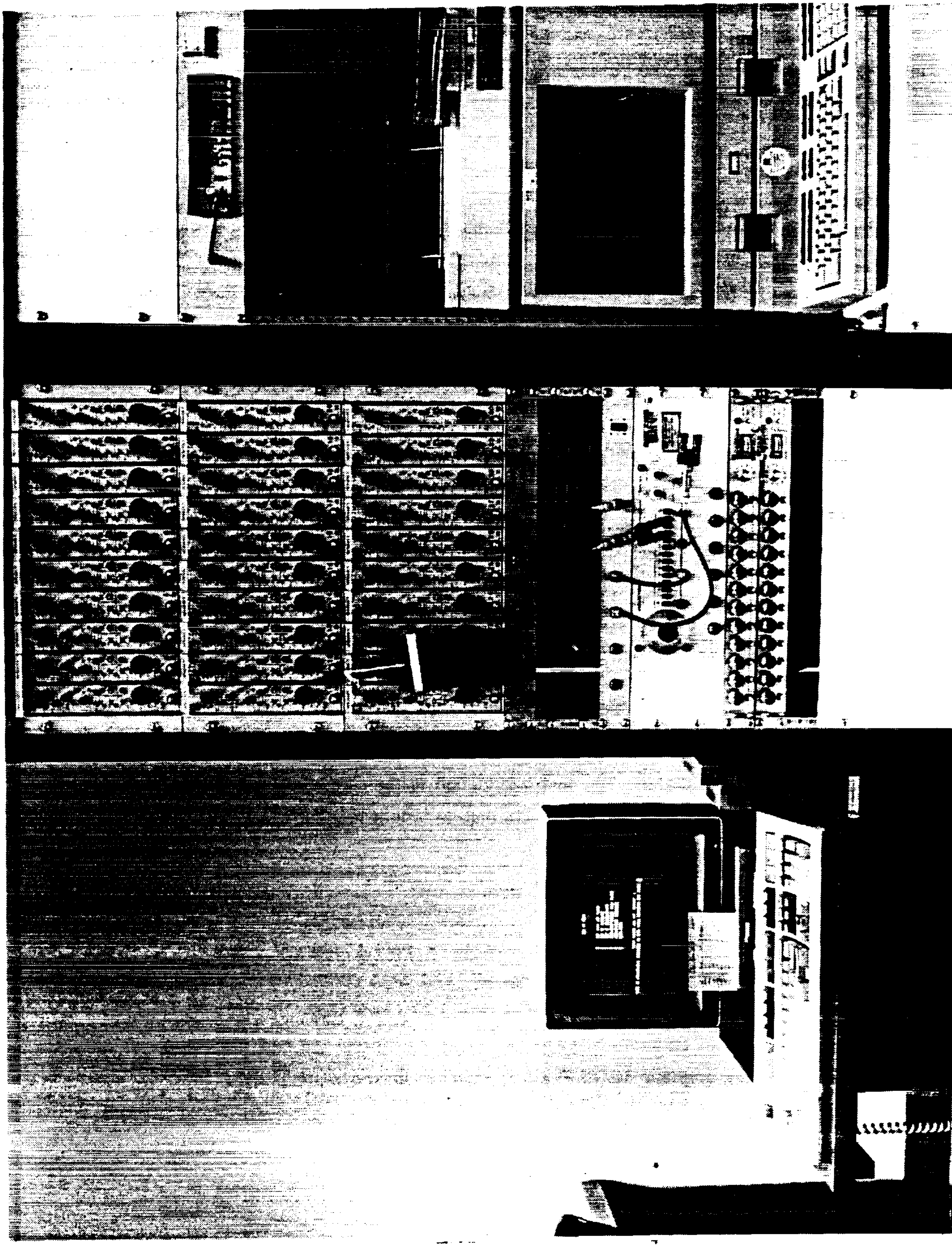


Figure 28 - Air Test Data Controller and Display Terminal

Table 8 presents a summary of the nine tests actually performed. Test 1, in air, provided a successful check out of the tester mechanical operation and facility systems. Figure 29 shows the crossover tester installed in the air test configuration at the Pump Test Facility. Test 2 was repeated the set points of Test 1 while rotating the Kiel probes to find the maximum total pressure. No effects were observed. Typical facility start up and mechanical problems occurred in tests 3, 5, 6, and 7 primarily related to the balance pressure drum operation which had not been used before in this facility and the tank vacuum system operation required for the suction performance test. The only instrumentation lost during the tests was the Kiel probe at the impeller discharge which failed early in Test 4, however, some good H-Q data were still achieved. This Kiel probe is located in a region of large dynamic variations due to the normal blade-to-blade flowfield in the rotating impeller and is likely to have experienced a high-cycle fatigue failure.

Table 8 - High Velocity Ratio Diffusing Crossover Test Summary

Test	Test Number	Test Fluid	Test Objectives	Comments
1	-	Air	Check Out & HQ	Objectives Achieved
2	-	Air	HQ with Kiel Probe	Objectives Achieved
3	T88A092	Water	Check Out @ 100 Q_d	Test Cut - Redline
4	T88A093	Water	Check Out @ 100% Q_d	Objectives Achieved
5	T88A094	Water	HQ and Stall Map	Facility Issue
6	T88A095	Water	Detailed Mapping	Facility Issue
7	T88A096	Water	Suction Performance	Limited Data Achieved
8	T88A097	Water	HQ & Stall Mapping	Objectives Achieved
9	T88A098	Water	Suction Performance	Redline Cut. Data Achieved - Tester Failed

Test 7 was very successful and several H-Q points were achieved, diffuser stall was mapped, and some suction performance tests completed. In Test 8, the remaining suction performance data points were completed. Test 8, however, was terminated prematurely by a torque redline cutoff. At the time of cutoff, the cavitation test at 80% design flow had just been completed and the inlet line was being re-pressurized. During the automatic shutdown sequence, the one-inch diameter quill shaft failed. Tester disassembly revealed that the pump end bearing had failed and the impeller front shroud had rubbed severely on the inlet housing. Post test analysis of the pressure parameters

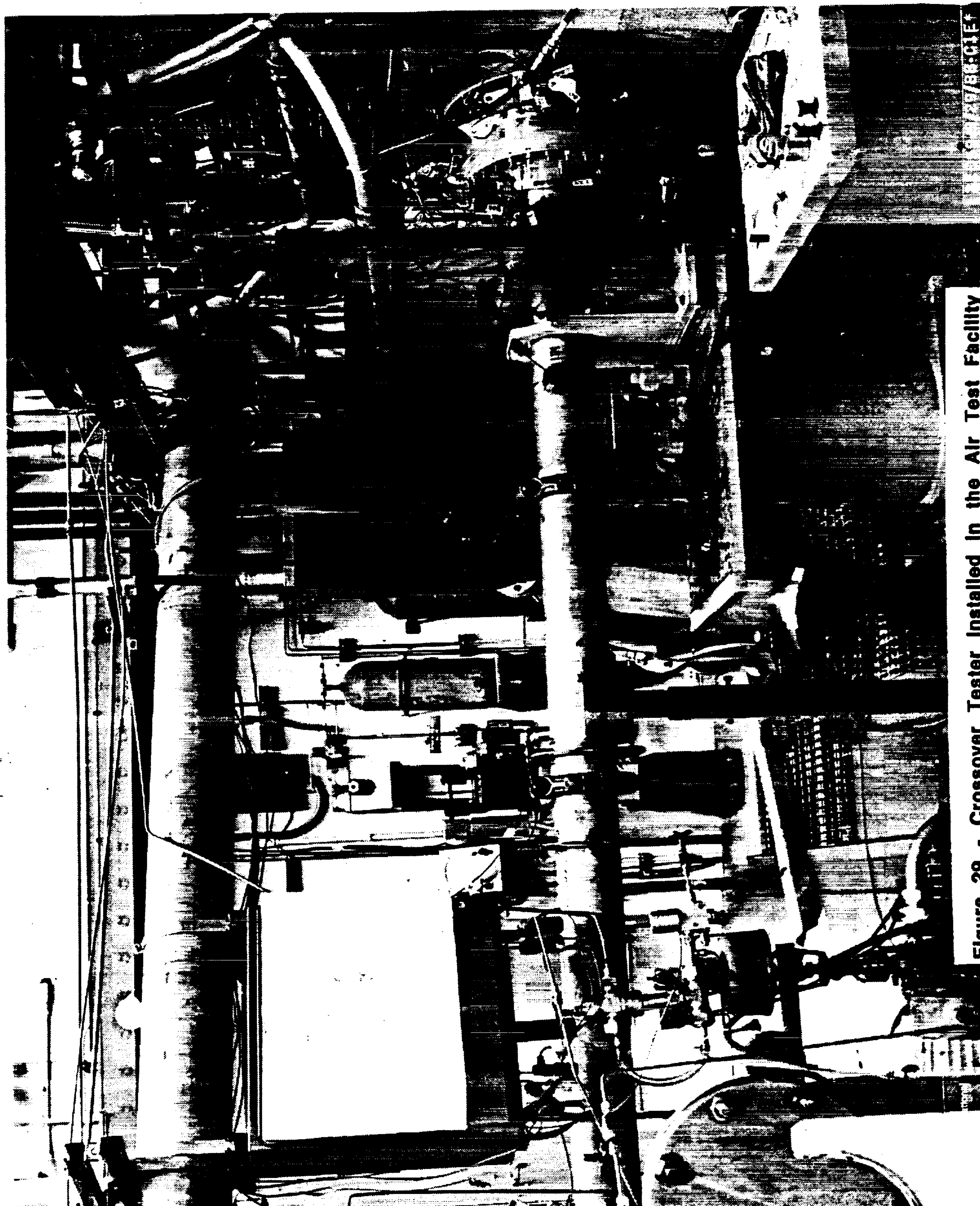


Figure 29 - Crossover Tester Installed in the Air Test Facility

indicated that the axial thrust of the pump had dramatically changed due to shifting pressures caused by the deep cavitation in the pump. Figure 30 shows the axial loads calculated for the test where the failure occurred. With the pressures changing so rapidly, the accuracy of calculating this load is in question because it is obtained by vector addition of large forces which yield a relatively small residual. However, the trend is certainly correct. As can be seen from the Figure 30, the thrust suddenly changed direction at the end of the test by a magnitude of over 6,000 lb. resulting in an unloaded pump end ball bearing. Subsequent pressurization of the inlet and recovery from cavitation would then force the bearing back into a highly loaded condition which caused the bearing failure.

Hardware Disassembly

At the conclusion of the final test, the high velocity ratio diffusing crossover tester was disassembled and the condition of the major components documented. Two major observations were noted. First, there was significant rubbing on all the close radial clearance locations, and second, the shaft had translated axially toward the inlet sufficiently enough to rub the impeller.

When the axial load reversed during the 90% and 80% Q_d cavitation tests, the pump end bearing was unloaded, providing no radial support to the shaft. The rotor proceeded to whirl with amplitudes sufficient enough to cause the rotor to rub in the soft seal areas. Most of the damage incurred was at the inducer/tunnel, impeller hub/interstage seal, and thrust disk/seal interfaces.

The inducer tunnel and interstage seals were made with Hexcel 3125 polyurethane as described earlier. The interstage seal was badly damaged, including large cracks and significant material loss. However, there was no damage found on the inside diameter of the crossover housing. The rubbing velocity at the interstage seal was approximately 110 feet per second.

The inducer tip seal was moderately damaged. The inducer tip seal showed scratches from rubbing of the aluminum inducer blades, as well as pitting caused by the deep cavitation. Some minor damage to the inducer blade tips were also noted, but were considered superficial and easily repairable. The rubbing velocity at the inducer tip seal was approximately 154 feet per second.

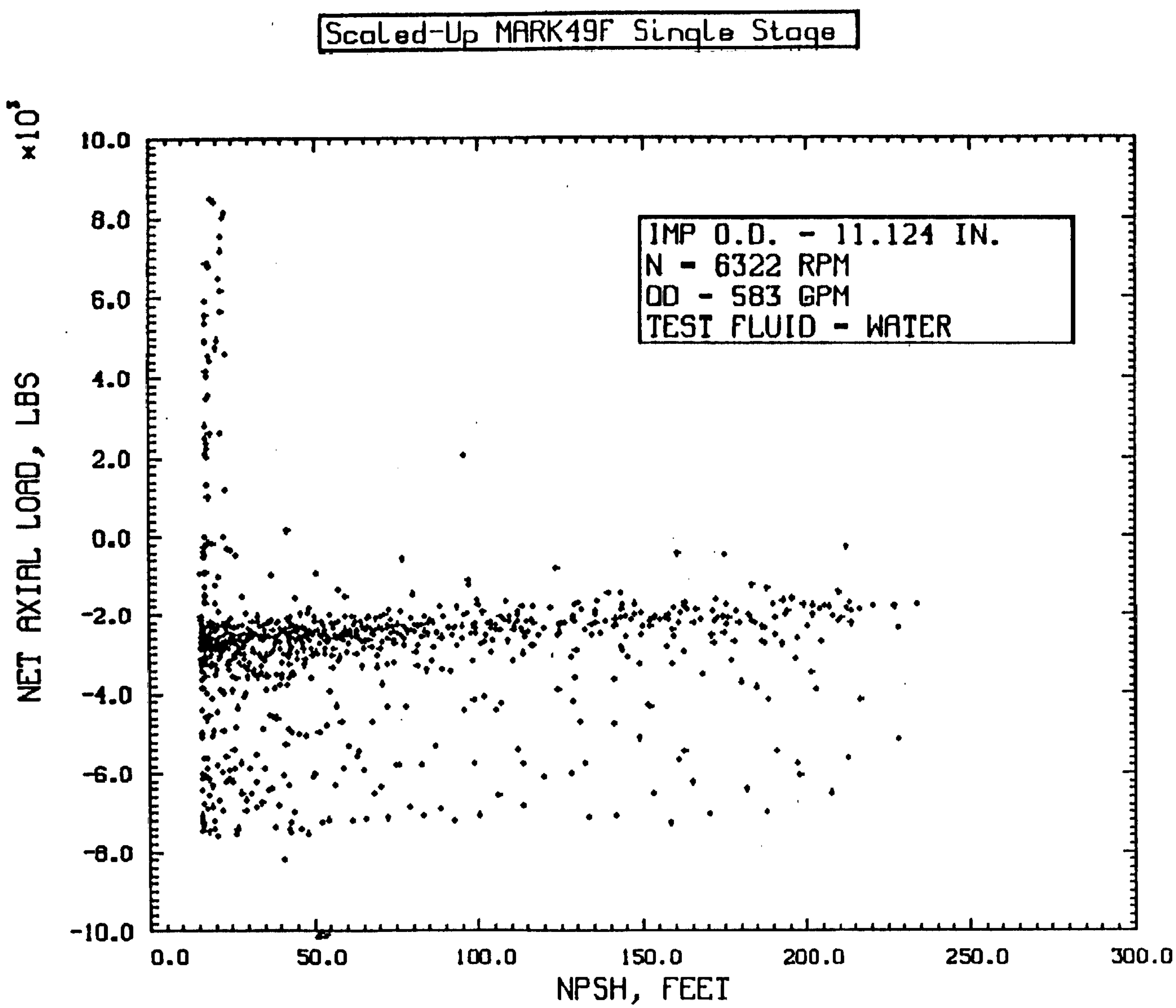


Figure 30 - Calculated Axial Thrust vs. NPSH at 80%Q_d

Further investigation into the survivability of Hexcel 3125 as a soft seal material is required to fully evaluate the findings of the post test disassembly. The condition of these seals were documented for the data base being compiled under the Soft Wear Ring Seal Technology Program, Task B.5.

The thrust disk, made from A-286, also rubbed the Kel-F thrust disk seal during the bearing unloading. The wear track in the Kel-F was not uncommon for this seal/rotor combination. Some heat generation was noted on the disk tip. The rubbing velocity in this location was approximately 235 feet per second.

The soft seal materials, though heavily damaged, were very successful. One of the main goals of this type of seal is to tolerate rubbing without damaging the rotor or stationary housings. In each case, the seals were worn, but did not cause severe damage to the rotating part or the soft seal retainer system. This was important because if significant rubbing were observed in an actual turbopump, only the soft seal material would have to be replaced and not the expensive rotor or seal retainer parts. This was evident in the interstage seal area. If a metallic seal would have been used in this application (and not uncommon) the impeller and the crossover as well as the soft seal would have to be replaced. During the crossover tests, however, neither the impeller hub nor crossover were damaged.

The axial rubbing damage caused by the axial translation of the shaft was much more severe than the radial rubbing damage. Some of the damaged parts included the impeller, front shroud carbon face seal, bearing sleeve, and labyrinth seal retainer.

The axial travel that was witnessed during the failure was over .025 inch towards the inlet. This was caused when the axial load returned towards the inlet after unloading the bearing during the 80% Q_d test. When the thrust reversed the bearing seized, and the power of the motor kept turning the tester shaft. The tester shaft rotated inside the inner ring of the failed bearing heating the shaft sleeve and bearing area. With the 3,000 lb. load towards the inlet the high frictional heating in this area, the sleeve between the bearings started to deform allowing the shaft to travel until the impeller shroud started to rub on the pump and housing. At some point, the torque from the rubbing of the shaft and impeller was enough to shear the quill shaft. Excessive damage was incurred to the front shroud of the impeller, tester shaft and bearing separator sleeve. A list documenting the current damage status of the tester parts and the action required to fix the tester are shown in Table 9.

TABLE 9: CROSSOVER TESTER POST TEST PARTS STATUS

PART NO.	DESCRIPTION	DAMAGE	ACTION	(N)EW (R)EWORK (U)SE AS IS
7R0017923-3	INLET HOUSING	Rub at Seal Retainer	Clean Up with Lathe	R
7R0017924	COVER	None	None	U
7R0017925	CROSSOVER	Interstage Seal Worn	Replace Interstage Seal	R
7R0017927	THRUST DISK	Tip Rub	None	U
7R0017928-1	THRUST DISK SEAL	Seal Worn	Replace Seal	N
7R0017930-3	IMPELLER	Tip Rub, Front Shroud Rub	Remove Shroud & Braze New	R
7R0017931-3	INDUCER	Blade Tip Rub	Sharpen Plade Tips	R
7R0017940-3	IMP LABY SEAL	None	None	U
7R0017940-5	LABY RETAINER	Severely Rubbed by Impeller	Replace Retainer	N
7R0017944-1	INLET TUNNEL	Minor Rubbing/Cavitation Damage	Replace Seal	R
T-5100073-120	FACE SEAL	Normally Worn	None	U
T-5100073-501	BEARING SPACER	Severely Damaged	Replace Sleeve	N
SKF 7214	BALL BEARINGS	One Failure/One Good Condition	Replace (buy 2 minimum)	N
EWR3072086-007	VOLUTE MANIFOLD	None	None	U
EWR306802-003	SHAFT	Severe Rubbing from Bearing	Grind, Plate, Grind	R
EWR306803-003	BEARING CARRIER	Bore Scratches from Bearing	Polish Bore	R

TEST DATA ANALYSIS

Data from the two air tests and four of the seven water tests were compiled to determine the performance of the crossover tester. The tester performance was analyzed to review the crossover as well as the pumping element performance (inducer and impeller). In this section, the crossover test results of head and efficiency, axial thrust, critical NPSH, and crossover pressure recovery will be discussed and compared with the analytical models used to design this tester and the MK49-F LH_2 turbopump. Data from the MK49-F turbopump tests conducted in 1986 will also be compared with these results. The raw data for the Air Tests 1 and 2 can be found in Appendix A and the water test data from tests T88a094, T88a096, and T88a097 can be seen in Appendix B.

Stage Head and Efficiency versus Flow Results

The overall stage head was determined using the crossover exit total pressure measurements and the calculated inlet total pressure where the latter was based on the measured static pressure and the calculated velocity head from the measured flowrate. At the crossover exit, three total pressures were measured at different radii representing the l/4, l/2, and 3/4 blade height positions. These three total pressures were in excellent agreement as can be seen in Figure 31 (notice the suppressed zero to expand the scale). This was the expected result and shows that the crossover exit flow was relatively uniform hub-to-tip as designed. If there had been a significant separation at the hub or tip, a variation in total pressure would have been seen.

Data from two water tests (T88A094 and 096) were combined in Figure 32 to show the stage head-flow relationship for the water test in comparison with the predicted head. The predicted head was calculated using Rocketdyne's Loss Isolation Program for centrifugal pumps with the actual dimensions and fluid properties for the water test configuration. This program accounts for the Reynolds number change for the test set up versus that for hydrogen testing of the MK49-F. The comparison between measured and predicted values was good, with the measured values of head being approximately 4 percent low at the design flow (Q_d). Tests of the 3-stage MK49-F hydrogen pump had also shown the head low by about 8.0 percent. With a known overboard seal leakage problem partially contributing to the low head, a direct comparison of the tester and the MK49-F turbopump could not be made. Based on the water data, however, it appears that the stage performance of the hydrodynamic design was slightly lower than predicted. Figure 32 also shows the stall characteristic. The analysis had predicted the stall to occur at approximately 80 percent of design flow with a rather moderate decrease in head. The Loss Isolation program only predicts stall due to leading edge flow angle

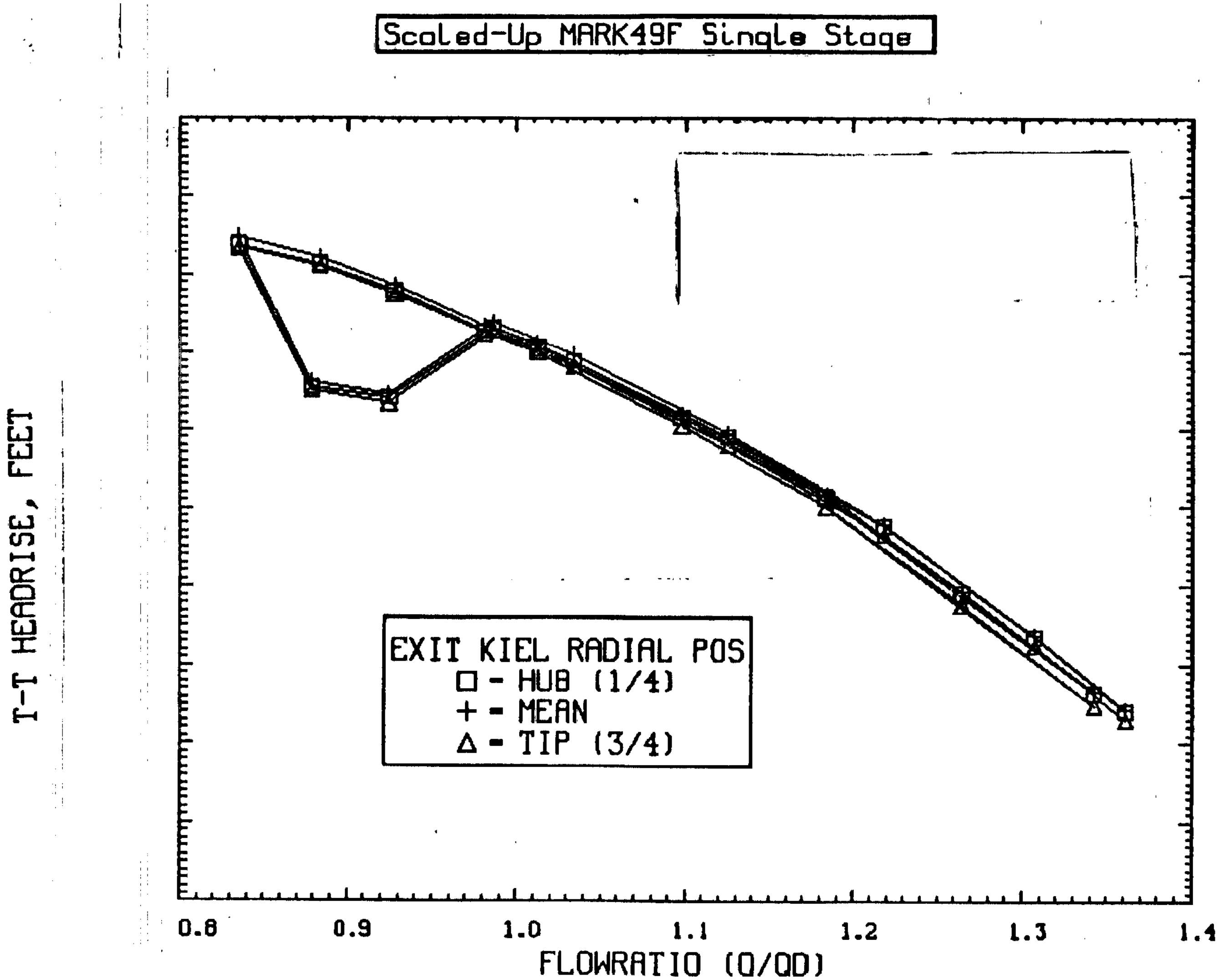


Figure 31 - Crossover Exit Total Head-Flow In Water

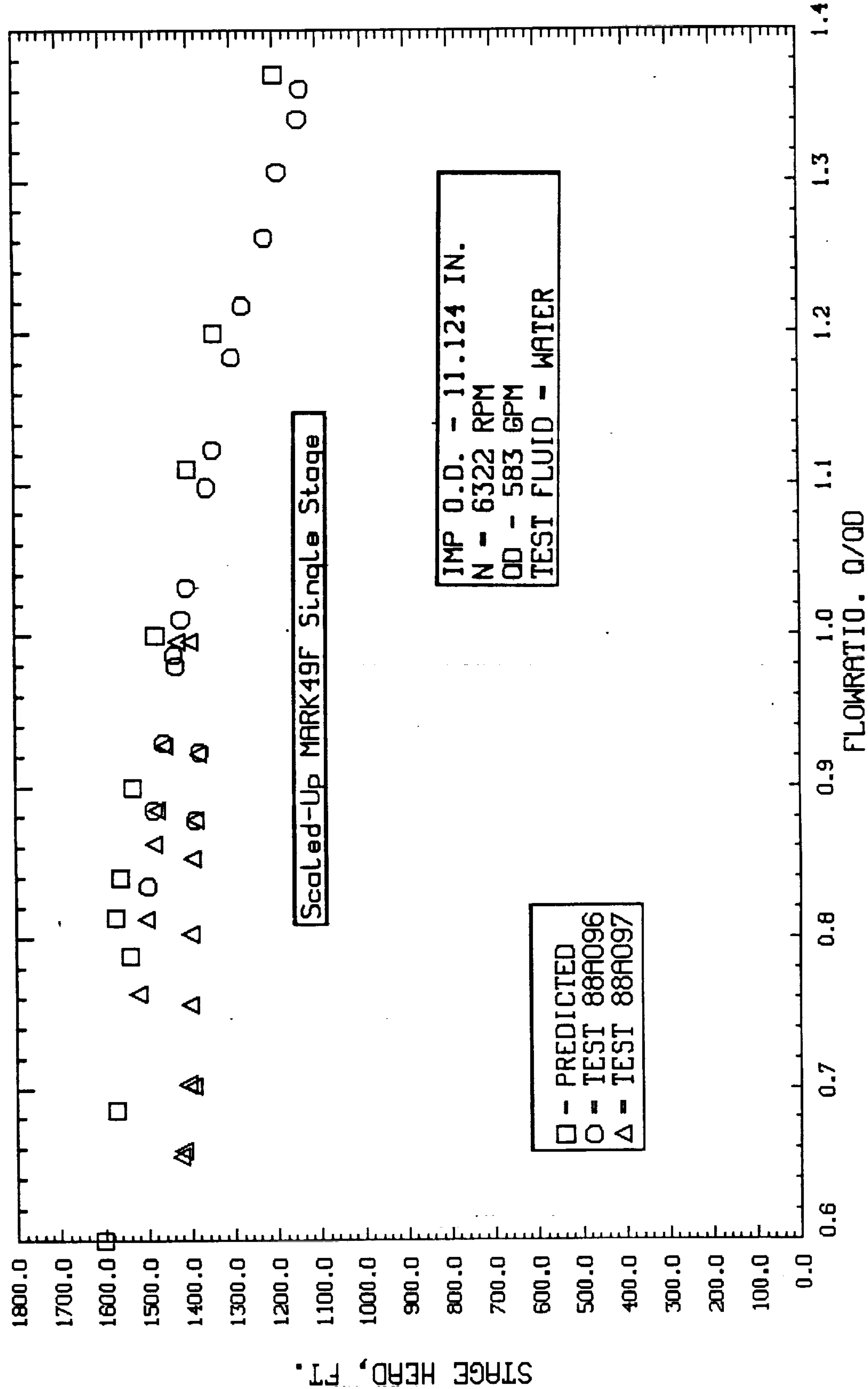


Figure 32 - Tester Stage Head-Flow Data versus Predicted

mismatch. The water test data shows that the stall initiates at approximately 76% Q_d while the flow was decreased. While increasing the flow, the stalled condition persisted until approximately 100% Q_d. This is known as the stall hysteresis effect.

The stall hysteresis phenomena could have important implications in the engine start sequence. For example, if the pump operated at a low Q/N (flow-speed ratio) during the start transient and the diffuser stalled, then the pump may remain in the stalled condition if the pump operated at a Q/N lower than 100%. This scenario is being reviewed for the MK49-F turbopump performance issues on the Integrated Component Evaluator (ICE) completed under Task F.4 of this contract.

The total head loss due to the stall was not severe and was only approximately 9% lower than the predicted head at 70% Q_d in the "unstalled" condition. This low head loss is characteristic of leading edge type stall in a centrifugal pump.

To determine the pump stage efficiency, the power absorbed by the rotating axial thrust balance disk was subtracted from the measured power (torque and speed) to arrive at the pump absorbed pump power. The thrust balance disk power was calculated using the Daily and Nece friction coefficients (Ref. 1). Figure 33 shows the resulting pump efficiency for the water test as a function of flow and compares it with predicted values. Near design flow, the efficiency was approximately 3 percentage points lower than predicted. The lower calculated efficiency was due in part to the accuracy of the calculated and measured power terms. The general shape of the curve again agrees well with prediction. As was the case with the head characteristic, the measured stall initiated later than the predicted stall.

The effect of Reynolds No. on head was larger than expected. Figure 34 shows the head-flow relationship for the stage from the air test, again comparing the measured to predicted values. The measured head near 100% Q_d was about 18 percent lower than predicted even though the predicted curve in air was 18 percent less than the prediction in water. Also, note that the air data does not show any stall characteristic in the curve. Data to be presented below will actually show that the diffuser was stalled over the full range of flow for the air test, so that the head characteristic in the data presented was the stalled head.

The stage efficiency could not be determined from the air test because of the low power absorption compared to the system tare torque. Table 10 presents the predicted and

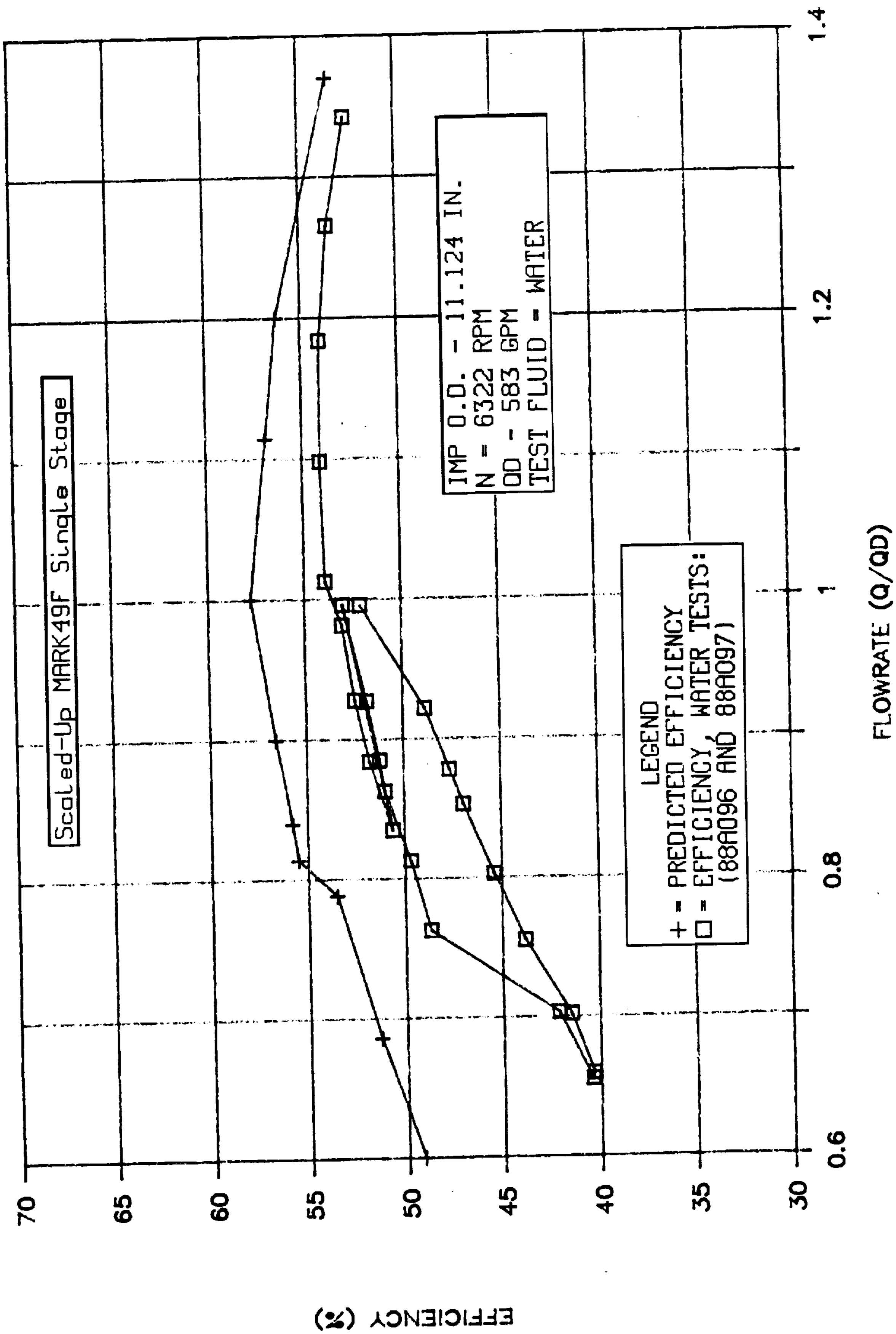


Figure 33 - Tester Stage Efficiency In Water Test Versus Predicted

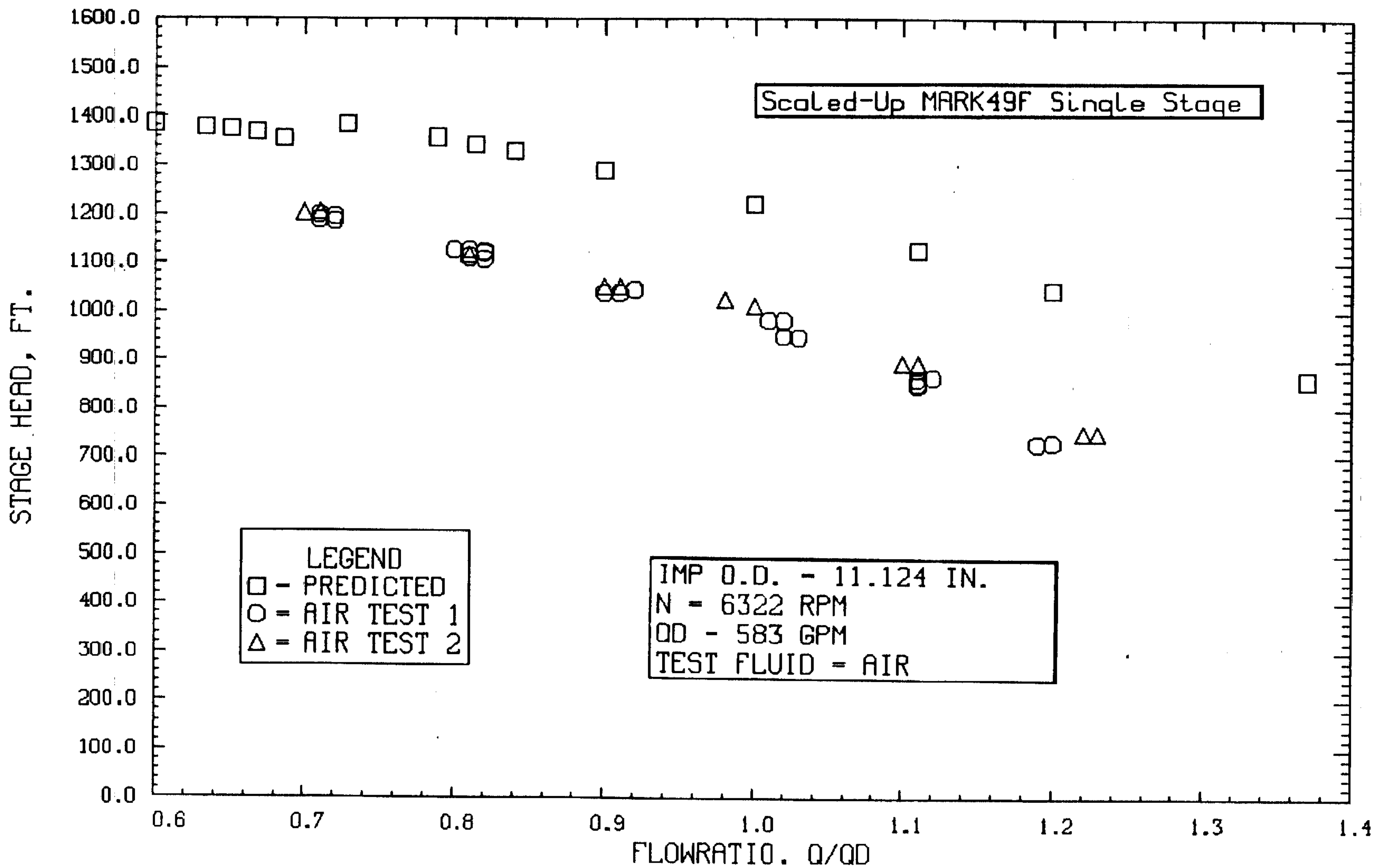


Figure 34 - Tester Stage Static Head in Air Test Versus Predicted

Table 10 - Head & Efficiency versus Flow - Air, Water,and LH_2 Measured & Predicted

	Inducer				Inducer + Impeller				Stage - Ind+Imp+Xover			
	Static Head (ft)		Efficiency		Static Head (ft)		Efficiency		Static Head (ft)		Efficiency	
	Pred	Meas	Pred	Meas	Pred	Meas	Pred	Meas	Pred	Meas	Pred	Meas
Crossover Tester (Water)	100	57	78%	-	1037	1074	91.3%	-	1461	1420	56.5%	55.4%
Crossover Tester (Air)	73	96	67%	-	909	1065	85.0%	-	1203	1011	45.7%	-
MK49-F Turbopump in LH_2 at 60,000 rpm	1362	1235	79%	-	11693	12029	92.9%	-	16882	15768	69.7%	-

measured head and efficiency of the crossover tester in water and air along with those data available from the MK49-F turbopump testing.

Internal Pressure Distributions

With the numerous internal pressures used in the test, the performance of individual components of the pump was estimated.

For the air test, the total pressure at the impeller discharge was measured using a single Kiel probe. Using this, the total head across the inducer-impeller combination was determined. The measured head was actually slightly higher than the predicted. The results are shown in Figure 35. This was consistent with the observations of stage head and efficiency reported above. The water data had shown the head closer percentage-wise to the prediction than the efficiency. This could be obtained if the impeller head were higher than predicted, and the losses in the diffusion system were higher than predicted. The two effects tend to cancel each other in the stage head but the higher losses show a direct effect on the efficiency.

Another interesting feature in Figure 35 was the difference between the two air tests. The first air test was started at a lower Q/N which apparently put the impeller into stall, and due to hysteresis the impeller did not come out of stall until approximately Q_d was achieved. Once out of stall, the flow could be decreased to 70% Q_d without initiating stall. On the second air test, the pump was started at a higher flow but still began in an apparent stalled condition but, even more surprising, never got out of the "stalled" condition. This behavior has not been explained. The stage head characteristic in air did not show the same trends from test one to test two. In Figure 34, the two tests were shown to give about the same head value, and in fact, the data for the second test was higher than for the first test. With severe stall in the diffuser system, the stage performance results are not necessarily expected to be consistent.

Figures 36 and 37 show the static-to-static pressure rise across the inducer-impeller for the air and water, respectively. The air data (Figure 36) shows the same general features as the total head curve, but the difference between measured and predicted was much higher for the static rise. This was possible if there was some diffusion in the vaneless space due to the difference in radial position between the impeller diameter and the sensing port diameter. For the water data, the prediction and measurement are closer but the measured value was still higher. Note that for the water, the predicted

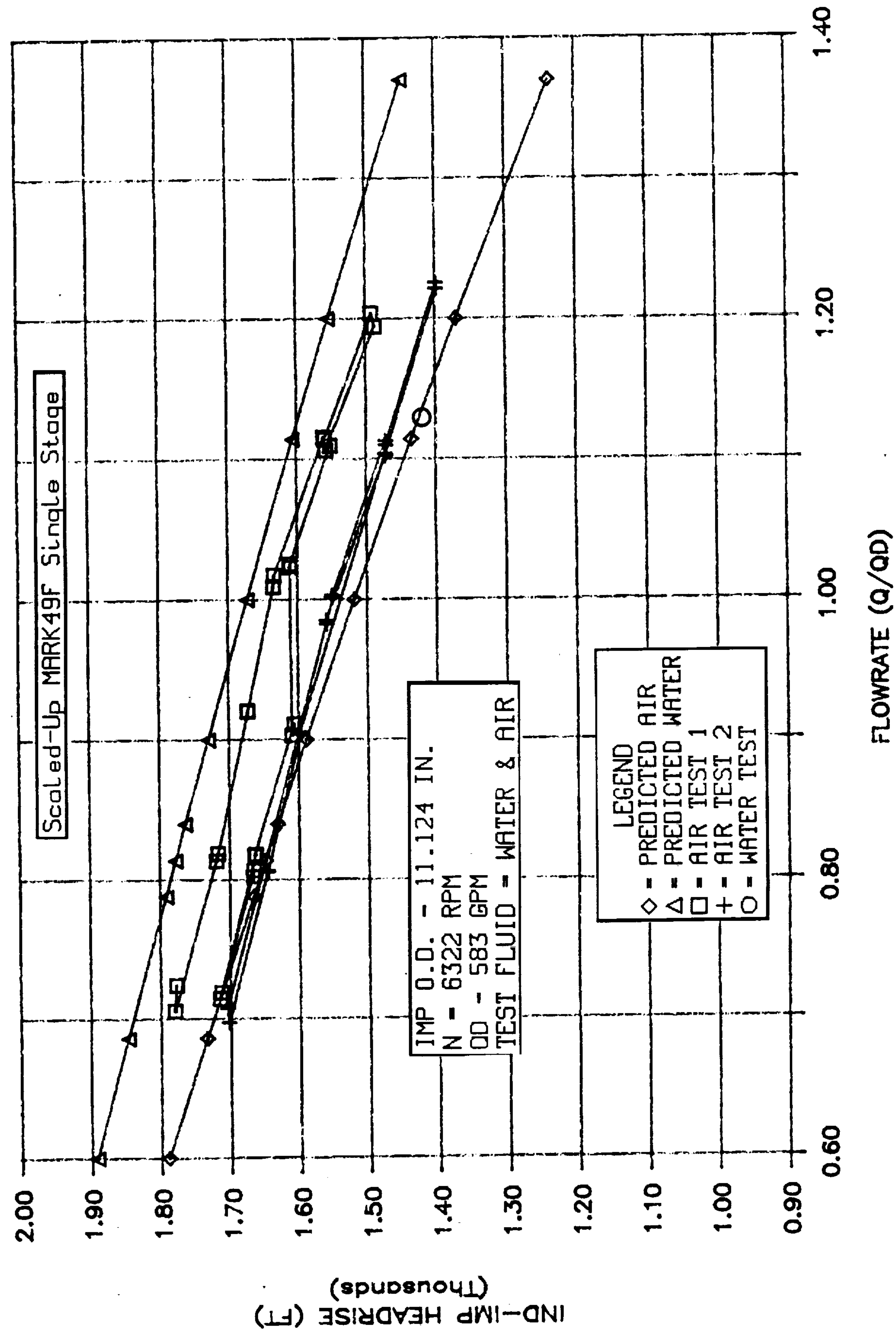


Figure 35 - Inducer + Impeller Total Head in Water and Air Test Versus Predicted

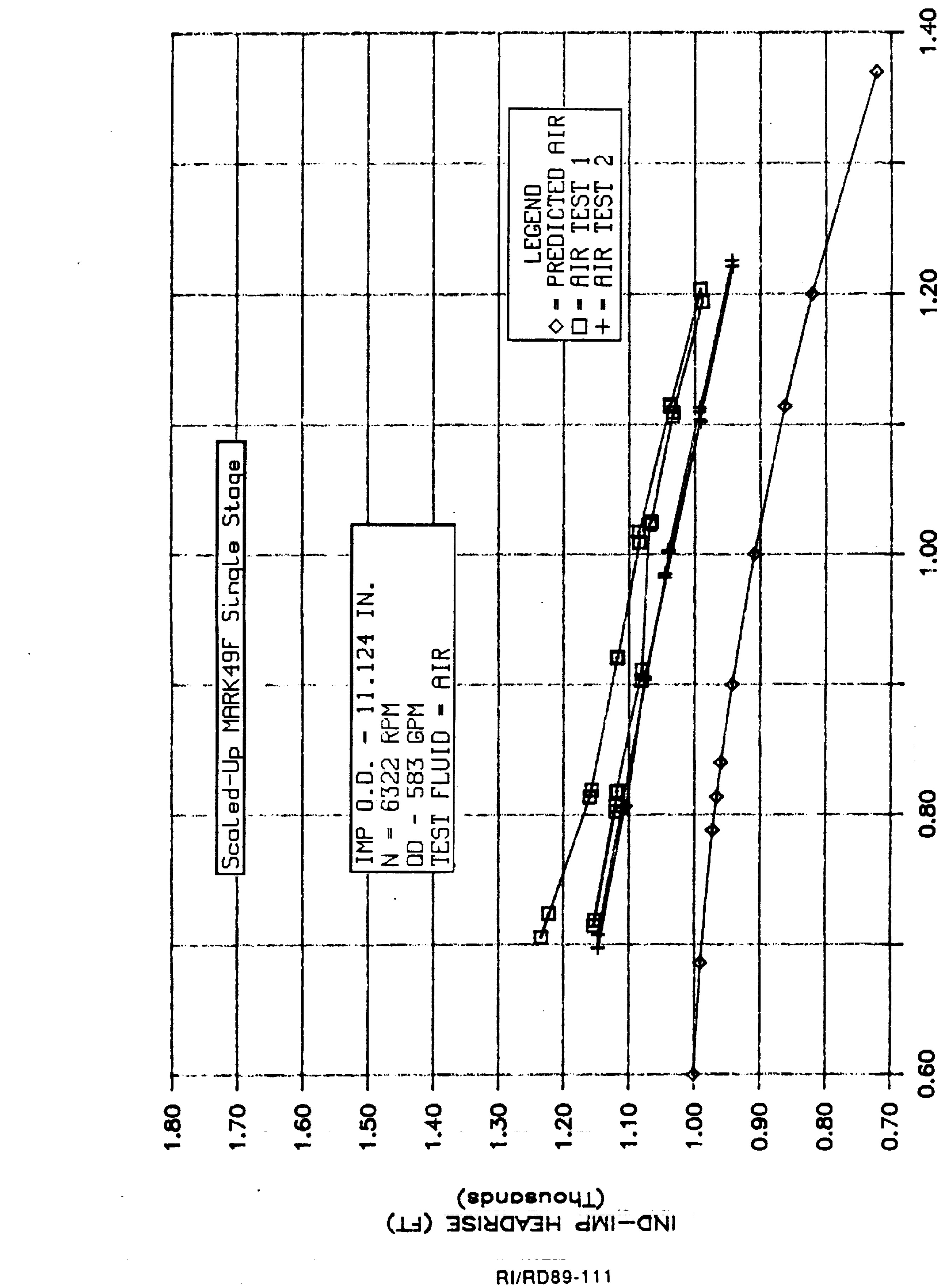


Figure 36 - Inducer + Impeller Static Head in Air Test Versus Predicted

static pressure was actually 14 percent higher than for air, but the measured values are essentially the same.

Figure 38 shows the static-to-static pressure rise across the inducer only for both air and water tests. Again, the second air test gave lower results. This could be indicative of inducer "stall" in the second test which would have aggravated the impeller stall. However, it was still not clear why the inducer would not come out of stall at the higher flows. The water data agreed with the data from the first air test. The air test data did not show a definitive stall, although there was some indication of hysteresis between 65% and 75% Q_d. The predicted inducer discharge static pressure was close to the measured value for the air test at the design flow using the Loss Isolation Program. The predicted inducer discharge static pressure, for the water tests, was slightly higher.

To show the diffuser performance, plots of static-to-static head rise from pump inlet through crossover exit were prepared showing the intermediate stations through the diffuser-crossover system. The water test data pressure distribution at various flowrates are shown in Figure 39. The measurement stations (1 through 9) are delineated on the cross section of the pump in Figure 40. Note the significant increase in static pressure from station 3 to 4. This figure clearly shows the majority of the diffusion occurring in the upcomer diffuser. In the transition and the downcomer diffuser, little diffusion can be achieved because the boundary layers are already large before entering these sections. Figure 39 also shows the stall occurring in the upcomer diffuser at the 70% Q_d flow. Note that the pressure at station 3 (impeller exit) was still high at this flow but the pressure at station 4 decreases.

The two air tests gave similar results so only those of the second air test were shown in Figure 41. The majority of the diffusion should be occurring in the upcomer diffuser, station 3 to station 4, as was seen in the water test data. The static pressure, however, for most flows significantly decreases from stations 3 to 4. Thus, the inlet to the upcomer diffuser was the point of initiation of the stall. The diffusion system never recovers from this stall. The stall was caused by increased boundary layer blockage due to a low Reynolds number. This effect resulted in an impeller discharge flow which entered the diffuser at a velocity and angle which would produce flow separation at the leading edge.

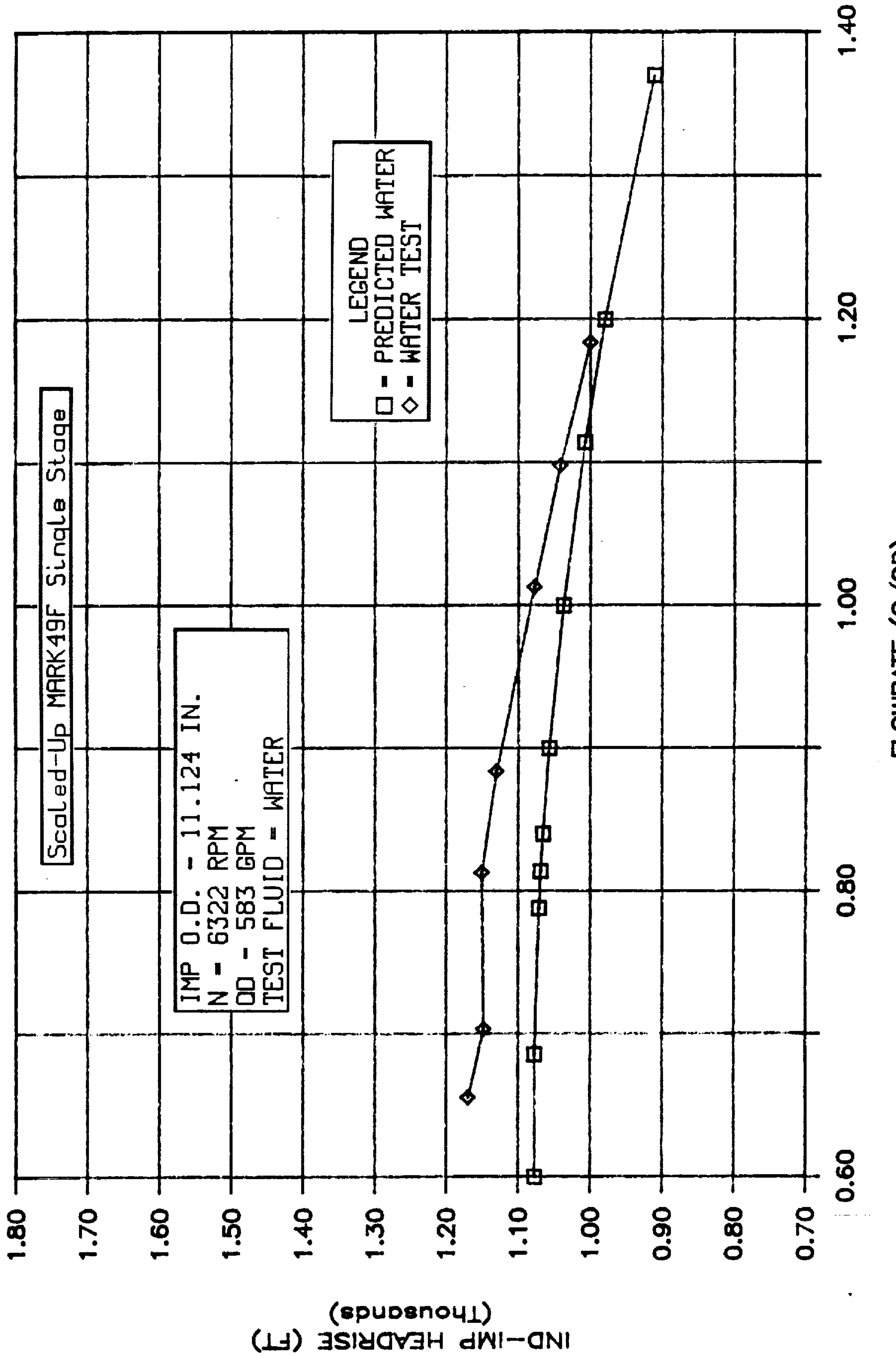


Figure 37 - Inducer + Impeller Static Head in Water Test Versus Predicted

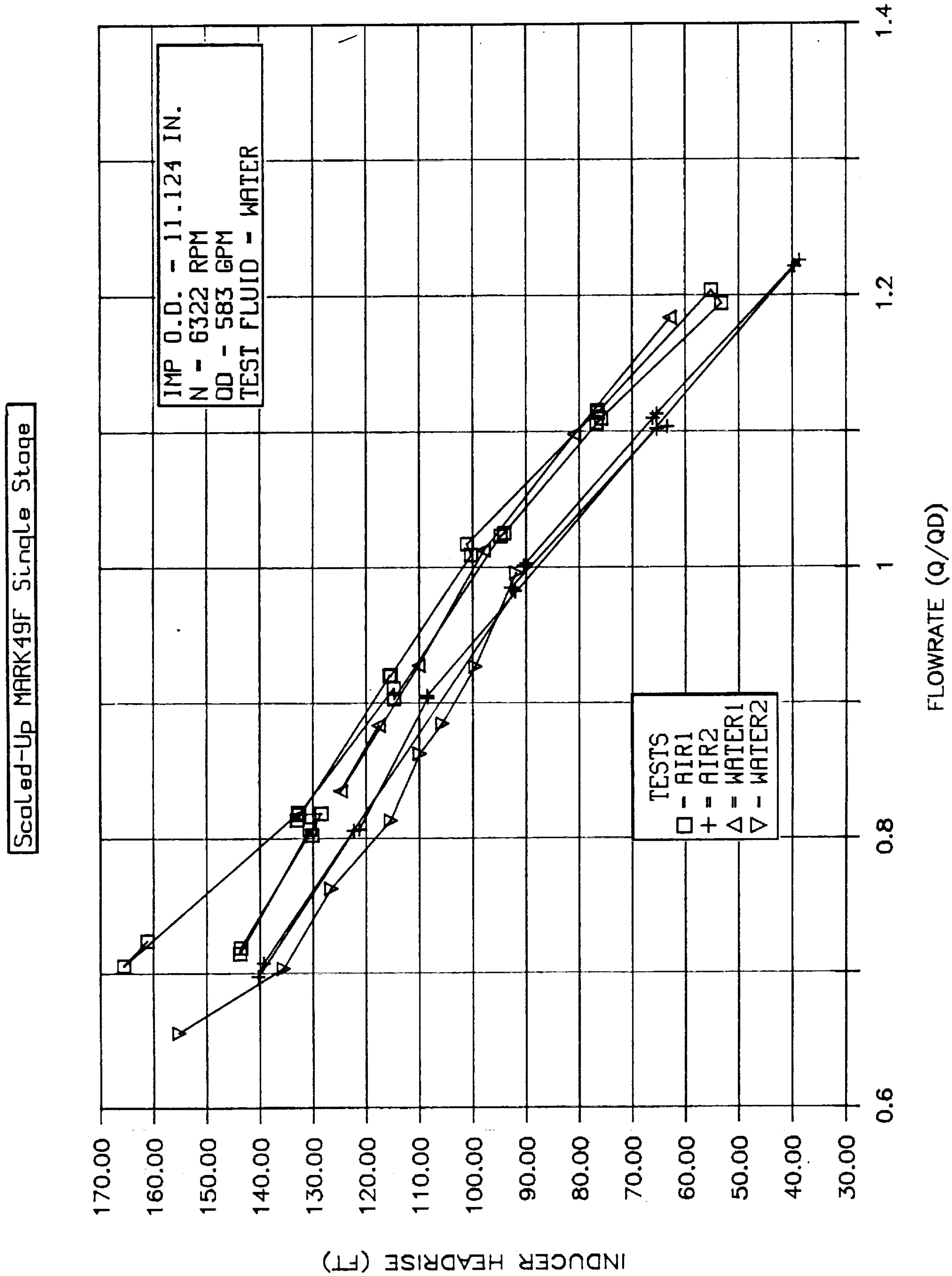


Figure 38 - Inducer Static Head in Water and Air Test Versus Predicted

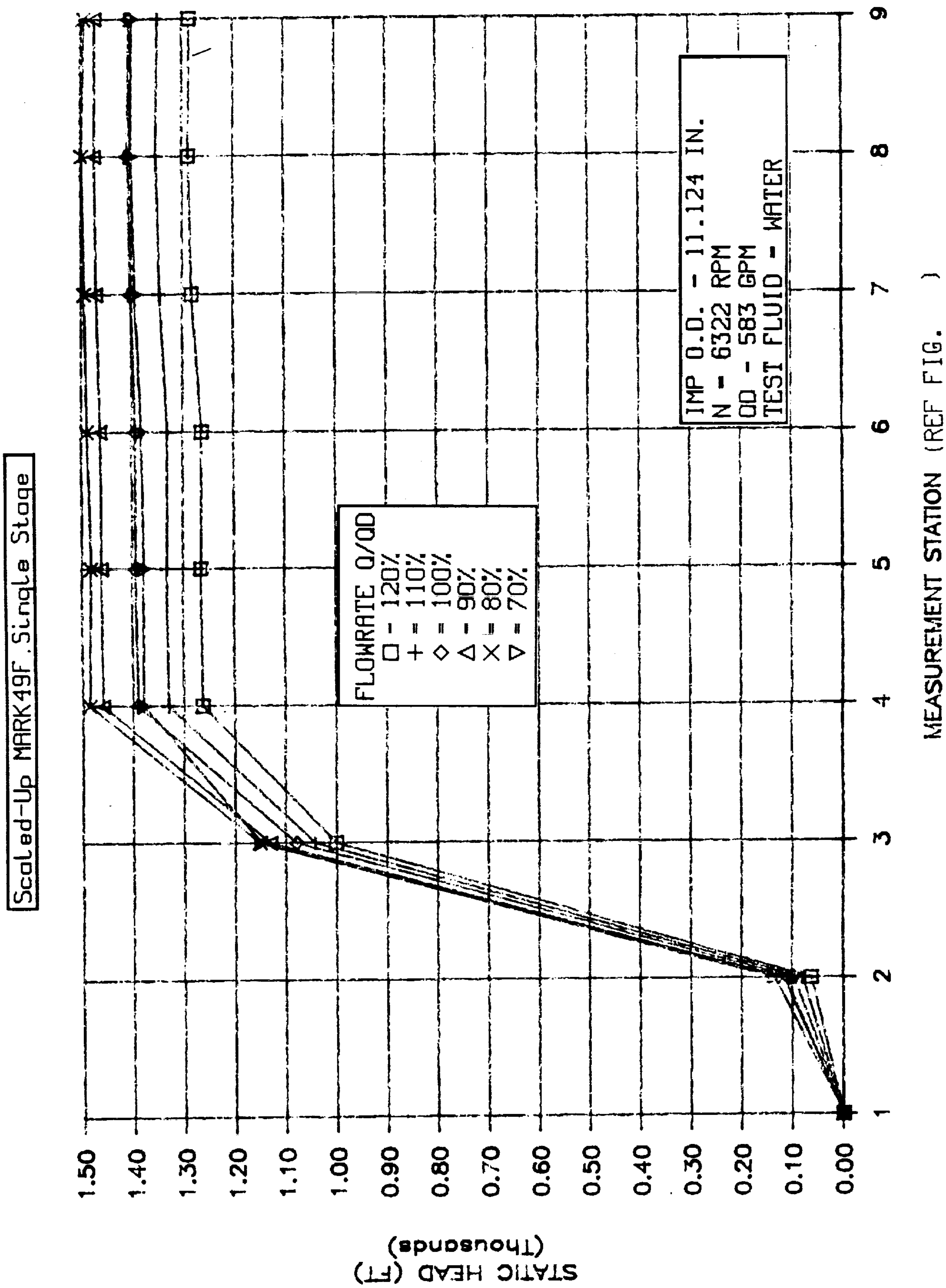
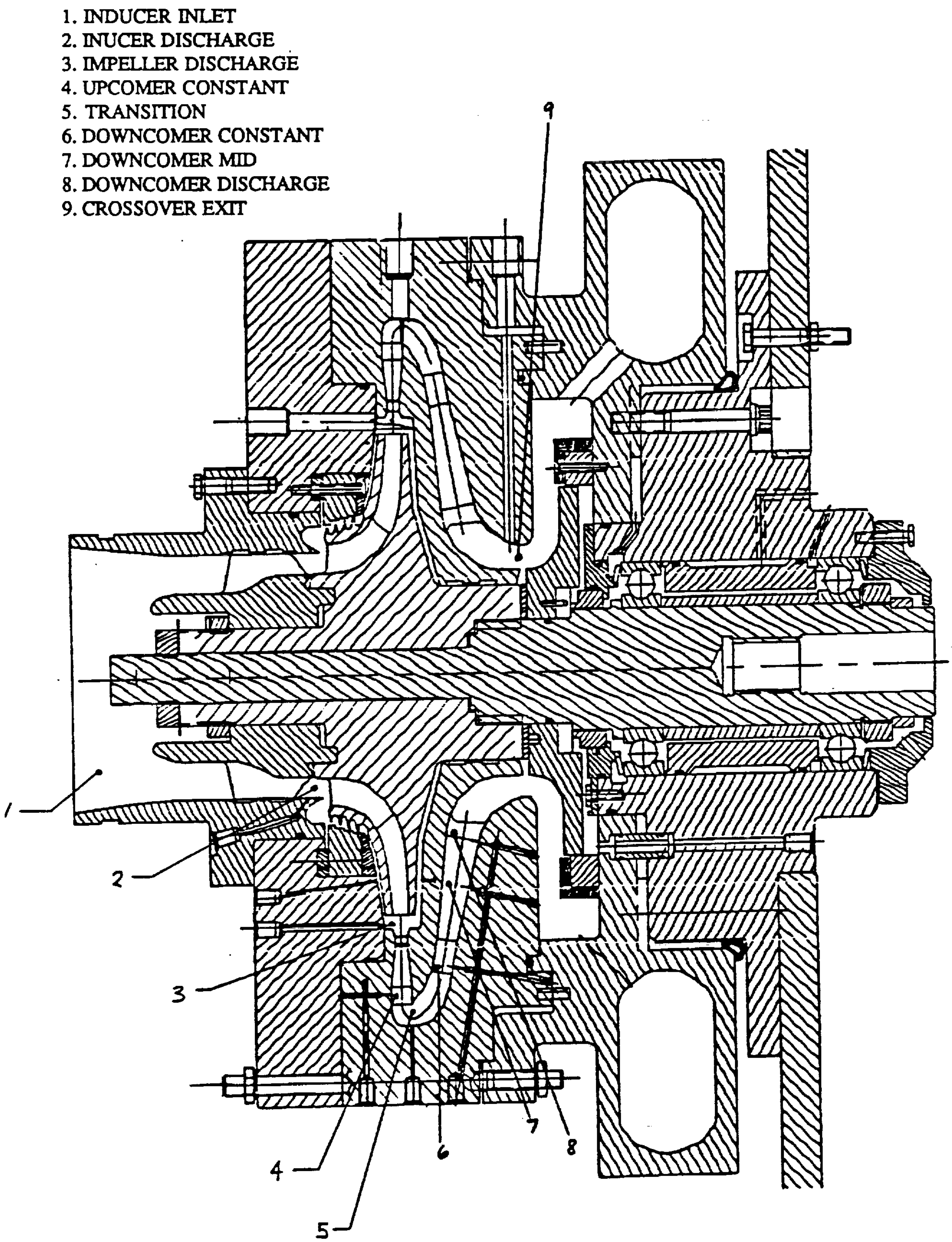


Figure 39 - Static Head vs. Tester Location in Water

Figure 40 - Crossover Tester Static Pressure Locations



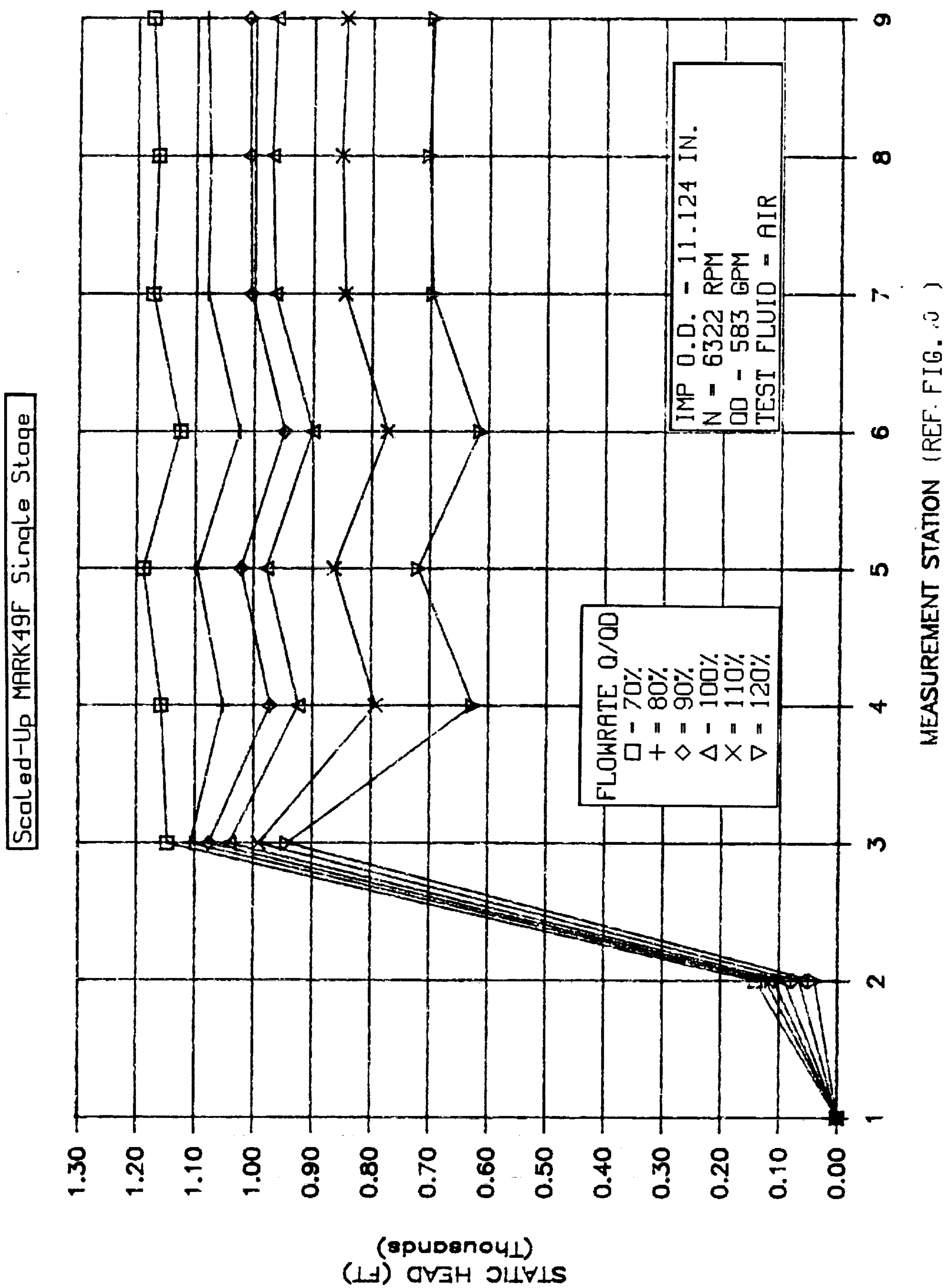


Figure 41 - Static Head vs. Tester Location in Air

Pump Suction Performance

Suction performance data were obtained from 80% to 124% Q_d at approximately 10% Q_d increments. It was during the 80% Q_d flow test when the tester bearing failure occurred. By this point in the test program all flow conditions had been tested. Some data points, including the design flow point, would have been repeated because less than 3% head loss was seen. However, enough data existed to project reasonable estimates of the suction performance for all flows.

The test data were typically reduced by plotting stage head as a function of NPSH (Net Positive Suction Head) for each constant flow condition. Flow was held constant during these test via the pump discharge throttle valve. Typical results were shown in Figure 42 through 50, beginning at 80% and increasing to 124% Q_d.

At the lower flows, the head was seen to hold relatively constant and drop sharply once cavitation effects were seen. Figure 43, at 87% Q_d, shows a very interesting characteristic in that the head drops noticeably into stall as the NPSH was decreased. It can be said that the ensuing cavitation phenomena was a sufficient disturbance to drop the head to the lower level of the stall hysteresis characteristic.

As mentioned, in Figure 44 and 45, the tests were terminated before significant head loss occurred. The resulting suction specific speed values could not be accurately determined. Unfortunately, the failure occurred before these key points could be repeated.

As the flow was increased, the head was seen to drop at a higher NPSH, as expected. However, head loss was less severe before eventually dropping into super-cavitation, as seen Figures 46 through 50, which was indicative of the inception of impeller stall. This phenomena has been seen in other centrifugal pumps like Rocketdyne's MK29-F (used on the J2S Engine). Inducer performance was seen to be lower than expected and may have also contributed to this situation.

Using the Head versus NPSH data, suction specific speed curves were generated to compare with the design predicted value. These curves are given in Figure 51 for 3, 5, and 10 percent head fall off. Suction specific speed was defined as:

$$\text{Suction Specific Speed} = N_{ss} = \frac{N\sqrt{Q}}{(\text{NPSH})^{.75}} \qquad (1)$$

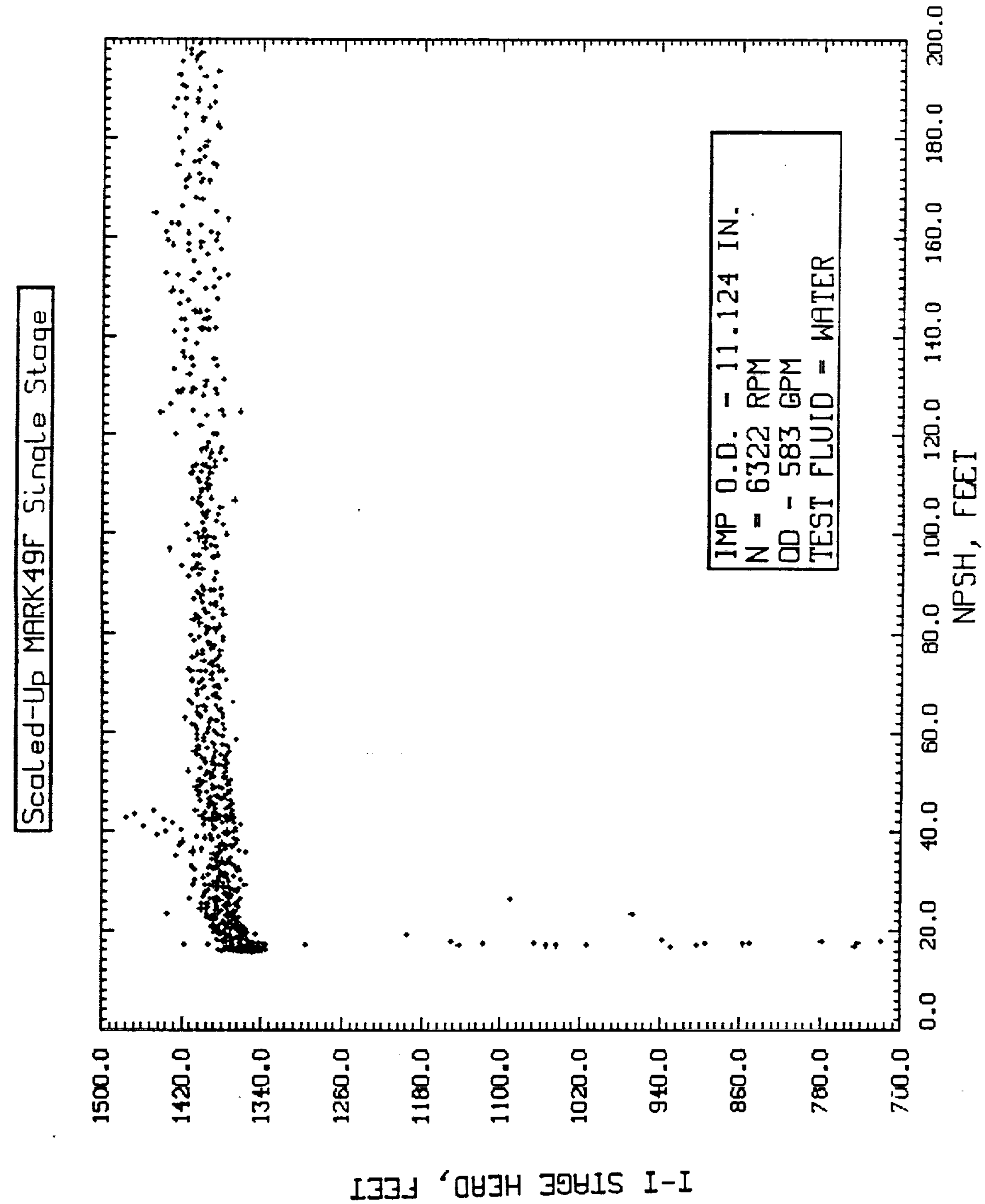


Figure 42 - Suction Performance Test at 80%Qd

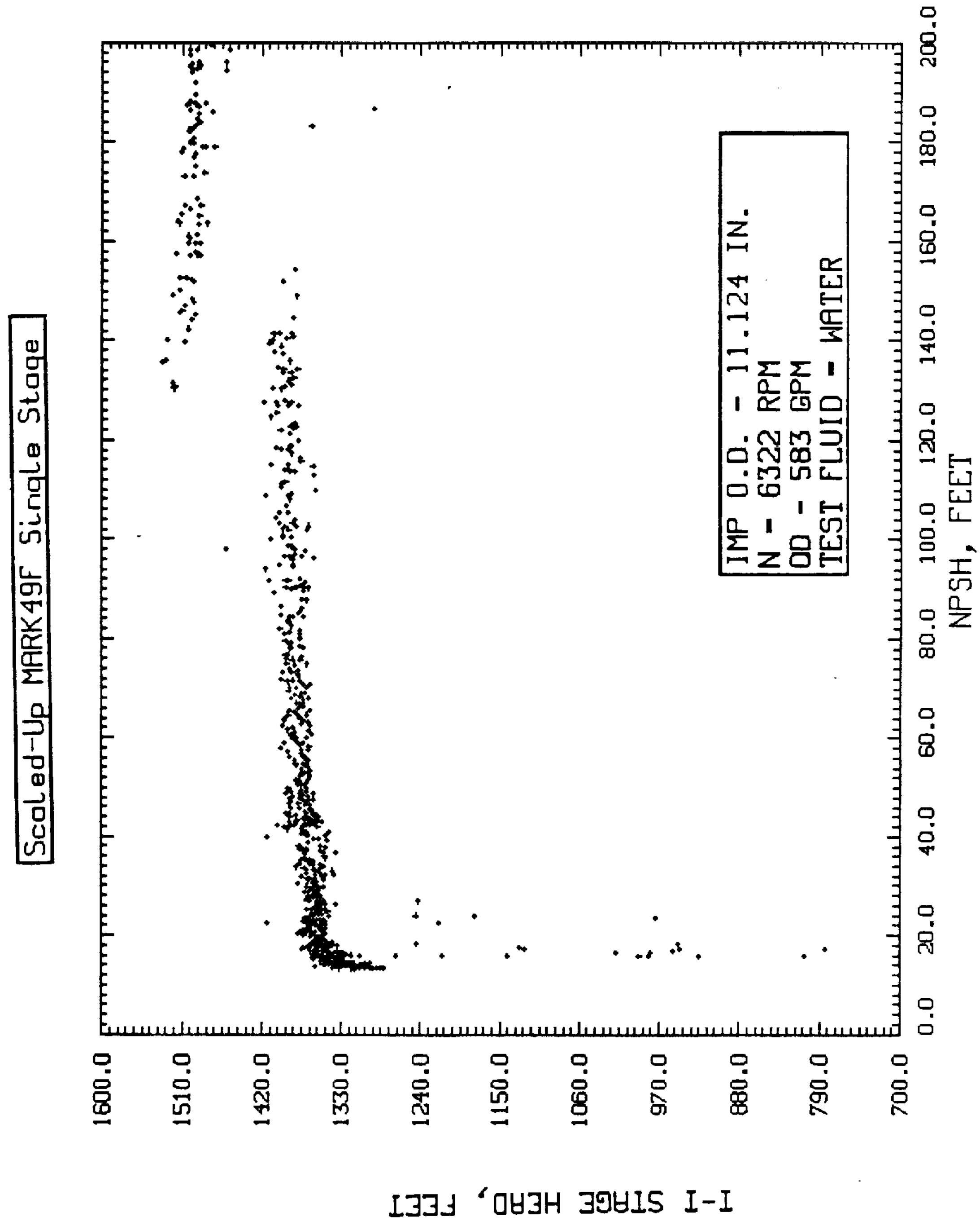


Figure 43 - Suction Performance Test at 87%Qd

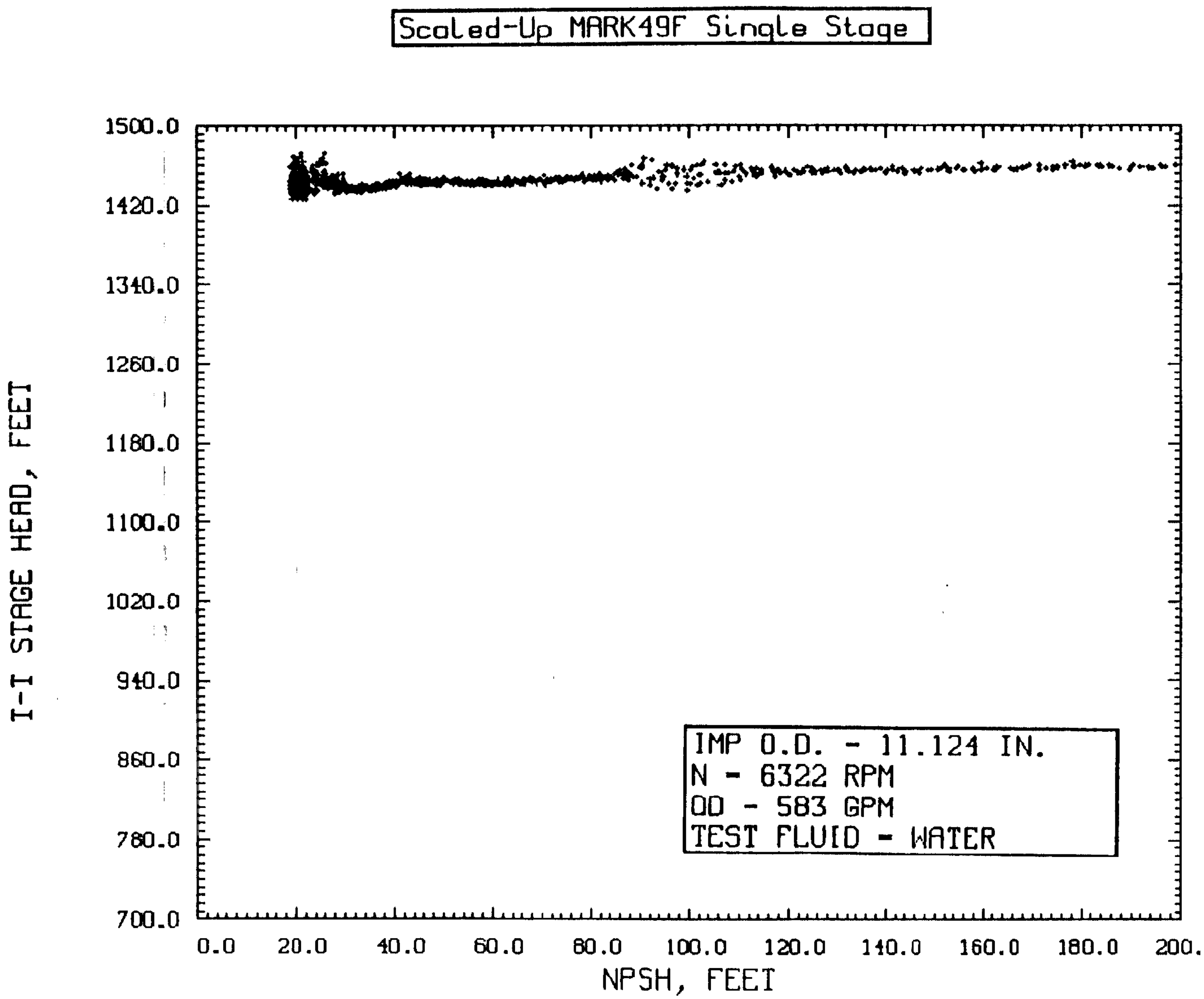


Figure 44 - Suction Performance Test at 92%Q_d

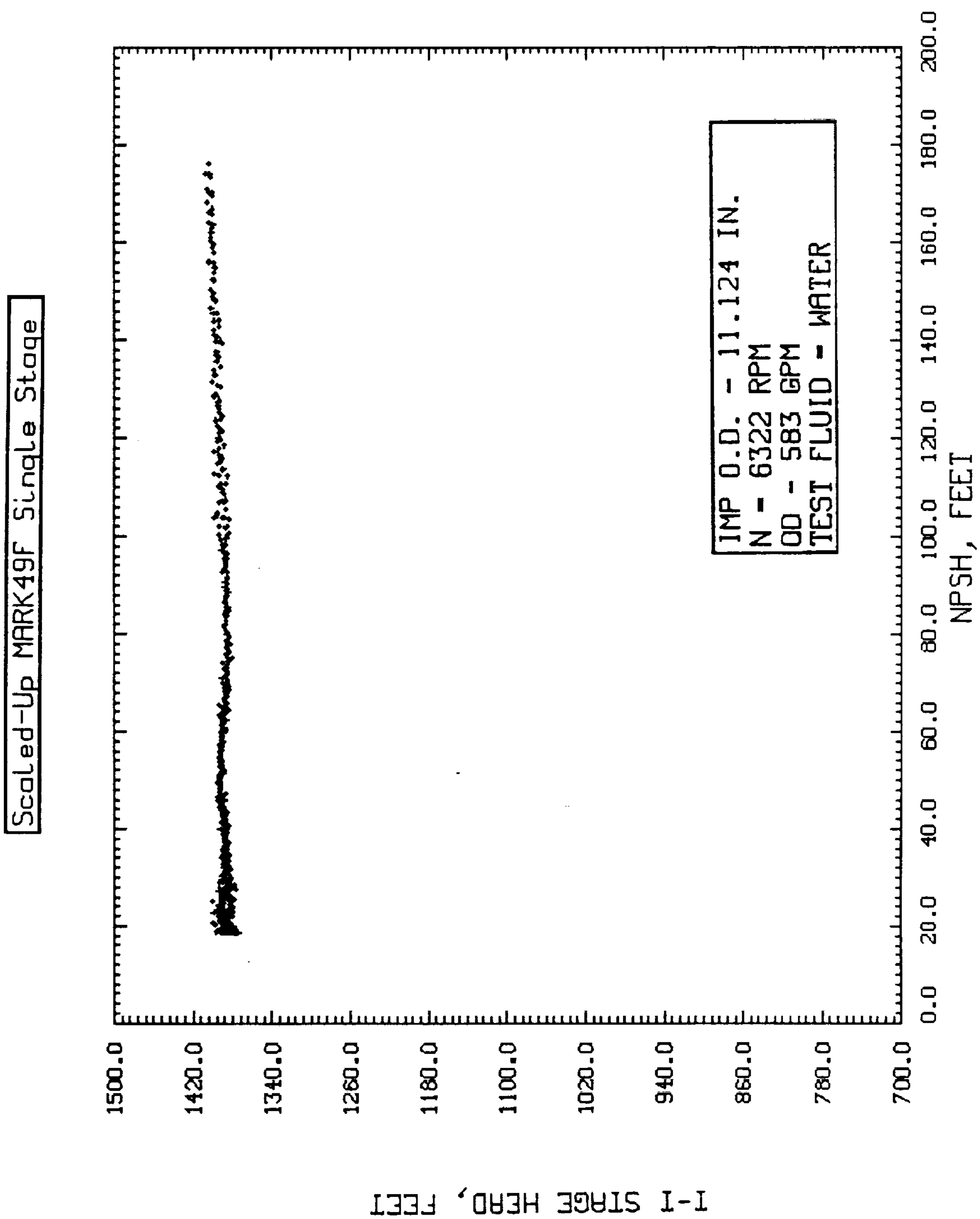


Figure 45 - Suction Performance Test at 101%Q_d

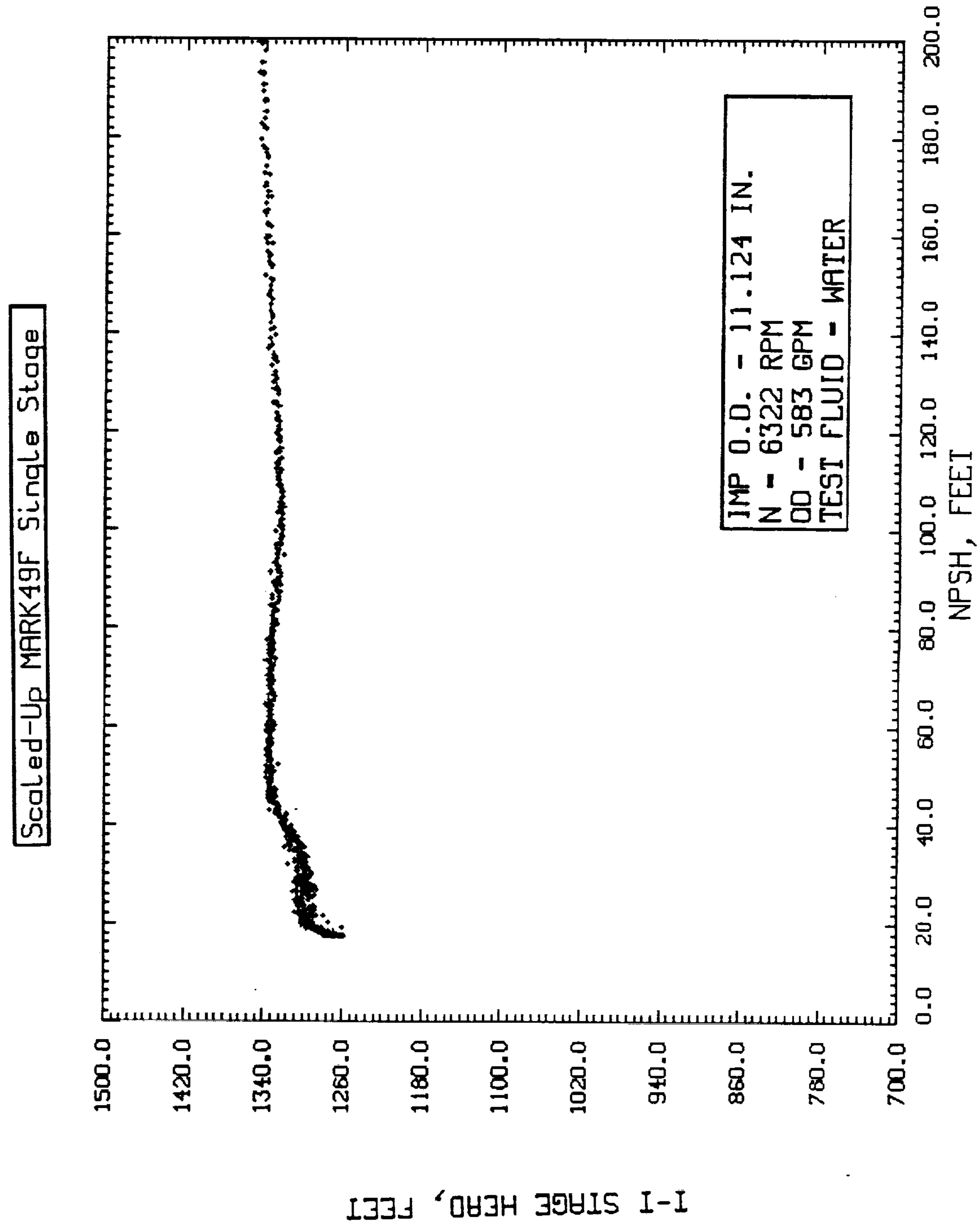


Figure 46 - Suction Performance Test at 108%Qd

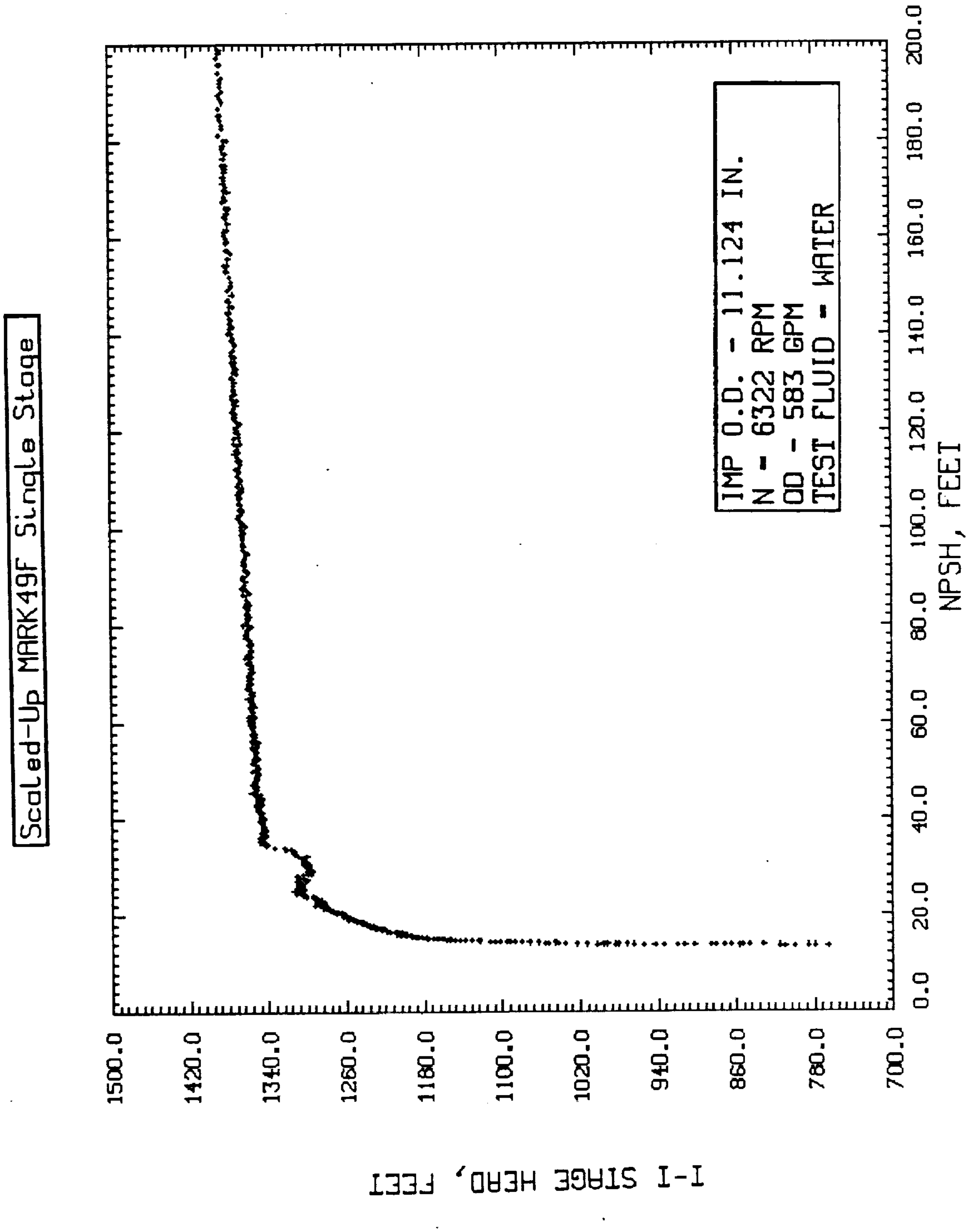


Figure 47 - Suction Performance Test at 109%Qd

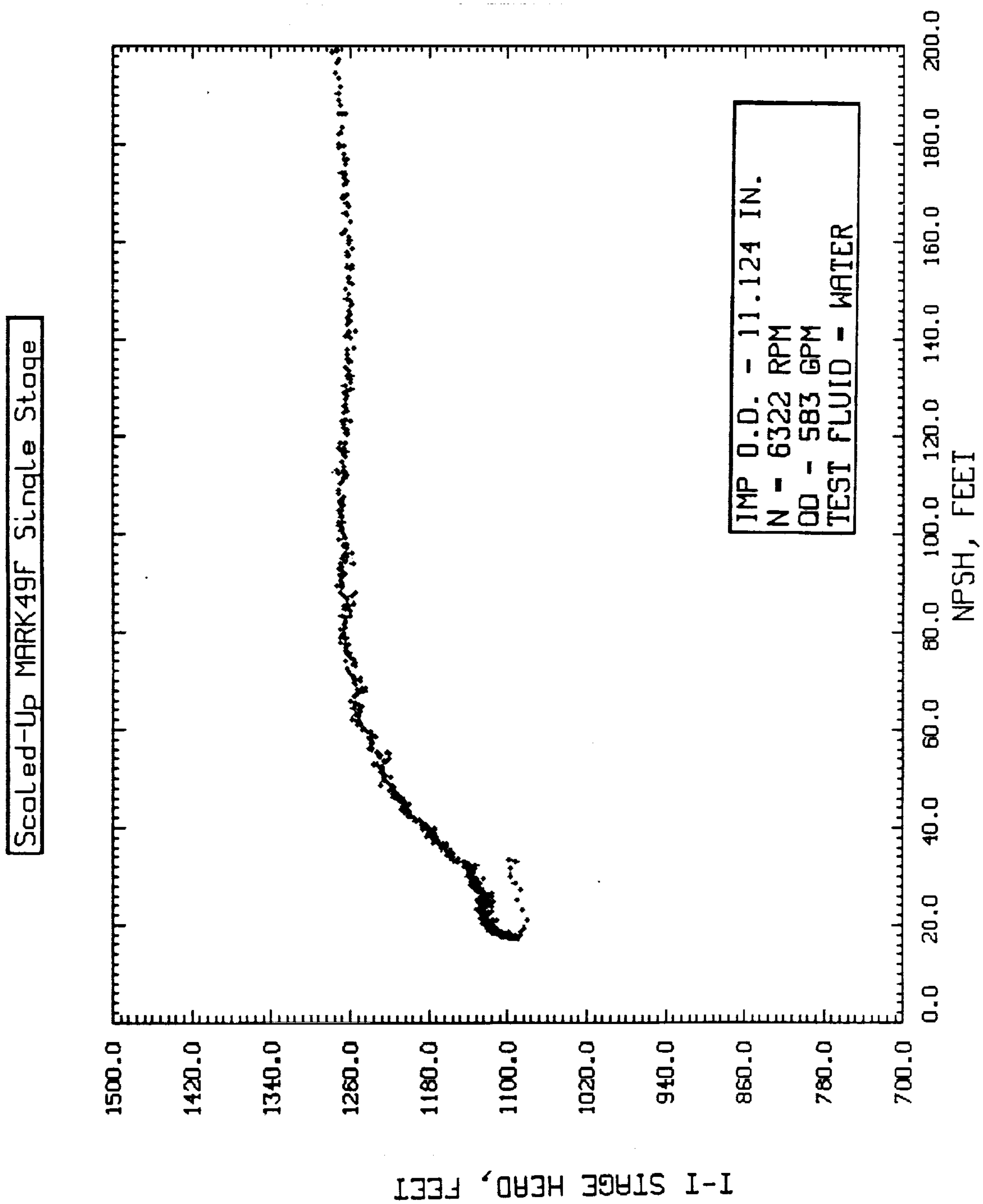


Figure 48 - Suction Performance Test at 116%Qd

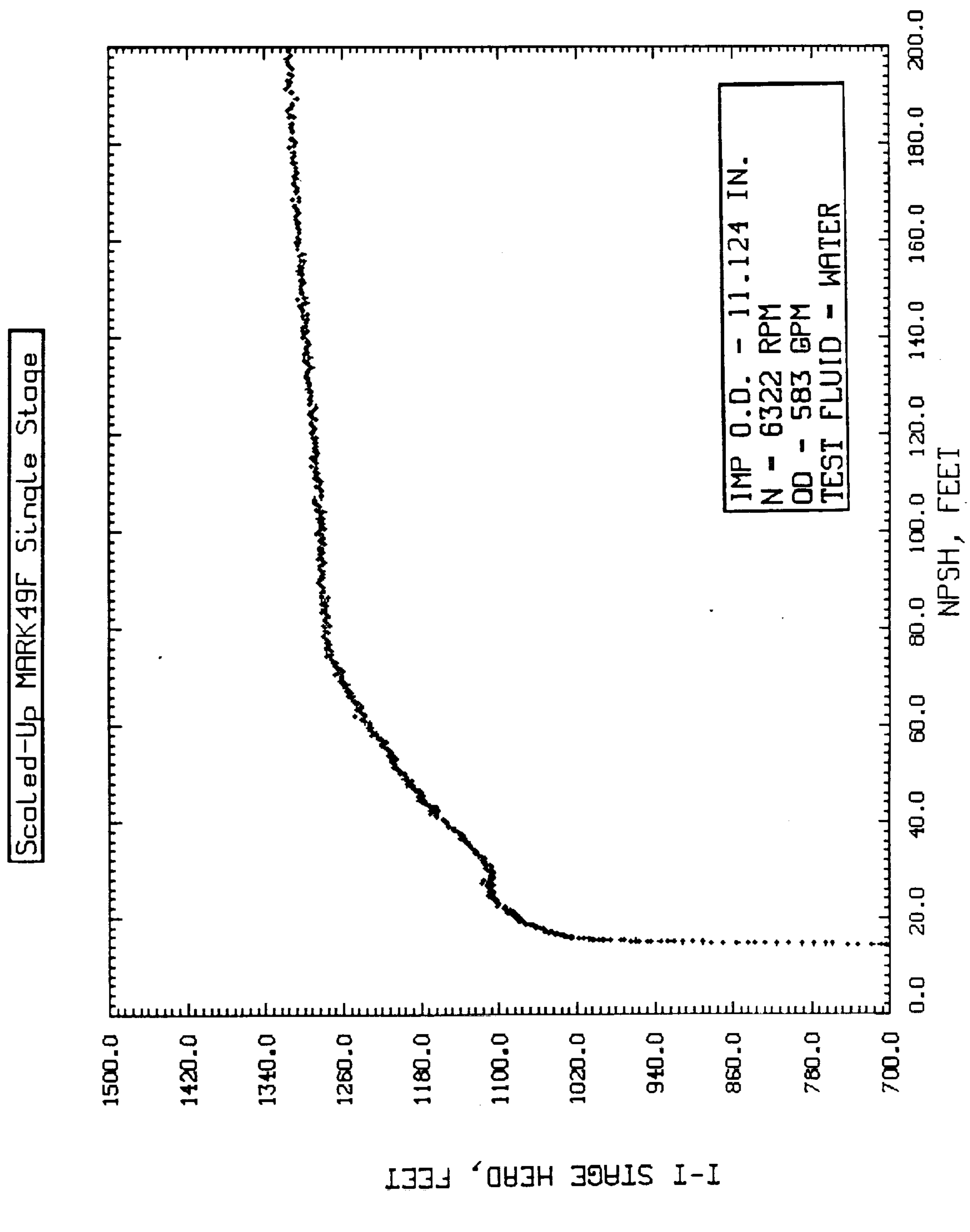


Figure 49 - Suction Performance Test at 119%Qd

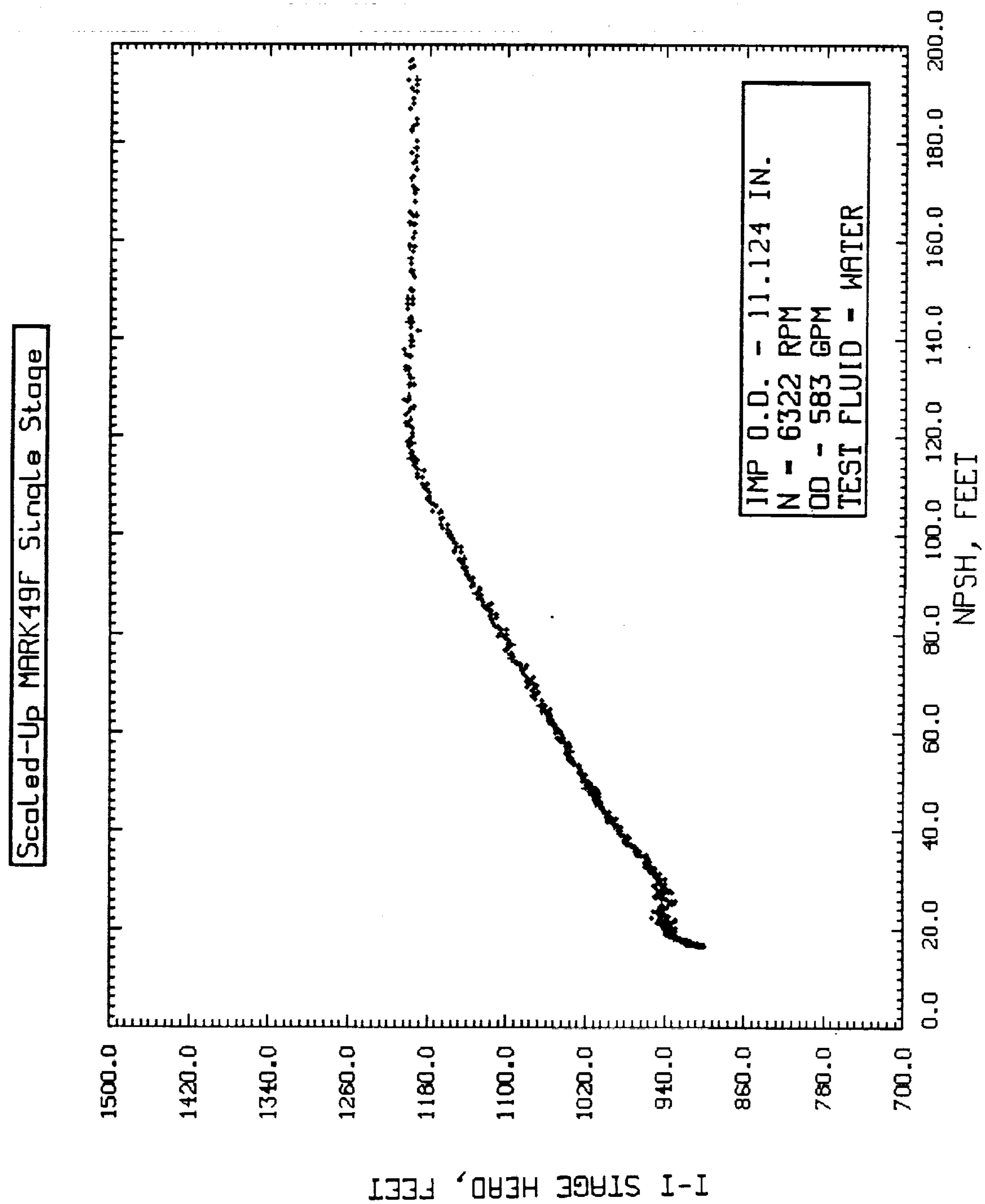


Figure 50 - Suction Performance Test at 124%Q_d

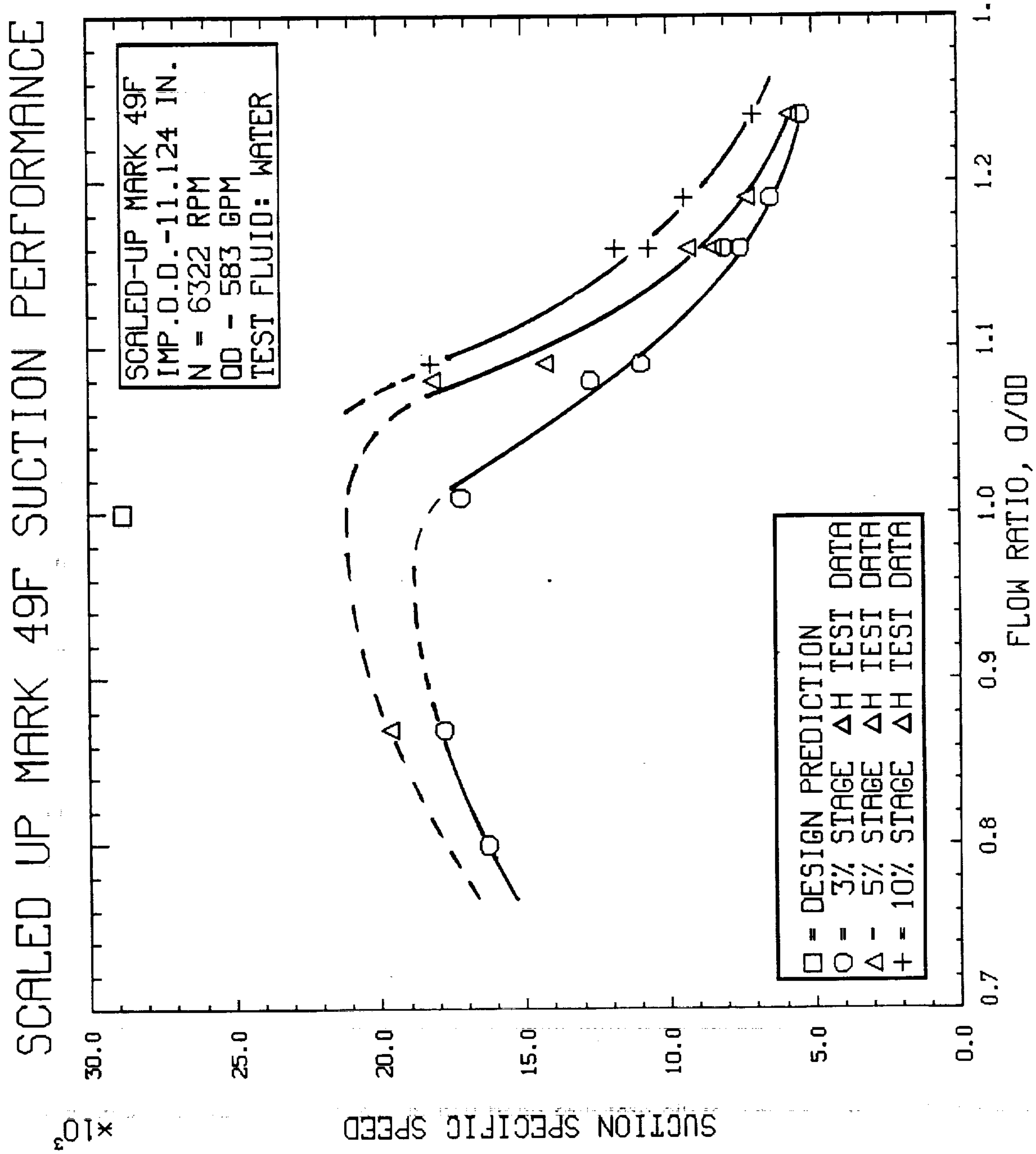


Figure 51 - Suction Specific Speed Capability versus Flowrate

where the parameters were speed (N) in rpm, flow (Q) in gpm, and NPSH in feet. Also shown in the figure was the predicted ideal capability at 3% head fall off based on the design flow coefficient and inlet hub/tip diameter ratio of the inducer. The ideal suction specific speed in water without thermodynamic suppression head (TSH) benefit was nearly 29,000. The suction specific speed calculated from the water data was only about 18,000. The low N_{SS} could have been caused by several factors: (1) leading edge of inducer not fabricated to print, particularly with regard to thickness, (2) tip clearance of the inducer and leading edge thickness too large, (3) large hub-to-tip diameter ratio of the inducer, or (4) design deficiency. The latter does not appear to be the problem based on review of the hydrodynamic design. With the size of the MK49-F inducer being so small, the parameters typically controlled for good suction performance could not be scaled down. Consequently, the inducer tip clearance and leading edge radii, used in this tester, when scaled up from the small MK49-F, were larger than the ideal dimensions used on a turbopump of similar size. By scaling up these dimensions, suction performance would be reduced from the ideal case, hence the lower performance found during the tests.

It should be noted that the results of Figure 51 were for a single stage and with no TSH benefit. For a 3-stage pump in hydrogen the results would be much better. For example, 10 percent head loss on the first stage would represent only about 3 percent over all for the 3-stage design. The 10% head fall off curve was not defined in Figure 51 at design flow but the suction specific speed (N_{SS}) could easily reach 25,000. With added TSH benefits, the suction specific speed capability in hydrogen could be much higher than 30,000.

At the time the MK49-F was designed, the required suction specific speed was only 10,000 at design flow. This value was exceeded even in water for a single stage. Thus, the operating requirements would be met even though the performance was down from the predicted potential at the design flow coefficient.

Using the inducer and impeller discharge static pressures, the relative performance of the inducer and impeller can be distinguished over the flow and NPSH range tested. Figure 52 shows the inducer static pressure head rise above inlet total at 87% Q_d, and Figure 53 shows the corresponding static pressure head differential across the impeller. Obviously, at this flow the inducer was determining the suction performance of the stage while the impeller continues to generate the static pressure head until the inducer performance drops. In Figure 53, note the very interesting result of the stall that was

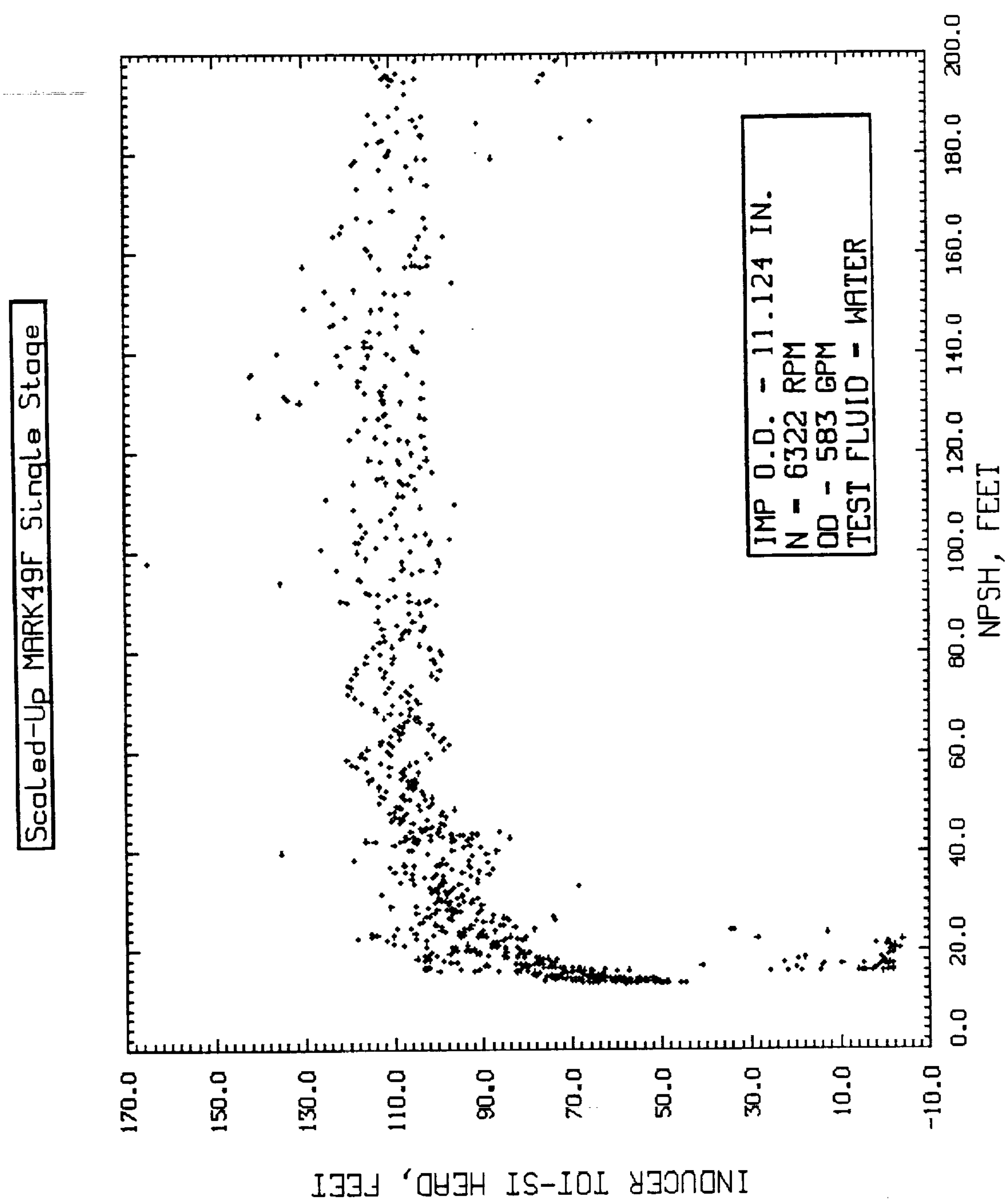


Figure 52 - Inducer Static Head Loss at Q/Q_d=87%

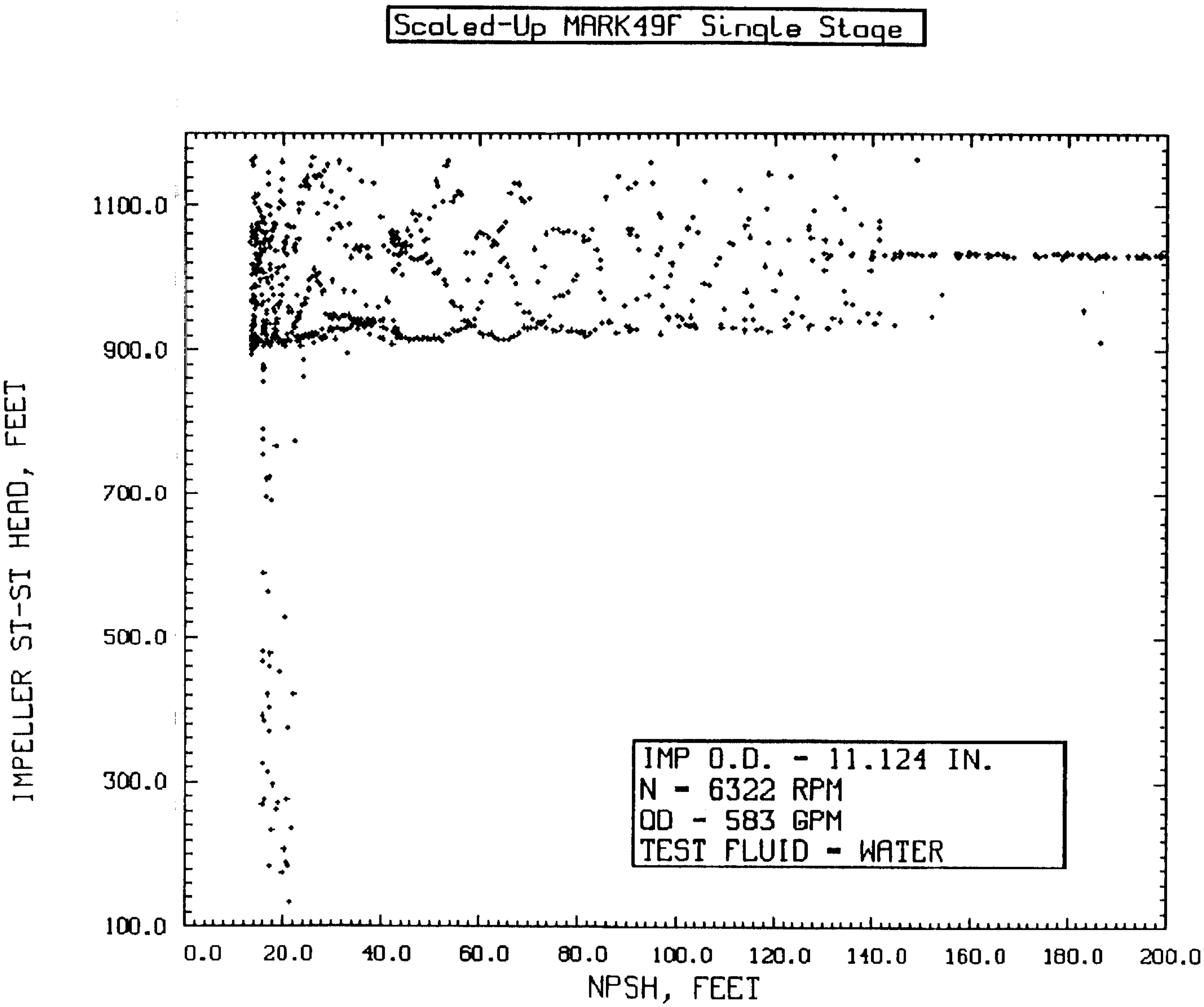


Figure 53 - Impeller Static Head Loss at Q/Q_d=87%

also seen to occur at an NPSH of approximately 140 ft. in Figure 43. Although the impeller experienced a significant discharge pressure oscillation during pump stall, it did not lose head, showing that the pump stall occurred in the diffuser. The static pressure head was actually varying by 250 feet, peak-peak. With a stage head rise of only 1400 feet this was a peak-peak variation of over 15 percent of the stage head. Operation under such a large dynamic oscillation would not be recommended.

In contrast to Figure 52 and 53, Figure 54 and 55 present the same two parameters at 109% Q_d. At this flow the impeller can be seen to slowly lose static pressure head as NPSH was decreased even though the inducer static head remains the same. As the inducer head decays the effect was also seen in the impeller, but the impeller began losing head earlier. Even at this flow however, the super-cavitation point was determined by the inducer, not the impeller. This was, of course, typical. At higher flows, the impeller suction performance was most critical while at design flow and below, the inducer determined the suction performance.

Shroud Vortex Strength

Static pressure measurements were made on the front and rear shroud of the impeller to permit evaluation of the vortex strength in these regions. The pressure distribution on these shrouds, which are strongly affected by these vortices, determine both the axial thrust and the shroud leakage rates. Data from the water tests was used to establish the front and rear shroud pressure distributions. Figure 56 presents an illustration of the impeller shroud pressure distributions and the direction of leakage flow.

The front shroud flow enters from the impeller outer diameter and down the shroud cavity to the impeller labyrinth seal. This leakage combine with the inducer discharge flow before re-entering the impeller eye. Because the front shroud flow enters at the impeller tip, the fluid already has a strong tangential velocity. According to the Loss Isolation program results, the fluid tangential velocity to impeller tip velocity ratio, defined as Cu/U_t, at the design flow is 0.63. This velocity ratio varies from 0.67 to 0.61 at the 80% to 120% design flow, respectively. Since the impeller discharge static pressure was measured 0.213 inch radially outboard from the impeller outside diameter, the static pressure at the impeller tip was calculated, using the velocity ratio and assuming no total pressure loss per the following;

$$P_{tip} = P_{meas} + \frac{1}{2g}\rho Cu_{tip}^2\left(\frac{r_{tip}}{r_{meas}} - 1\right) \quad (2)$$

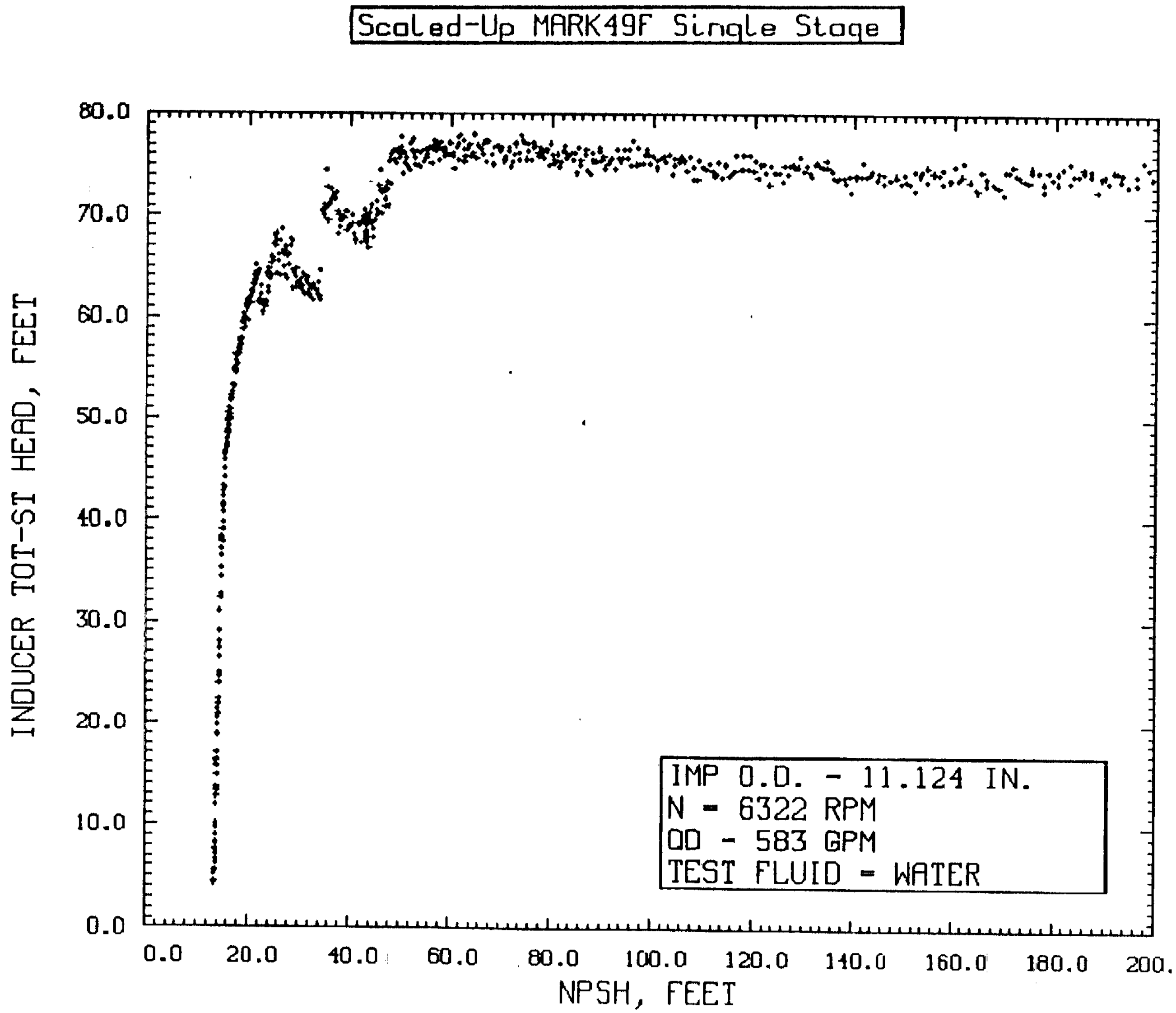


Figure 54 - Inducer Static Head Loss at Q/Q_d=109%

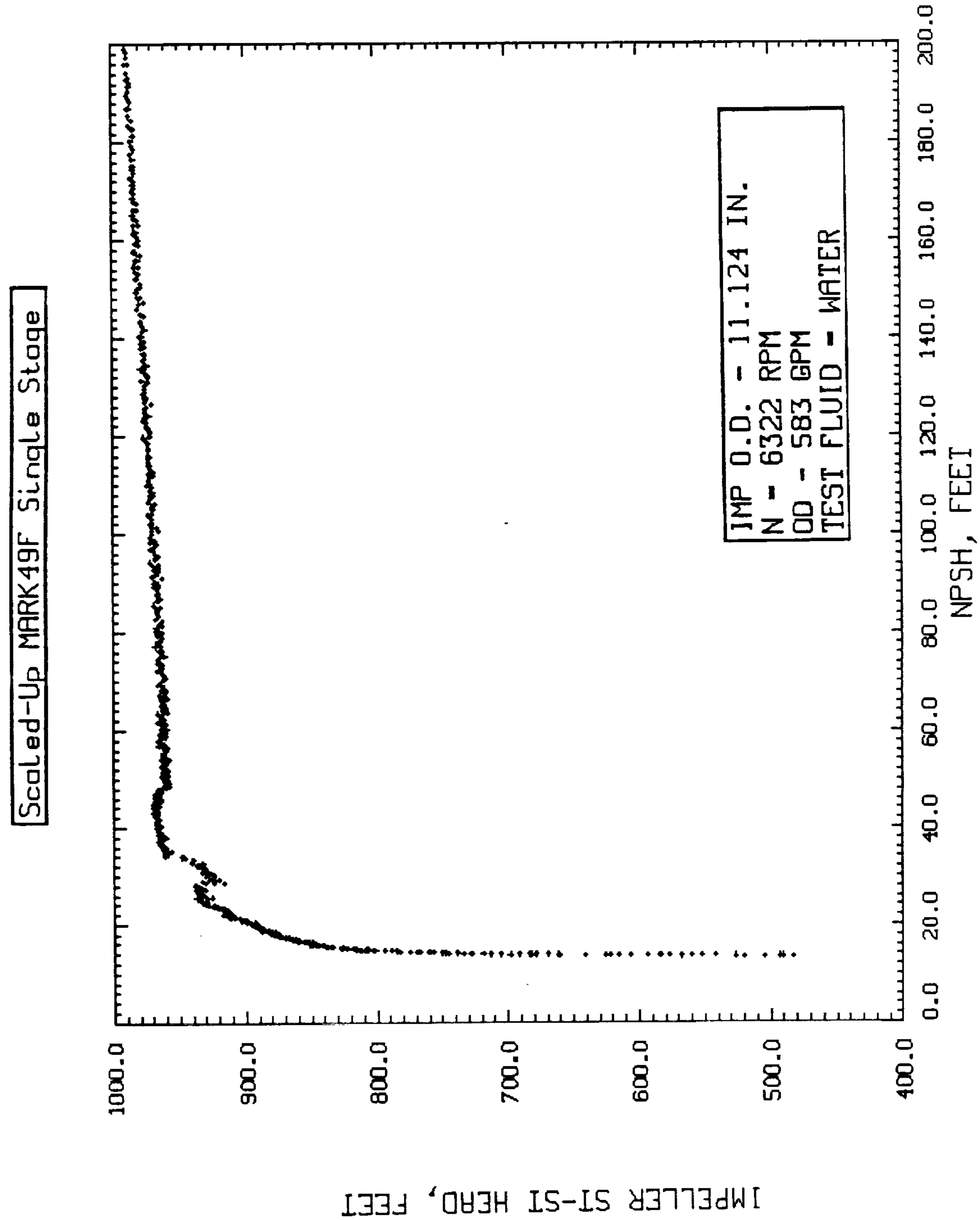
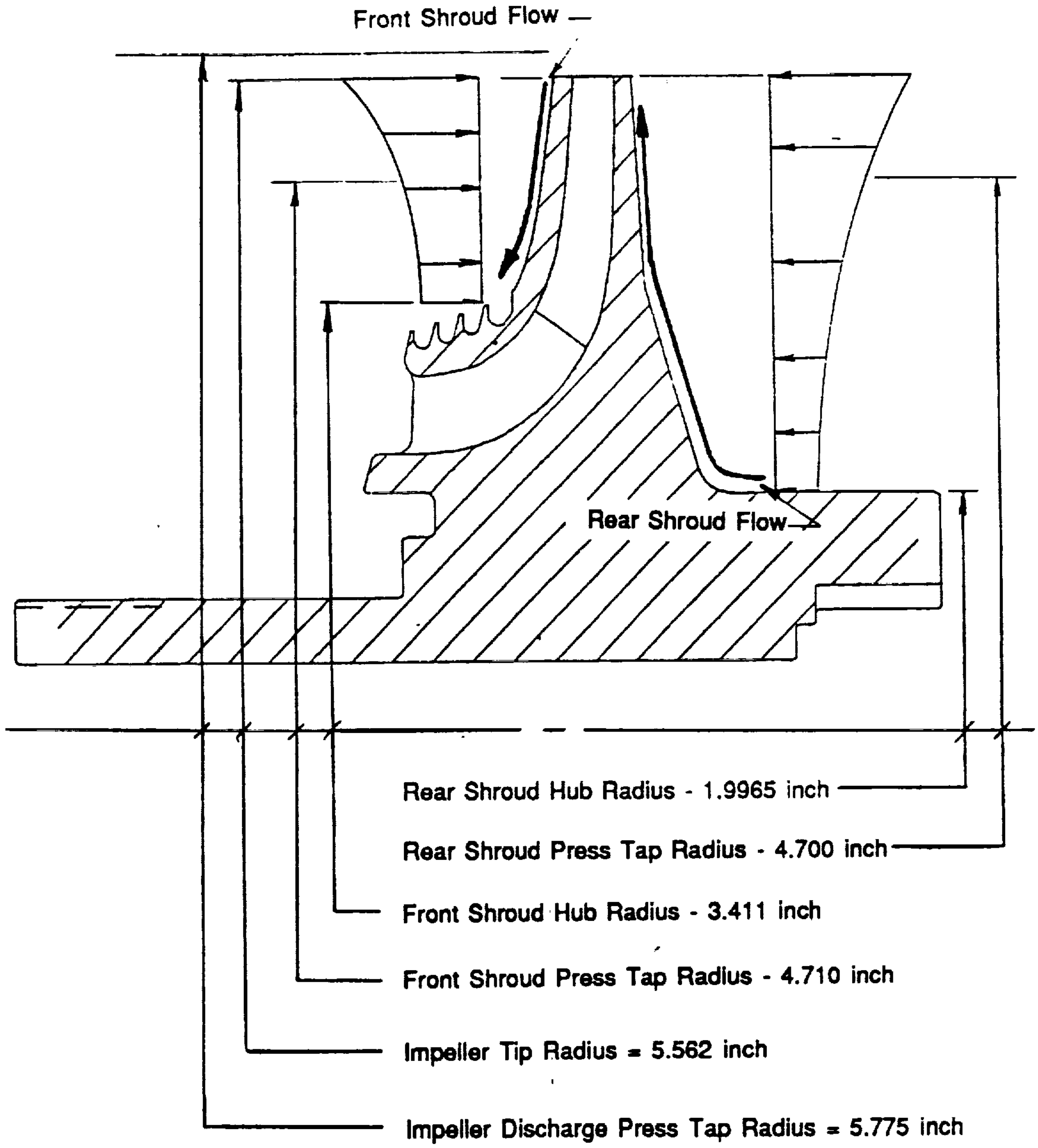


Figure 55 - Impeller Static Head Loss at Q/Q_d=109%

Figure 56 - Crossover Tester Impeller Shroud Geometry



The effective ratio of fluid to wheel velocity, K, in the front shroud region was determined from the relationship,

$$\Delta P = \frac{\rho K^2 N^2 (d_2^2 - d_1^2)}{144(2g)(229.2)^2} \tag{3}$$

where ρ was the specific weight in pounds per cubic feet, g was acceleration due to gravity (ft/sec^2), N was the shaft speed in rpm, d_2 and d_1 (in inches) are the diameters at the pressures measurements (d_2 being at the impeller tip) and ΔP was the differential pressure in psi from d_2 to d_1. The constants in the denominator were used for engineering unit conversion. A predicted front shroud velocity ratio, K_{fs}, of 0.7 was selected based on the high tangential velocity entering the cavity and from turbopump data with similar geometries, such as the SSME HPFTP. As seen in Table 11, the measured values of K_{fs}, ranged from 0.72 to 0.68 from 80% to 120%Q_d, respectively, and were in excellent agreement with this prediction. Because of the higher than predicted impeller discharge pressure at 80% and 100%Q_d , a modest increase in axial thrust, 824 and 808 pounds, respectively, was calculated.

For the impeller rear shroud, the flow field was very different. In this case, the flow originates from the crossover exit with very low tangential velocity, flows through the interstage seal, and up the rear face of the impeller. Analysis had predicted the K value on this face to be as low as 0.23 due to the low entering velocity. The test data showed, however showed that the rear shroud velocity ratio, K_{rs}, to be between 0.36 to 0.33. The higher value may have been due to a higher than expected angular velocity exiting the interstage seal.

If the flow were low, a value close to 0.5 would be expected (this being the average value for a rotating flat disk in a stationary housing with no through-flow). A higher K_{rs} would tend to reduce the axial force on this face, as seen in the 100% and 120%Q_d calculations, where a reduction of 694 and 1626 lbf, respectively, was seen. At the low flow condition, 80%Q_d, the higher than predicted impeller discharge pressure overwhelmed the influence of K_{rs} on axial thrust, and therefore, a slightly higher value (340 lbf) was calculated. The K factor information generated will be used to recalculate the axial loads of the MK49-F turbopump.

Table 11 - Shroud Vortex Strength - Predicted versus Measured

High Velocity Ratio Crossover Tester Pump Parameters	Predicted 80%	Measured 80%	Predicted 100%	Measured 100%	Predicted 120%	Measured 120%
Impeller Discharge Tap Pr (psia)	-	591	-	571	-	521
Impeller Tip Press * (psia)	549	567	536	550	504	501
Imp Front Shroud Pr (psia)	-	475	-	462	-	417
Imp Frnt Shrd Hub Pr** (psia)	355	364	343	356	311	316
Impeller Rear Shrd Pr (psia)	-	548	-	526	-	481
Imp Rear Shrd Hub Pr** (psia)	520	510	507	478	475	440
Imp Front Shroud K factor, Kfs	0.70	0.72	0.70	0.70	0.70	0.68
Front Shroud Axial Force (lbf)	27,409	28,233	26,663	27,471	24,718	24,765
Δ Frnt Shrd Axial Force (lbf)	-	824	-	808	-	47
Imp Rear Shroud K factor, Krs	0.23	0.32	0.23	0.36	0.23	0.33
Rear Shroud Axial Force (lbf)	45,224	45,564	44,183	43,489	41,467	39,841
Δ Rear Shrd Axial Force (lbf)	-	340	-	-694	-	-1,626
Net Ax Thrust Toward Inlet (lbf)	17,815	17,331	17,519	16,017	16,749	15,076

* Imp Tip pressure calculated from measured imp discharge pressure assuming rCu constant.

** Hub Pressures calculated using measured K Factors

(See Figure 22 for Pressure Tap Locations)

Diffuser Crossover System Design Verification

The diffuser-crossover system plays an important part in the operation of a high efficiency multistage pump. The diffuser and crossover (DC) system consists of a vaneless space upstream of two straight mean line diffusers with a constant area turning channel in between, Figure 57.

The vaneless space was necessary for the suppression of pressure and velocity perturbations from the impeller blade wakes. These perturbations cause local variations in the diffuser inlet flow angle resulting in dynamic loads on the leading edges of the diffuser vanes. The gap size was restricted since increasing the gap size above the minimum necessary will reduce efficiency and increase diameter and weight.

Design of the first diffuser of the DC system, the upcomer, requires one of the most critical calculations in diffuser design: the calculation of the effective blockage at the diffuser throat. This calculation requires estimation of the boundary layer growth up to the throat in the following regions:

1) Along the side walls in the vaneless space

2) Along the side walls in the diffuser inlet region represented by the triangular section DEF (Figure 58)

3) Along the vane suction surface (line DE in Figure 58)

The boundary layer displacement thicknesses were simply added to arrive at a total area blockage at the throat. The blockage formula can be stated as:

$$BLG_4 = \frac{2\delta_{SW}}{b_4} + \frac{\delta_{SS}}{h_4} \qquad (4)$$

and represented in Figure 58. Note that eq. (4) double counts the boundary layer blockage in the corners, which tends to overestimate blockage, but this was assumed to partially account for 3-D boundary layer interaction effects not represented in the simple 1-D displacement thickness calculations. Coincidentally, double counting the boundary layer blockage in the corners may compensate for the actual metallic blockage due to corner radii or fillets.

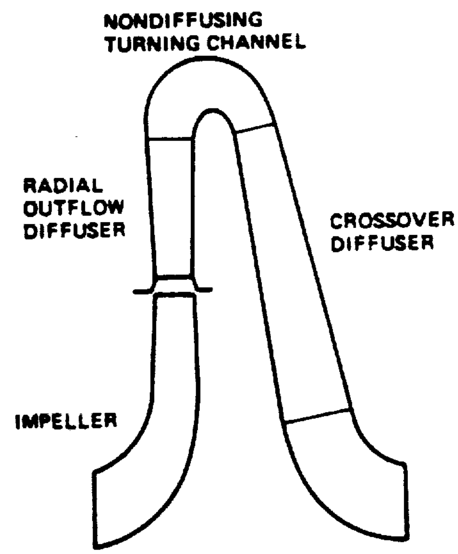


Figure 57 - Diffusing Crossover System

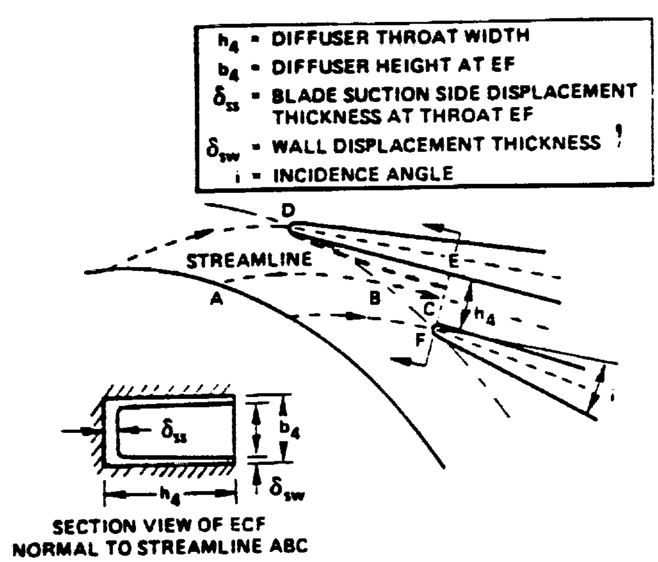


Figure 58 - Boundary Layer Build Up in Diffuser Inlet

Determination of the throat blockage has been correlated with the pressure recovery from the diffuser inlet to the throat (Ref. 2, 3):

$$\frac{\Delta P}{q_3} = \frac{(P_4 - P_3)}{q_3} \tag{5}$$

where P_3 and P_4 were the static pressures at diffuser inlet and throat and q_3 was the inlet dynamic pressure defined as:

$$q_3 = \frac{1}{2}\rho C_3^2 \tag{6}$$

where C_3 was the diffuser inlet flow velocity. Figure 59 shows the correlation plotted at various inlet blade angles, α. As expected, the smaller the blade angle the larger the blockage due to the increased length of the fluid path to the diffuser throat. Since these curves were developed for a Reynolds number of 1×10^5, a correction for significant variation in the Reynolds number was derived:

$$CR = 10\ Re^{-0.2} \qquad \text{(Ref. 2)} \tag{7}$$

The blockage was read from the curves in Figure 59 and multiplied by CR to determine the effective throat blockage. This blockage was then used to determine the pressure recovery of the diffuser channel from the 2-D diffuser performance C_P maps; an example of which was given in Figure 60.

The diffuser pressure recovery can be defined in various ways. The pressure recovery as defined by the diffuser maps described above was:

$$C_p = \frac{2(P_d - P_t)}{\rho C_t^2} \tag{8}$$

where $P_d - P_t$ was the static pressure difference between the diffuser discharge and the diffuser throat and C_t was the velocity at the throat including any throat flow blockage due to the boundary layers. Since the blockage was not known, a priory in this case, an alternate form of the pressure recovery factor was defined by not including the blockage

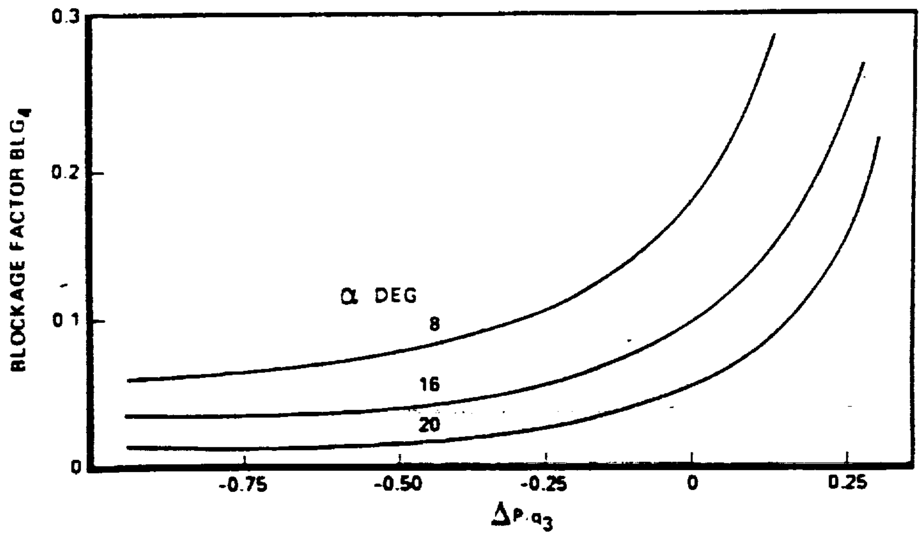


Figure 59 - Curve Fits of Blockage Factor for Diffuser Angles
(Ref. 3)

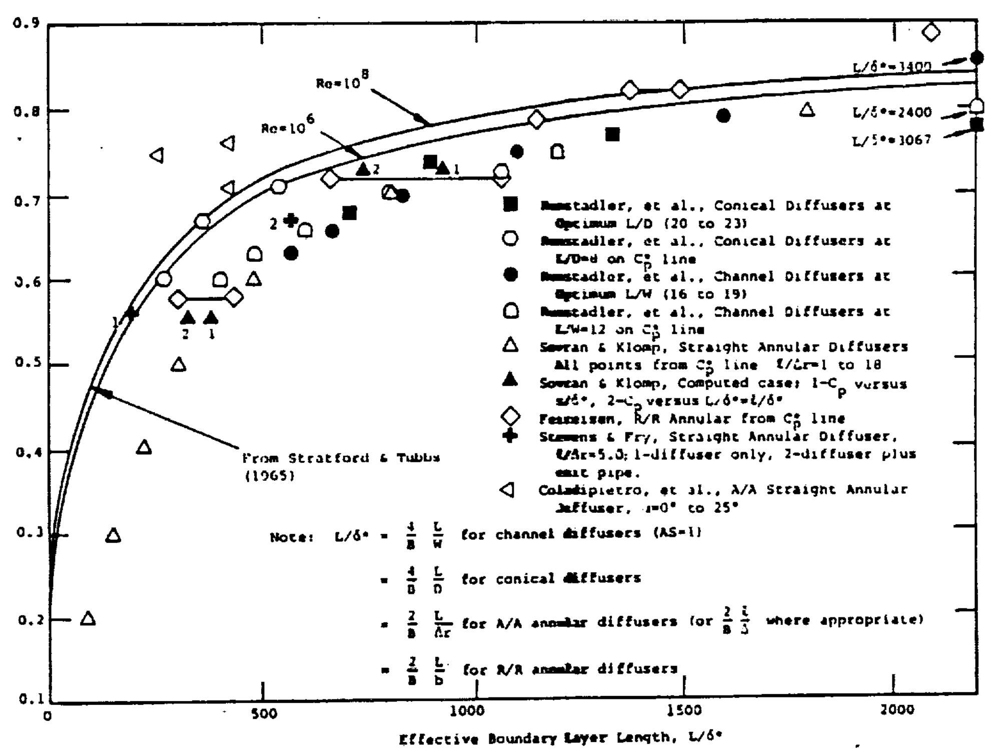


Figure 60 - Comparison of Pressure Recovery vs. L/δ*
(Ref 4)

in the velocity term:

$$C_p = \frac{2(P_d - P_1)}{\rho \bar{C}_t^2} \tag{9}$$

where P_d and P_1 were the static pressure at the inlet and discharge to the diffuser and C_t was the mean velocity in the diffuser throat calculated only from the flowrate and the diffuser throat area. It was felt that this coefficient was the most representative to compare the analysis calculations to the data results because it allowed direct comparison between experimental and analytical results. The original design criteria was for no diffusion between the inlet and the throat of the upcomer. The test results were compared to this analysis and then the required throat blockage and leading edge suction surface diffusion required to match the test data were calculated. Similarly for the downcomer the pressure recovery was predicted analytically and then the throat blockage was calculated from the measured pressure recovery.

Data analysis for the upcomer involved using the same techniques as those utilized during the design analysis, but using the data results to calculate the amount of inlet blockage and the diffusion occurring in the inlet section of the diffuser. The analysis required iteration of the inlet pressure recovery, $\Delta P/q_3$, to determine the blockage from Figure 58 This blockage was then used to determine the predicted throat velocity for calculation of the throat Reynolds number defined as:

$$Re = \frac{C_t W_1}{\upsilon} \tag{10}$$

where C_t was the throat velocity including the predicted blockage, W_1 was the throat width, and υ was the kinematic viscosity. The blockage term as determined from Figure 58 was then corrected for Reynolds number using the correlation previously determined in eq. (3). This value of blockage was then used to find the L/δ^*, where L was the effective diffuser channel length from throat to discharge and δ^* was an effective blockage determined from the Reynolds number corrected blockage. This term was necessary for the determination of the diffuser pressure recovery from Figure 60. The obtained Cp can easily be transformed to a mean pressure recovery, $\bar{C_p}$, by adjusting the throat velocity in the denominator by the predicted blockage. The inlet pressure recovery term was then converted to a common denominator by multiplying by the ratio of the throat dynamic pressure,

$$q_t = \frac{1}{2}\rho \overline{C}_t^2 \tag{11}$$

to the inlet dynamic pressure, q_3. This ratio was determined by assuming a "lossless" core flow in the diffuser inlet section. This is an often used assumption for 2-D diffuser analysis and assumes that the boundary layers do not merge. The q_3/q_t ratio was:

$$\frac{q_3}{q_t} = \left(1 - \frac{\Delta P}{q_3}\right)^{-1} \tag{12}$$

The C_p calculated from the data can be compared to the analysis $\overline{C}_p$,

$$\overline{C}_p = \frac{C_p}{(1-BLG_4)^2} + \left(\frac{\Delta P}{q_3}\right)\left(\frac{q_3}{q_t}\right) \tag{13}$$

The analysis was then completed by iterating on the inlet pressure recovery until the data and analysis mean pressure recoveries were matched. From this analysis, it was possible to obtain a good estimate of the actual throat blockage.

Data was available in three test mediums: hydrogen, water and air. One speed was selected from the hydrogen turbopump tests (60K rpm) giving data at three Reynolds numbers. As will be shown, the data predicted that the diffuser was stalled in air, allowing the diffuser performance predictions to be verified at two Reynolds numbers and the stall prediction to be checked for the third.

Hydrogen test data of the complete turbopump showed that the upcomer had a mean pressure recovery, $\overline{C}_p$, of 0.749 at 60,000 rpm. Design analysis predicted a $\overline{C}_p$ of 0.684 and a throat blockage of 8%. Analysis of the data indicated that diffusion had occurred in the diffuser inlet. The analysis showed that the inlet $\Delta P/q_3$ was 0.07 and the throat blockage 10.8% to match the test data $\overline{C}_p$. This analysis of the design was confirmed by comparing the inlet velocity of the analysis to that which was predicted by Rocketdyne's Loss Isolation program for centrifugal impeller design. The velocities were very close: 620.7 ft/sec from the data analysis and 619.7 ft/sec from the Loss Isolation program. The amount of diffusion represented by the $\Delta P/q_3$ was only 3.6% of the inlet velocity and probably represents the time average effect of the unsteady flow at the upcomer inlet. Table 12 gives a summary of the analysis results.

Table 12 - MK49-F Turbopump Crossover Data Analysis (LH_2)

	$\overline{C_p}$ Data	$\overline{C_{pi}}$	$\Delta P/q_3$	BLG_4	Re	C_p	$\overline{C_p}$	C_3 Analysis	C_3 Loss Prgm
Design	-	0.866	0	0.08	2.6×10^6	0.58	0.684	-	619.7
Data Analysis	0.749	0.866	0.07	0.108	2.85×10^6	0.52	0.748	620.2	619.7

Note: C_3 in feet per second.

Water test data showed that the upcomer had a mean pressure recovery of 0.81. Analysis showed that to achieve this amount of pressure recovery there was approximately 6% diffusion in the diffuser inlet. This indicates that the inlet $\Delta P/q_3$ was 0.l2 and the throat blockage was 17.8%. This analysis was substantiated by a comparison of the inlet velocity calculated from the data analysis with that predicted by the Loss Isolation program. The values agree within 5% as shown in Table 13. The increased throat blockage was expected since the lower Reynolds number of the water test, compared to the hydrogen tests, would tend to increase the boundary layer growth on the diffuser walls.

Table 13 - Crossover Tester Data Analysis (Water)

$\overline{C_p}$ Data	$\overline{C_{pi}}$	$\Delta P/q_3$	BLG_4	Re	C_p	$\overline{C_p}$	C_3 Analysis	C_3 Loss Prgm
0.81	0.866	0.12	0.178	4.32×10^5	0.41	0.808	194.6 (fps)	181.6 (fps)

The diffusion system turning channel was designed for minimum losses. Rocketdyne data has shown that it was best to avoid diffusion in the turning channel, achieving all the diffusion in the radial inflow or outflow sections of the passage. Design of the turning channel for no diffusion and to minimize the losses does not simply mean designing for a constant cross section duct. Losses arising from secondary flows developed in the turning channel due to the centrifugal forces of the fluid flowing around the bend must be minimized. An area distribution to achieve this was developed by the Southwest Research Institute (Ref. 5). A correction factor was applied to the duct height as a function of radius to minimize the migration of boundary layer fluid from the outside to the inside of the bend.

The effectiveness of the turn-around duct could not be determined directly due to the complexity of the flow in the bend which would have required extensive flow measurements. An estimate of the effectiveness was found from the data analysis of the second diffuser inlet blockage as compared to the discharge blockage of the first diffuser.

Design analysis of the second diffuser, the downcomer, was much the same as the upcomer although there was no inlet blade section. Again, accurate calculation of the inlet blockage was essential to the design. A first approximation of the inlet blockage can be made by assuming a loss-less flow from the upcomer discharge through the turning channel. Thus, the inlet, or throat, blockage of the downcomer would be equivalent to the discharge blockage of the upcomer. This analysis indicates that the inlet blockages for hydrogen and water would be 55% and 61%, respectively. Using these blockages the mean pressure recoveries were predicted to be 0.57 in hydrogen and 0.76 in water. Data showed that the pressure recoveries were actually 0.867 in hydrogen and 0.586 in water. The necessary throat blockages to match the data were found to be 65% for hydrogen and 55% for water. The data analysis for the hydrogen shows that the blockage only grew by a factor of 10% in the turnaround duct. The water data indicated that the blockage decreased from that predicted by the "lossless" flow approximation which was probably due to experimental and analytical inaccuracies. The analysis, however, does show the criticality of predicting the throat blockage in calculating diffuser performance, and also that the turnaround duct has achieved its purpose of minimizing the increase in blockage from the upcomer discharge to the downcomer inlet. The results were summarized in Table 14.

Table 14 - Crossover Analysis Data (Water and LH_2)

Test Fluid	$\overline{C_{pi}}$	BLG_4	$\overline{C_p}$	$\overline{C_p}$ Analysis
LH_2 (Loss-Less Core Analysis)	0.866	0.55	0.115	0.572
LH_2 Data Analysis	0.866	0.65	0.106	0.865
Water (Loss-Less Core Analysis)	0.866	0.61	0.10	0.755
Water Data Analysis	0.866	0.55	0.12	0.593

The effectiveness of the overall diffusion system can be measured by assuming that the system was one diffuser. Determination of the ideal pressure recovery, $\overline{C_{pi}}$:

$$\overline{C_{pi}} = 1 - (AR)^2 \quad (14)$$

where AR was the area ratio of the diffuser as defined by the downcomer discharge area to the unblocked upcomer throat area. The calculated overall $\overline{C_{pi}}$ was 0.982, and for each individual diffuser it was 0.866. The data analysis shows the overall $\overline{C_{pi}}$ to be .853 in hydrogen and 0.887 in water. Calculation of the effectiveness ($\overline{C_p}/\overline{C_{pi}}$), which was an indication of the diffuser efficiency, was 0.887. This was of the order expected for a diffuser with the calculated area ratio and length to throat width, L/W_1. Table 15 gives a summary of the mean pressure recoveries computed from the data and the analysis. Figure 60 shows the first stage diffusion system operation at 60K and 87K rpm in hydrogen and the current test at 6,322 rpm in water, plotted as a static pressure rise normalized via the tip speed of the impeller versus the position in the diffuser. The performance loss seen in the 87K hydrogen test was not due to the diffuser, but due to a performance loss in the impeller probably caused by excessive overboard leakage.

Table 15 - Crossover Overall Performance (Water and LH_2)

				Total Pressure Loss (P_8-P_3)	
Test Fluid	$\overline{C_{pi}}$	C_p Analysis	C_p Data	Data (psia)	Analysis (psia)
MK49-F Turbopump (LH_2)	0.982	0.853	0.854	-	-
Crossover Tester (Water)	0.982	0.887	0.888	90.16	101.24

Note: No total pressures measurements were taken during the MK49-F Turbopump tests.

A method of verifying the analysis was to compare the total pressure loss through the system as determined by the analysis and the data. This information was recorded in the water test and was found to be 90.2 psia as determined by the calculated impeller exit total pressure and the measured crossover exit total pressure. The analysis predicted that the total pressure loss would be 101.2 psia. The system performed better than predicted by the analysis.

Results from the air test (Figure 61) show a static pressure loss in the upcomer, indicating a stall either at the leading edge or in the 2-D diffuser. Analysis showed that the pressure recovery for the upcomer in air should have been 0.29, which was very low, but does not represent a stalled condition. The pressure recovery was low due to the boundary layer blockage of the upcomer throat, approximately 30% as extrapolated from the hydrogen and water data analysis. This was much larger than in the water and hydrogen tests because the Reynolds number of the air test was only of the order of 1×10^4, two orders of a magnitude less than the hydrogen test. This data and analysis indicates that the stall occurred at the diffuser leading edge.

The leading edge stall model was based on modeling the flow incidence angle and blade geometry of the diffuser inlet vane suction surface as a 2-D channel diffuser (Ref. 2). The diffuser blade row can be approximated as shown in Figure 62, where the transition region ABCD can be treated as a 2-D diffuser. The 2-D diffuser stall model was used to predict a leading edge stall, Figure 63, using line a-a. Using the diffuser geometry and the expected inlet flow angle as determined by the Loss Isolation program, stall was predicted at a flow angle of 4.5 degrees or an incidence angle of 4.9 degrees. The expected flow angle was 7.65 degrees, which corresponds to an incidence angle of 1.75 degrees which was below the predicted stall angle. It was expected that the stall incidence would increase with decreasing Reynolds number, and making a correction based on variations of peak diffuser pressure recovery with Reynolds number and inlet blockage, the stall incidence was predicted to be 3.5 degrees, corresponding to an 0.6a-a line on Figure 62. Again, stall was not predicted, but the tendency for stall to occur in the case of air was evident. A compressor performance prediction code should be used to calculate the rotor exits conditions and, hence, may predict the stall. More analysis is required to evaluate the stall model for high blockage and low Reynolds number flows. In addition, an investigation is required to evaluate the dynamic effects of the varying incidence angle due to the impeller blade wakes on the mean stall incidence.

The DC system has been shown to achieve the required pressure recovery with lower total pressure loss than predicted. The test series was designed to verify the analytical approach and prove the usefulness in future design efforts. As was shown, the analysis does well provided that the throat blockage can be adequately predicted. The difficulty for the upcomer was trying to predict the time-averaged effect of an unsteady inlet flow field due to the impeller blade wakes. This may account for the difference between the original design and the data analysis results as determined in this report. The downcomer design was dependent on the correct estimation of the upcomer exit blockage

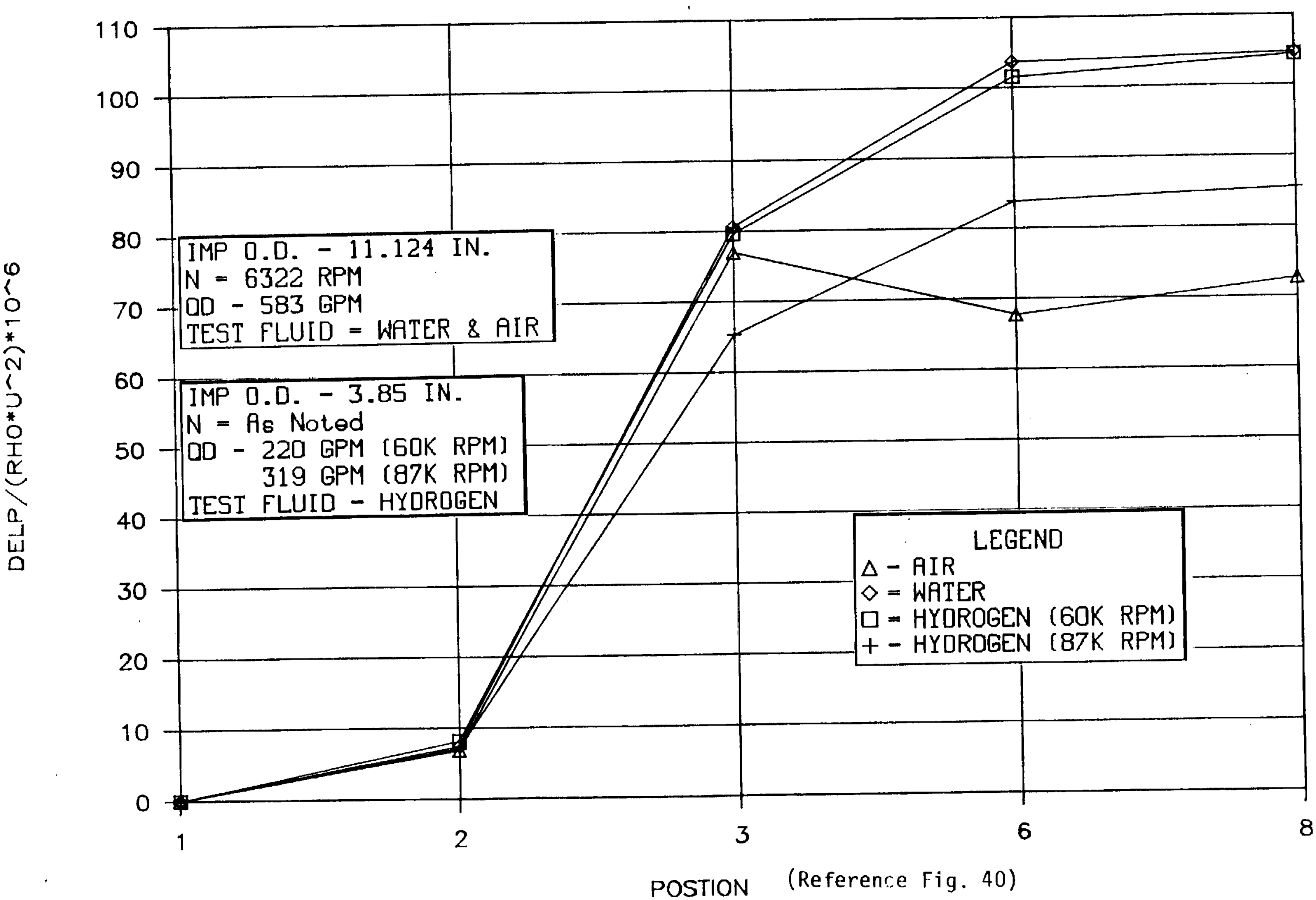


Figure 61 - Head Coefficient vs. Position in Air and Water

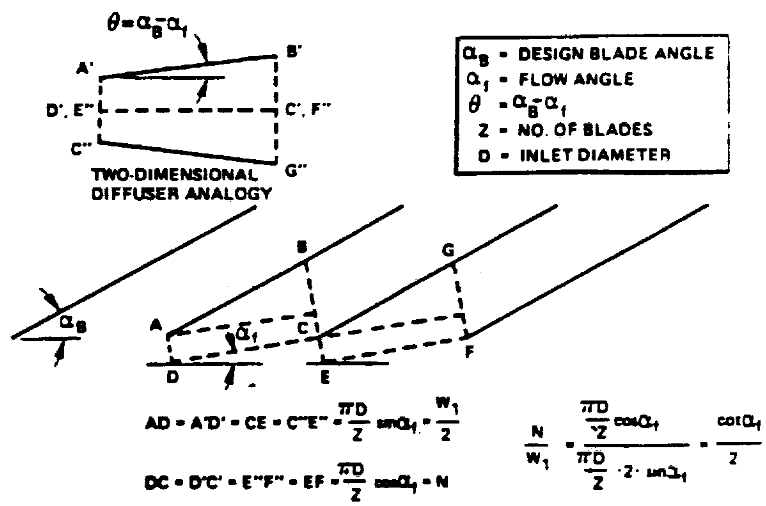


Figure 62 - Two-Dimensional Diffuser Analogy
(Ref. 2)

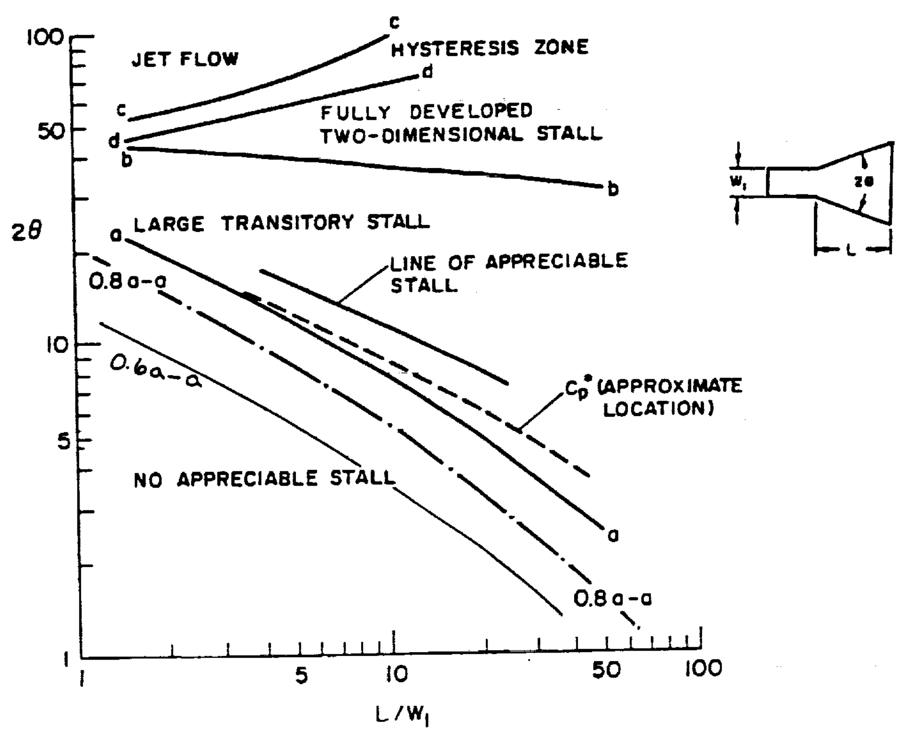


Figure 63 - Flow Regime Chart for Two-Dimensional Diffuser
(Ref. 4)

and determination of the extent of the boundary layer growth in the turnaround duct. The design approach for the constant area turnaround was verified. This was critical for designing effective downcomers with high diffusion upcomers.

REFERENCES

1. Daily, J. W. and Nece, R. E., "Chamber Dimension Effects on Induced Flow Frictional Resistance of Enclosed Rotation Disks", Transactions of the ASME, Journal of Basic Engineering, pp.217-232, March 1960.

2. Meng, S. Y. and E. D. Jackson, The Continuous Diffusion Crossover System Design, Presented at the Symposium on Return Passages of Multi-Stage Turbomachinery, Fluid Machinery Spring Conference, Houston, Texas, June 1983.

3. Conrad, O., K. Raif, and M. Wessles, "The Calculation of Performance Maps for Centrifugal Compressors with Vane-Island Diffusers," Proceedings of the 25th Annual International Gas Turbine Conference, pp. 135-147, 9-13 March 1980.

4. Japikse, David, Turbomachinery Diffuser Design Technology, Concepts ETI, Inc., Vermont 1984.

5. Gerlach, C. R., Study of Minimum Pressure Loss in High Velocity Duct Systems, NASA CR 102499, Southwest Research Institute, 3 November 1967.

APPENDIX A - AIR TEST DATA
TEST 1 AND TEST 2

CR-194447

Air Test 1 - Dated 9/26/88

Record #	Q/QD	Inlet Orf U/S Pr	Inlet Orf ΔP	Inlet Orf U/S Temp	Inducer In #1 Pr	Shaft Speed	Inducer In #2 Pr	Inducer Out Pr #1
	-	psia	psi	°R	psia	rpm	psia	psia
7	80.2	14.3598	0.0486	538.3	14.312	6322	14.312	14.3771
8	80.7	14.3599	0.0491	538.6	14.312	6322	14.312	14.3773
9	71.5	14.3601	0.0384	539.3	14.323	6322	14.323	14.3948
10	71.9	14.3600	0.0389	538.5	14.323	6322	14.323	14.3948
11	81.8	14.3600	0.0504	539.5	14.312	6322	14.312	14.3761
12	81.8	14.3599	0.0503	539.6	14.312	6322	14.312	14.3782
13	91.1	14.3599	0.0625	539.6	14.299	6322	14.299	14.3563
14	90.3	14.3598	0.0614	540.1	14.300	6322	14.300	14.3572
15	102.3	14.3598	0.0787	540.6	14.286	6322	14.286	14.3332
16	102.5	14.3597	0.0792	540.1	14.286	6322	14.286	14.3329
17	110.9	14.3596	0.0925	541.5	14.271	6322	14.271	14.3087
18	110.6	14.3597	0.0919	542.3	14.272	6322	14.272	14.3101
19	119.4	14.3596	0.1073	541.2	14.257	6322	14.257	14.2835
20	120.4	14.3596	0.1087	542.5	14.256	6322	14.256	14.2834
21	111.4	14.3598	0.0927	544.8	14.273	6322	14.273	14.3108
22	111.5	14.3597	0.0929	545.0	14.273	6322	14.273	14.3108
23	101.7	14.3598	0.0772	545.4	14.290	6322	14.290	14.3399
24	100.9	14.3598	0.0759	545.4	14.290	6322	14.290	14.3395
25	92.1	14.3599	0.0632	545.0	14.302	6322	14.303	14.3590
26	92.0	14.3598	0.0631	545.4	14.303	6322	14.303	14.3601
27	81.4	14.3600	0.0493	545.0	14.319	6322	14.319	14.3847
28	81.9	14.3601	0.0500	544.9	14.318	6322	14.318	14.3836
29	70.6	14.3599	0.0370	547.1	14.331	6322	14.331	14.4125
30	72.4	14.3600	0.0389	547.1	14.330	6322	14.330	14.4093

Air Test 1 - Dated 9/26/88

Inducer Out Pr #2	Impeller Frnt Shrd #1 Pr	Impeller Aft Shrd #1 Pr	Impllr Disch Static Pr	Upcomer Const Area Pr #2	Upcomer Const Area Pr #3	Transition Static Pr #1	Downcomer Disch Pr #2	Downcomer Cnst Area #2
psia	psia	psia	psia	psia	psia	psia	psia	psia
14.3726	14.7336	14.8064	14.8721	14.8598	14.8371	14.8693	14.8600	14.8351
14.3724	14.7335	14.8066	14.8721	14.8592	14.8372	14.8691	14.8600	14.8351
14.3905	14.7577	14.8367	14.8991	14.9109	14.8890	14.9176	14.9067	14.8872
14.3904	14.7581	14.8366	14.8993	14.9103	14.8883	14.9169	14.9062	14.8866
14.3717	14.7317	14.8043	14.8698	14.8547	14.8331	14.8649	14.8565	14.8304
14.3744	14.7332	14.8058	14.8706	14.8585	14.8374	14.8685	14.8587	14.8337
14.3523	14.7040	14.7686	14.8383	14.7974	14.7758	14.8088	14.8039	14.7718
14.3534	14.7050	14.7701	14.8389	14.7986	14.7774	14.8117	14.8057	14.7739
14.3286	14.6874	14.7211	14.8185	14.7227	14.7155	14.7546	14.7468	14.7101
14.3290	14.6873	14.7213	14.8179	14.7212	14.7148	14.7536	14.7462	14.7098
14.3050	14.6573	14.6864	14.7842	14.6497	14.6442	14.6899	14.6794	14.6396
14.3059	14.6587	14.6887	14.7856	14.6532	14.6483	14.6943	14.6830	14.6434
14.2798	14.6253	14.6516	14.7488	14.5701	14.5661	14.6203	14.6064	14.5624
14.2794	14.6255	14.6516	14.7482	14.5688	14.5657	14.6195	14.6057	14.5612
14.3068	14.6585	14.6905	14.7859	14.6568	14.6524	14.6980	14.6869	14.6466
14.3069	14.6589	14.6901	14.7857	14.6579	14.6523	14.6982	14.6874	14.6476
14.3356	14.6938	14.7329	14.8258	14.7397	14.7322	14.7698	14.7630	14.7269
14.3358	14.6936	14.7321	14.8255	14.7396	14.7321	14.7705	14.7632	14.7274
14.3563	14.7183	14.7654	14.8540	14.7868	14.7781	14.8132	14.8066	14.7736
14.3572	14.7197	14.7669	14.8554	14.7901	14.7807	14.8154	14.8089	14.7761
14.3828	14.7527	14.8137	14.8921	14.8444	14.8311	14.8631	14.8545	14.8268
14.3816	14.7505	14.8116	14.8899	14.8410	14.8271	14.8604	14.8517	14.8235
14.4070	14.7927	14.8494	14.9386	14.8960	14.8807	14.9030	14.9006	14.8770
14.4048	14.7875	14.8459	14.9318	14.8942	14.8795	14.9028	14.8994	14.8756

Air Test 1 - Dated 9/26/88

Downcomer Mid Diff #1 psia	Xover Disch Static Pr #1 psia	Impllr Disch Total Press psiat	Transition Total Press psiat	Xover Exit-Mid Mid Pass Pr psiat	Xover Exit Mid Pass Pr psiat	Xover Exit Inner Hub Pr psiat	Inlet Orf Disch Pr psia	Pump Inlet Temp °F	ɔalculateı nlet Flov lbm/sec
14.8630	14.8634	15.1460	14.8551	14.8752	14.8630	14.8645	14.3147	77.05	1.043
14.8634	14.8635	15.1449	14.8547	14.8747	14.8630	14.8645	14.3148	77.38	1.049
14.9116	14.9115	15.1797	14.9053	14.9222	14.9113	14.9130	14.3256	77.08	0.929
14.9115	14.9112	15.1798	14.9051	14.9210	14.9111	14.9128	14.3253	77.16	0.934
14.8588	14.8595	15.1419	14.8513	14.8714	14.8590	14.8609	14.3144	77.99	1.064
14.8619	14.8632	15.1428	14.8538	14.8733	14.8627	14.8642	14.3155	78.13	1.063
14.8031	14.8048	15.1009	14.7941	14.8168	14.8044	14.8032	14.3026	78.42	1.184
14.8041	14.8065	15.1027	14.7957	14.8184	14.8062	14.8051	14.3030	78.57	1.174
14.7452	14.7465	15.0889	14.7345	14.7588	14.7448	14.7486	14.2893	79.23	1.330
14.7446	14.7458	15.0892	14.7342	14.7585	14.7443	14.7482	14.2892	78.82	1.333
14.6779	14.6790	15.0432	14.6648	14.6927	14.6766	14.6814	14.2750	80.11	1.442
14.6819	14.6827	15.0461	14.6684	14.6963	14.6805	14.6849	14.2759	80.35	1.438
14.6043	14.6056	14.9973	14.5883	14.6200	14.6036	14.6079	14.2606	80.89	1.553
14.6039	14.6047	14.9967	14.5874	14.6192	14.6029	14.6068	14.2603	80.52	1.565
14.6862	14.6860	15.0448	14.6720	14.6998	14.6837	14.6887	14.2773	82.93	1.448
14.6858	14.6868	15.0451	14.6717	14.7002	14.6842	14.6889	14.2771	83.58	1.450
14.7608	14.7618	15.0970	14.7504	14.7747	14.7593	14.7644	14.2941	83.11	1.322
14.7613	14.7623	15.0976	14.7503	14.7748	14.7595	14.7648	14.2939	83.34	1.312
14.8046	14.8064	15.1288	14.7949	14.8179	14.8035	14.8082	14.3059	83.87	1.197
14.8075	14.8089	15.1292	14.7961	14.8191	14.8054	14.8099	14.3065	83.83	1.196
14.8570	14.8590	15.1686	14.8473	14.8685	14.8566	14.8598	14.3217	84.05	1.058
14.8531	14.8555	15.1665	14.8446	14.8657	14.8532	14.8568	14.3209	83.78	1.065
14.9060	14.9052	15.2074	14.8971	14.9156	14.9052	14.9070	14.3335	86.72	0.917
14.9034	14.9036	15.2052	14.8954	14.9137	14.9031	14.9043	14.3324	85.42	0.941

Air Test 1 - Dated 9/26/88

Inducer Static ΔP psi	Impeller Static ΔP psi	Transition Static ΔP psi	Downcomer Static ΔP psi	Crossover Static ΔP psi	Transition Total ΔP psi	Downcomer Total ΔP psi	Crossover Total ΔP psi	Calc In Dens lbm/ft3
0.0651	0.4950	-0.0028	0.0059	-0.0087	0.2909	0.0201	0.2708	0.0720
0.0653	0.4948	-0.0030	0.0056	-0.0086	0.2902	0.0200	0.2702	0.0720
0.0718	0.5043	0.0185	0.0046	0.0124	0.2744	0.0169	0.2575	0.0719
0.0718	0.5045	0.0176	0.0041	0.0119	0.2747	0.0159	0.2588	0.0720
0.0641	0.4937	-0.0049	0.0065	-0.0103	0.2906	0.0201	0.2705	0.0719
0.0662	0.4924	-0.0021	0.0048	-0.0074	0.2890	0.0195	0.2695	0.0718
0.0573	0.4820	-0.0295	0.0080	-0.0335	0.3068	0.0227	0.2841	0.0718
0.0572	0.4817	-0.0272	0.0067	-0.0324	0.3070	0.0227	0.2843	0.0718
0.0472	0.4853	-0.0639	0.0042	-0.0720	0.3544	0.0243	0.3301	0.0717
0.0469	0.4850	-0.0643	0.0049	-0.0721	0.3550	0.0243	0.3307	0.0718
0.0377	0.4755	-0.0943	0.0028	-0.1052	0.3784	0.0279	0.3505	0.0716
0.0381	0.4755	-0.0913	0.0020	-0.1029	0.3777	0.0279	0.3498	0.0715
0.0265	0.4653	-0.1285	-0.0003	-0.1432	0.4090	0.0317	0.3773	0.0716
0.0274	0.4648	-0.1287	-0.0003	-0.1435	0.4093	0.0318	0.3775	0.0715
0.0378	0.4751	-0.0879	0.0018	-0.0999	0.3728	0.0278	0.3450	0.0712
0.0378	0.4749	-0.0875	0.0020	-0.0989	0.3734	0.0285	0.3449	0.0711
0.0499	0.4859	-0.0560	0.0049	-0.0640	0.3466	0.0243	0.3223	0.0711
0.0495	0.4860	-0.0550	0.0043	-0.0632	0.3473	0.0245	0.3228	0.0711
0.0570	0.4950	-0.0408	0.0047	-0.0476	0.3339	0.0230	0.3109	0.0711
0.0571	0.4953	-0.0400	0.0037	-0.0465	0.3331	0.0230	0.3101	0.0711
0.0657	0.5074	-0.0290	0.0054	-0.0331	0.3213	0.0212	0.3001	0.0711
0.0656	0.5063	-0.0295	0.0053	-0.0344	0.3219	0.0211	0.3008	0.0711
0.0815	0.5261	-0.0356	0.0126	-0.0334	0.3103	0.0185	0.2918	0.0709
0.0793	0.5225	-0.0290	0.0109	-0.0282	0.3098	0.0183	0.2915	0.0709

Air Test 2 - Dated 9/29/88

Record #	Q/QD -	Inlet Orf U/S Pr psia	Inlet Orf ΔP psi	Inlet Orf U/S Temp °R	Inducer In #1 Pr psia	Shaft Speed rpm	Inducer In #2 Pr psia	Inducer Out Pr #1 psia
1	100.3	14.3396	0.0757	539.9	14.262	6322	14.262	14.3068
2	100.2	14.3395	0.0754	540.4	14.262	6322	14.262	14.3070
3	111.3	14.3394	0.0931	541.2	14.244	6322	14.244	14.2765
4	111.0	14.3394	0.0926	541.0	14.244	6322	14.244	14.2769
5	122.6	14.3393	0.1128	541.9	14.224	6322	14.224	14.2432
6	122.2	14.3394	0.1122	541.3	14.224	6322	14.224	14.2437
7	90.6	14.3397	0.0613	542.7	14.277	6322	14.277	14.3308
8	90.4	14.3397	0.0610	543.2	14.277	6322	14.277	14.3307
9	80.7	14.3397	0.0485	543.8	14.287	6322	14.287	14.3470
10	80.6	14.3397	0.0484	544.1	14.287	6322	14.287	14.3475
11	69.8	14.3397	0.0363	543.6	14.301	6322	14.301	14.3704
12	70.8	14.3399	0.0373	544.5	14.301	6322	14.301	14.3698
13	98.3	14.3397	0.0722	543.7	14.265	6322	14.265	14.3105
14	98.5	14.3396	0.0725	543.6	14.265	6322	14.265	14.3109
15	110.3	14.3396	0.0908	544.4	14.245	6322	14.245	14.2773
16	110.4	14.3394	0.0909	544.9	14.246	6322	14.246	14.2773

Air Test 2 - Dated 9/29/88

Inducer Out Pr #2	Impeller Frnt Shrd #1 Pr	Impeller Aft Shrd #1 Pr	Impllr Disch Static Pr	Upcomer Const Area Pr #2	Upcomer Const Area Pr #3	Transition Static Pr #1	Downcomer Disch Pr #2	Downcomer Cnst Area #2
psia	psia	psia	psia	psia	psia	psia	psia	psia
14.3033	14.6514	14.6983	14.7802	14.7226	14.7135	14.7501	14.7455	14.7107
14.3033	14.6506	14.6988	14.7800	14.7223	14.7130	14.7493	14.7451	14.7103
14.2730	14.6134	14.6526	14.7370	14.6357	14.6303	14.6721	14.6668	14.6268
14.2726	14.6132	14.6526	14.7374	14.6359	14.6301	14.6724	14.6670	14.6270
14.2395	14.5724	14.6066	14.6919	14.5336	14.5307	14.5814	14.5728	14.5294
14.2400	14.5724	14.6067	14.6923	14.5352	14.5318	14.5820	14.5735	14.5295
14.3275	14.6767	14.7419	14.8103	14.7599	14.7476	14.7829	14.7759	14.7469
14.3273	14.6764	14.7417	14.8096	14.7588	14.7469	14.7831	14.7761	14.7465
14.3444	14.6979	14.7674	14.8333	14.8069	14.7940	14.8283	14.8190	14.7934
14.3440	14.6978	14.7681	14.8344	14.8077	14.7946	14.8289	14.8194	14.7937
14.3676	14.7285	14.8056	14.8686	14.8741	14.8594	14.8888	14.8772	14.8578
14.3669	14.7282	14.8050	14.8673	14.8739	14.8592	14.8884	14.8764	14.8579
14.3069	14.6525	14.7001	14.7819	14.7323	14.7234	14.7580	14.7536	14.7194
14.3072	14.6526	14.6998	14.7819	14.7321	14.7235	14.7583	14.7534	14.7194
14.2737	14.6117	14.6516	14.7348	14.6367	14.6312	14.6718	14.6664	14.6269
14.2743	14.6120	14.6518	14.7356	14.6372	14.6321	14.6733	14.6675	14.6281

Air Test 2 - Dated 9/29/88

Downcomer Mid Diff #1 psia	Xover Disch Static Pr #1 psia	Impllr Disch Total Press psiat	Transition Total Press psiat	Xover Exit-Mid Mid Pass Pr psiat	Xover Exit Mid Pass Pr psiat	Xover Exit Inner Hub Pr psiat	Inlet Orf Disch Pr psia	Pump Inlet Temp °F
14.7427	14.7421	15.0346	14.7374	14.7657	14.7549	14.7460	14.2654	78.40
14.7426	14.7418	15.0342	14.7394	14.7656	14.7549	14.7455	14.2656	78.80
14.6635	14.6632	14.9759	14.6575	14.6881	14.6768	14.6666	14.2478	79.20
14.6637	14.6634	14.9760	14.6571	14.6882	14.6765	14.6666	14.2482	79.40
14.5703	14.5693	14.9187	14.5603	14.5973	14.5834	14.5736	14.2281	80.50
14.5700	14.5698	14.9192	14.5612	14.5979	14.5835	14.5744	14.2283	79.60
14.7759	14.7779	15.0690	14.7709	14.7980	14.7887	14.7806	14.2801	81.10
14.7752	14.7774	15.0681	14.7702	14.7971	14.7883	14.7802	14.2800	81.70
14.8200	14.8216	15.1007	14.8161	14.8394	14.8311	14.8247	14.2902	81.80
14.8208	14.8220	15.1005	14.8162	14.8393	14.8319	14.8247	14.2904	82.40
14.8816	14.8821	15.1433	14.8778	14.8964	14.8906	14.8849	14.3037	82.30
14.8812	14.8817	15.1430	14.8773	14.8963	14.8898	14.8843	14.3038	82.40
14.7503	14.7503	15.0362	14.7443	14.7723	14.7613	14.7533	14.2685	81.90
14.7504	14.7501	15.0367	14.7442	14.7718	14.7610	14.7534	14.2687	82.50
14.6631	14.6624	14.9729	14.6553	14.6874	14.6752	14.6659	14.2495	83.30
14.6643	14.6634	14.9731	14.6555	14.6875	14.6752	14.6669	14.2494	82.90

Air Test 2 - Dated 9/29/88

Calculated Inlet Flow lbm/sec	Inducer Static ΔP psi	Impeller Static ΔP psi	Transition Static ΔP psi	Downcomer Static ΔP psi	Crossover Static ΔP psi	Transition Total ΔP psi	Downcomer Total ΔP psi	Crossover Total ΔP psi
1.304	0.0448	0.4734	-0.0301	0.0156	-0.0381	0.2972	0.0283	0.2689
1.302	0.0450	0.4730	-0.0307	0.0163	-0.0382	0.2948	0.0262	0.2686
1.448	0.0325	0.4605	-0.0649	0.0160	-0.0738	0.3184	0.0306	0.2878
1.443	0.0329	0.4605	-0.0650	0.0158	-0.0740	0.3189	0.0311	0.2878
1.594	0.0192	0.4487	-0.1105	0.0159	-0.1226	0.3584	0.0370	0.3214
1.588	0.0197	0.4486	-0.1103	0.0159	-0.1225	0.3580	0.0367	0.3213
1.177	0.0538	0.4795	-0.0274	0.0151	-0.0324	0.2981	0.0271	0.2710
1.175	0.0537	0.4789	-0.0265	0.0140	-0.0322	0.2979	0.0269	0.2710
1.049	0.0600	0.4863	-0.0050	0.0111	-0.0117	0.2846	0.0233	0.2613
1.048	0.0605	0.4869	-0.0055	0.0104	-0.0124	0.2843	0.0231	0.2612
0.907	0.0694	0.4982	0.0202	0.0076	0.0135	0.2655	0.0186	0.2469
0.920	0.0688	0.4975	0.0211	0.0079	0.0144	0.2657	0.0190	0.2467
1.278	0.0455	0.4714	-0.0239	0.0143	-0.0316	0.2919	0.0280	0.2639
1.281	0.0459	0.4710	-0.0236	0.0135	-0.0318	0.2925	0.0276	0.2649
1.433	0.0323	0.4575	-0.0630	0.0156	-0.0724	0.3176	0.0321	0.2855
1.435	0.0313	0.4583	-0.0623	0.0142	-0.0722	0.3176	0.0320	0.2856

APPENDIX B - WATER TEST DATA

TEST NUMBER T88A094

TEST NUMBER T88A096

TEST NUMBER T88A097

INFORMATION FOR READING DATA TABLE SUMMARY AND DATA TABLES:

MDS: Measurement Data Sequence. Data record within a particular test.

NSCANS: Number of Scans in the data record.

TYPE: Type of data recorded;

- TYPE =1 Data are recorded at steady state operating conditions, e.g., HQ. The data are averaged based on the number of scans in the MDS.
- TYPE = 2 Data are recorded continuously for transient tests,e.g. start/shutdown transients and suction performance tests.

Data in tables are averaged over the number of scans and are presented by MDS number. All TYPE 2 data, since they are averaged, should be disregarded. Due to the volumes of suction performance data, it was considered too cumbersome for this report. These data can be made available upon request.

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DIRECTORY FILE:  RUN NUM: 88A094      , T DATE: 10/ 5/88, N MDS= 17, N CPS= 45
EDF HDR:     CROSSOVER HQ AND CAV TEST

I C P:          1   801     2   228   229   802   803   804   805   230
              231   806   807   808   809   810   811   812   813   815
              818   120   819   820   821   822   826     7     5     3
              838   900   901   903   902   904   905   950   951   952
                4   953   850   851   926

MDS NSCANS TYPE        HEADER
  1    20    1   PRE TEST STATIC @ 91.2 PSIA
  2   181    2   STARTUP TRANSIENT
  3    20    1   HQ @640 FLOW
  4    20    1   HQ @699 FLOW
  5    20    1   HQ @640 FLOW
  6    20    1   HQ @582 FLOW
  7    20    1   HQ @524 FLOW
  8    20    1   HQ @466 FLOW
  9    20    1   HQ @407 FLOW
 10    20    1   HQ @466 FLOW
 11    20    1   HQ @524 FLOW
 12    20    1   HQ @582 FLOW
 13   345    2   CAV @582 FLOW
 14     3    2   CAV @524 FLOW
 15   579    2   CAV @524 FLOW
 16   701    2   CAV @466 FLOW
 17    20    1   POST TEST STATIC @90 PSIA

T S TIME: 14:59:35.90,  P DATE: 10/06/88,  P TIME: 07:30:07
 N WS=  70,  N W STAT=  74,  N STAT=  12
ID W:     1   801     2   228   229   802   803   804   805   230
        231   806   807   808   809   810   811   812   813   815
        816   818   120   819   820   821   822   826     7     5
          3   838   900   901   903   902   904   905   950   951
        952     4   953   850   851   926  -152   -25   -26  -100
       -101  -106  -107   -34  -193  -194  -195  -202  -203  -800
       -801  -808  -809  -810  -811  -812  -813  -814  -815  -816
I W STAT:     1   801     2   228   229   802   803   804   805   230
            231   806   807   808   809   810   811   812   813   802
            815   816   818   120   819   820   821   822   826     7
              5     3   838   900   901   903   902   904   905   950
            951   952     4   953   850   851   926  -152   -25   -26
           -100  -101  -106  -107   -34  -152  -193  -194  -195  -202
           -203  -800  -801  -152  -808  -809  -810  -811  -812  -813
           -814  -152  -815  -816
M W 1 REC:    3    23   204   224   244   264   284   304   324   344
            364   384   404   749   752  1331  2032
I N STAT:     1     0     2     3     4     5     6     7     8     9
             10    11     0     0     0     0    12
```

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AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER HQ AND CAV TEST
TEST 88A094 TEST START TIME 10/ 5/88 14:59:35.90 PROCESS TIME 10/12/88 14:03:21

P/F ID#		1	801	2	228	229	802	803	804	805
		INLET ST ATIC PRE SSURE, P	INLET ST ATIC PR #2	FLOWMETE R #1	D/S STAT . PRESS. IND #1	D/S STAT . PRESS. IND #2	IMP FWD SHROUD P R #1	IMP FWD SHROUD P R #2	IMP AFT SHROUD P R #1	IMP AFT SHROUD P R #2
MDS#	TYPE									
1	1	91.364	91.620	4.3538	77.826	77.348	75.242	78.371	74.296	75.943
2	2	91.488	91.475	554.95	94.602	90.410	330.70	298.33	358.11	338.57
3	1	91.348	91.283	733.24	95.816	92.730	400.26	391.93	448.27	436.83
4	1	91.454	91.419	780.37	87.448	84.661	386.14	375.58	427.57	417.53
5	1	91.451	91.333	734.00	95.597	92.336	399.66	389.34	447.13	435.86
6	1	91.234	90.901	677.58	105.19	101.30	411.69	403.81	475.71	448.90
7	1	90.954	91.124	620.09	115.42	107.66	453.45	390.17	483.57	450.20
8	1	91.212	91.258	563.52	126.41	114.49	477.95	402.75	501.95	459.23
9	1	91.303	91.479	505.14	134.34	121.25	496.94	399.69	522.78	471.08
10	1	91.543	91.446	563.82	126.68	114.71	478.78	399.39	502.02	460.97
11	1	91.231	91.569	620.53	116.14	107.54	454.06	390.83	482.71	450.72
12	1	91.265	91.194	676.67	106.31	100.01	437.12	393.74	467.86	446.04
13	2	45.265	45.403	674.05	60.752	54.895	370.49	337.48	402.28	383.44
14	2	91.407	91.310	620.82	116.02	106.92	461.10	406.96	489.48	455.49
15	2	30.897	31.177	617.62	54.762	46.575	379.34	324.60	407.93	377.34
16	2	38.364	38.486	563.46	71.223	61.337	425.63	349.70	452.63	407.04
17	1	91.364	91.556	-0.15050	77.700	77.232	74.876	76.433	74.567	75.913

P/F ID#		230	231	806	807	808	809	810	811	812
		D/S STAT . PRESS. IMP #1	D/S STAT . PRESS. IMP #2	DWN MID DIFF #1	UPC CONS T SEC PR #3	UPC CONS T SEC PR #2	UPC CONS T SEC PR #4	TRANSITI ON ST PR	DWN DIFF DISCH P R #1	DWN DIFF DISCH P R #2
MDS#	TYPE									
1	1	78.005	77.098	74.817	76.258	75.076	75.945	75.115	75.249	74.193
2	2	407.32	406.00	413.21	405.30	392.81	399.32	410.29	416.20	414.88
3	1	509.87	487.85	569.03	556.83	543.46	565.55	554.46	570.53	568.13
4	1	488.18	469.58	532.59	518.21	506.58	523.51	518.43	533.91	532.16
5	1	508.92	487.60	569.52	557.14	544.03	565.60	555.85	570.92	568.44
6	1	526.98	497.96	583.70	571.10	559.81	582.42	572.04	588.01	585.91
7	1	551.80	558.61	590.85	577.72	561.61	580.31	582.00	590.91	591.34
8	1	572.80	582.51	607.51	594.96	578.35	588.71	596.67	606.10	607.06
9	1	597.71	593.78	627.23	613.43	597.75	617.57	611.78	624.55	625.98
10	1	574.14	581.25	608.61	595.79	579.32	590.48	595.15	607.04	608.54
11	1	547.03	563.51	587.03	578.05	561.50	569.70	581.15	589.94	590.65
12	1	534.12	546.25	572.25	564.98	547.19	556.68	568.39	576.98	577.62
13	2	467.61	477.91	504.93	497.58	481.03	490.35	501.01	509.50	510.25
14	2	555.44	568.47	592.68	582.39	565.02	574.89	582.32	593.51	594.79
15	2	470.47	485.19	509.30	499.55	483.29	492.09	501.60	511.37	512.47

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER HQ AND CAV TEST
TEST 88A094 TEST START TIME 10/ 5/88 14:59:35.90 PROCESS TIME 10/12/88 14:03:21

P/F ID#		230 D/S STAT . PRESS. IMP #1	231 D/S STAT . PRESS. IMP #2	806 DWN MID DIFF #1	807 UPC CONS T SEC PR #3	808 UPC CONS T SEC PR #2	809 UPC CONS T SEC PR #4	810 TRANSITI ON ST PR	811 DWN DIFF DISCH P R #1	812 DWN DIFF DISCH P R #2
MDS#	TYPE									
16	2	519.77	521.79	553.05	540.06	523.23	534.33	539.65	550.85	552.82
17	1	77.832	76.940	74.303	76.070	74.788	75.619	74.366	75.199	74.655

P/F ID#		813 DWN CONS T SEC PR #1	802 IMP FWD SHROUD P R #1	815 XOVER DI SCH ST P R #1	818 THRUST D ISK DRAI N PR	120 D/S TOT PRESS. 1 IMP #1	819 TRANSITI ON TOTAL PR	820 XOVER EX IT TOTAL PR #1	821 XOVER EX IT TOTAL PR #2	822 XOVER EX IT TOTAL PR #3
MDS#	TYPE									
1	1	75.998	75.242	75.926	78.789	78.927	78.049	79.907	78.702	79.123
2	2	401.03	330.70	416.19	360.68	298.03	378.24	427.05	426.20	425.73
3	1	553.11	400.26	568.79	471.07	388.27	523.76	583.46	579.82	579.89
4	1	516.44	386.14	532.56	441.92	367.97	483.10	549.48	544.68	545.00
5	1	553.44	399.66	569.00	472.10	388.97	526.14	586.28	581.77	581.84
6	1	568.93	411.69	586.10	486.24	432.32	537.36	602.77	598.61	597.80
7	1	570.13	453.45	591.45	487.21	422.01	550.65	610.28	604.27	603.15
8	1	586.25	477.95	606.81	498.70	381.60	565.69	624.79	618.96	617.08
9	1	605.86	496.94	625.63	513.86	442.81	581.80	645.72	639.12	634.06
10	1	587.09	478.78	608.10	499.81	396.56	564.15	624.15	619.06	617.03
11	1	569.47	454.06	590.64	486.64	389.14	550.50	610.34	603.02	604.48
12	1	556.09	437.12	577.50	475.90	375.45	533.62	595.02	590.07	593.08
13	2	489.55	370.49	510.40	413.69	304.95	468.42	527.71	521.79	525.02
14	2	573.36	461.10	595.98	492.07	381.33	551.43	614.86	608.36	608.81
15	2	491.40	379.34	512.66	414.46	301.21	471.92	530.77	524.24	524.73
16	2	530.95	425.63	552.65	448.38	336.52	514.62	571.94	565.87	562.20
17	1	76.116	74.876	76.301	78.484	76.779	75.857	77.497	76.922	76.744

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER HQ AND CAV TEST
TEST 88A094 TEST START TIME 10/ 5/88 14:59:35.90 PROCESS TIME 10/12/88 14:03:21

P/F ID# MDS#	TYPE	826 PUMP DEL TA PR	7 IN. TEMP ERATURE	5 TORQUE # 1	3 FLOWMETE R #2	838 THRUST D ISK DRAI N FLOW	900 REAR TOR QUE TEMP	901 FWD TORQ UE TEMP	903 LUBE OIL TEMP #1	902 LUBE OIL TEMP #2
1	1	0.75468	67.405	-1.7035	0.75280	4.4700	70.673	70.209	93.201	96.359
2	2	334.32	66.452	3242.0	503.98	62.269	73.109	72.333	105.05	101.09
3	1	489.74	66.667	4355.6	655.26	92.914	81.688	80.900	116.17	112.60
4	1	453.77	66.796	4408.5	706.91	89.819	82.474	81.670	117.92	111.11
5	1	490.37	66.924	4350.4	657.03	92.928	83.197	82.355	117.38	112.57
6	1	507.80	67.118	4249.4	597.86	94.229	83.836	83.066	123.05	116.11
7	1	513.93	67.247	4130.8	538.88	94.810	84.846	85.484	126.12	117.63
8	1	528.96	67.372	4015.5	479.79	96.105	85.808	87.145	131.69	118.53
9	1	549.56	67.476	3864.8	418.57	97.893	86.619	87.897	133.49	119.00
10	1	530.03	67.612	4020.1	479.62	96.212	87.409	88.905	133.95	119.15
11	1	512.51	67.697	4129.9	539.45	94.954	87.389	89.488	126.35	118.40
12	1	498.88	67.860	4260.0	597.91	93.564	88.317	90.069	124.10	117.44
13	2	477.29	68.254	4171.3	597.71	91.162	90.072	91.762	123.05	115.11
14	2	518.67	68.652	4139.6	538.96	95.392	91.858	94.922	126.00	117.12
15	2	494.80	69.054	4034.8	539.00	92.338	93.952	97.095	126.73	117.35
16	2	529.86	69.737	3957.7	479.50	95.856	97.322	101.15	131.89	117.49
17	1	1.3902	70.228	5.6784	0.95945E-01	-0.15482E-01	94.359	99.598	101.01	101.06

P/F ID# MDS#	TYPE	904 GEAR CAS E TEMP	905 LUBE OIL SUP T	950 ACCEL X AXIS	951 ACCEL Y AXIS	952 ACCEL Z AXIS	4 SPEED	953 LUBE OIL FLOW	850 FLEX FLO W PR	851 GBOX OIL PR
1	1	73.766	92.108	0.55525E-01	0.79573E-01	0.26343E-01	-1.7116	21.215	914.20	46.547
2	2	74.084	91.525	0.28876	0.15707	0.15718	4986.8	21.719	963.05	34.603
3	1	93.705	90.984	0.32616	0.17239	0.21661	6318.9	20.007	944.04	23.402
4	1	96.753	91.905	0.40583	0.56687	0.42381	6317.9	19.902	943.58	22.603
5	1	99.720	92.119	0.34261	0.17761	0.22195	6320.5	19.890	942.60	21.930
6	1	102.85	92.079	0.45394	0.17221	0.18806	6319.5	19.977	942.25	21.355
7	1	105.69	92.150	0.41847	0.16375	0.21291	6318.9	19.951	941.72	20.953
8	1	108.28	92.249	0.24286	0.15310	0.22909	6320.2	19.901	941.56	20.698
9	1	110.20	92.334	0.20898	0.14935	0.28297	6317.6	19.908	940.83	20.445
10	1	112.39	91.747	0.24811	0.15240	0.21444	6320.2	19.909	940.80	20.184
11	1	113.66	93.342	0.36395	0.15762	0.20717	6317.2	19.942	939.89	19.891
12	1	115.66	92.570	0.36007	0.15783	0.21160	6316.9	19.921	939.57	19.702
13	2	120.53	93.088	0.22744	0.15736	0.23215	6318.6	20.267	938.55	19.140
14	2	125.02	92.892	0.30932	0.14956	0.22019	6318.6	20.733	937.71	18.562
15	2	129.02	93.471	0.32048	0.16506	0.27875	6318.6	20.647	936.09	17.872

AVERAGED DATA ON MEASUREMENT DATA SETS

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P/F ID#		904 GEAR CAS E TEMP	905 LUBE OIL SUP T	950 ACCEL X AXIS	951 ACCEL Y AXIS	952 ACCEL Z AXIS	4 SPEED	953 LUBE OIL FLOW	850 FLEX FLO W PR	851 GBOX OIL PR
MDS#	TYPE									
16	2	133.87	93.645	0.31601	0.16592	0.26610	6319.6	21.591	934.33	17.298
17	1	136.97	92.712	0.51557E-01	0.77619E-01	0.22619E-01	-0.23337	22.411	932.79	23.145

P/F ID#		926 G-BOX TE MP ALARM	-152 FLOW 1 R ATIO IND . #1	-25 NPSH IND . #1	-26 NSS IND. #1	-107 ST-TOT H EAD 2 IM P. #1	-34 D/S PRES S. PIPE #1	-152 FLOW 1 R ATIO IND . #1	-193 SCALED N PSH IND. #1	-194 SCALED F LOW IND. #1
MDS#	TYPE									
1	1	3.3152	18.234	214.30	-0.63761E-01	4.2122	92.644	18.234	0.44755E+12	-85.634
2	2	3.3138	5.7014	215.16	2278.7	480.39	93.013	5.7014	0.52580E+11	78.611
3	1	3.3126	1.2605	215.06	3046.8	683.62	92.972	1.2605	8010.5	66.678
4	1	3.3128	1.3417	215.44	3138.6	655.36	93.134	1.3417	8027.1	71.918
5	1	3.3139	1.2615	215.30	3046.6	686.18	93.075	1.2615	8015.3	66.736
6	1	3.3131	1.1647	214.66	2933.3	765.65	92.799	1.1647	7994.0	60.736
7	1	3.3135	1.0660	213.89	2813.6	727.17	92.465	1.0660	7966.7	54.694
8	1	3.3122	0.96852	214.37	2678.0	617.97	92.675	0.96852	7981.6	48.658
9	1	3.3138	0.86855	214.48	2533.5	743.83	92.722	0.86855	7992.3	42.412
10	1	3.3124	0.96905	215.14	2671.6	652.07	93.006	0.96905	8010.2	48.678
11	1	3.3140	1.0670	214.53	2807.4	651.49	92.743	1.0670	7995.1	54.737
12	1	3.3137	1.1636	214.73	2929.5	637.24	92.830	1.1636	8003.3	60.730
13	2	3.3139	1.1588	108.32	5448.5	578.61	46.830	1.1588	4034.7	60.689
14	2	3.3126	1.0673	214.94	2804.6	634.94	92.919	1.0673	8006.6	54.703
15	2	3.3138	1.0618	74.955	7983.0	589.23	32.408	1.0618	2792.3	54.685
16	2	3.3136	0.96851	92.116	6253.6	636.80	39.827	0.96851	3430.2	48.669
17	1	3.3123	-0.54076	214.30	0.00000	-0.48455	92.643	-0.54076	0.31593E+12	-105.69

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER HQ AND CAV TEST
TEST 88A094 TEST START TIME 10/ 5/88 14:59:35.90 PROCESS TIME 10/12/88 14:03:21

P/F ID#		-195 SCALED HEAD IND. #1	-800 INDUCER TOT-ST HEAD #1	-801 INDUCER TOT-ST HEAD #2	-152 FLOW 1 RATIO IND . #1	-808 IMP STATIC HEADRISE	-809 XOVR U/S T-T HEADRISE	-810 XOVR D/S TT HEAD RISE #1	-811 XOVR D/S TT HEAD RISE #2	-812 XOVR D/S TT HEAD RISE #3
MDS#	TYPE									
1	1	0.66111E+10	0.35421	-0.75170	18.234	-0.57728	-2.0294	4.5761	1.7916	2.7644
2	2	0.27447E+09	38.310	28.612	5.7014	729.37	185.39	113.07	111.12	110.02
3	1	43232.	41.212	34.072	1.2605	913.21	313.14	138.27	129.86	130.03
4	1	40207.	21.478	15.033	1.3417	889.64	266.09	153.71	142.62	143.36
5	1	43370.	40.466	32.923	1.2615	913.58	317.04	139.28	128.85	129.01
6	1	44859.	63.301	54.302	1.1647	916.81	242.79	151.46	141.86	139.99
7	1	45382.	87.747	69.776	1.0660	1042.3	297.33	138.11	124.20	121.61
8	1	46611.	112.69	85.105	0.96852	1081.8	425.50	136.88	123.41	119.06
9	1	48383.	130.90	100.62	0.86855	1092.2	321.27	148.04	132.78	121.09
10	1	46593.	112.54	84.832	0.96905	1078.4	387.37	138.97	127.21	122.52
11	1	45279.	88.753	68.862	1.0670	1054.0	372.98	138.61	121.68	125.05
12	1	44160.	65.810	51.252	1.1636	1031.5	365.63	142.20	130.75	137.71
13	2	42221.	66.841	53.292	1.1588	977.86	377.86	137.35	123.68	131.13
14	2	45708.	88.083	67.016	1.0673	1067.0	393.23	146.92	131.88	132.92
15	2	43677.	86.346	67.406	1.0618	1014.0	394.67	136.34	121.23	122.37
16	2	46613.	107.27	84.394	0.96851	1064.6	411.77	132.81	118.78	110.30
17	1	-0.16255E+10	0.64980E-01	-1.0191	-0.54076	-0.67307	-2.1304	4.0739	2.7443	2.3316

P/F ID#		-813 STAGE T-T HEADRISE	-152 FLOW 1 RATIO IND . #1	-815 XOVR TT HEADRISE #2	-816 PUMP TT HEADRISE	-817 RESULTANT AXIAL LOAD (-)	-818 RESULTANT AXIAL LOAD (+)	-819 NET AXIAL LOAD
MDS#	TYPE							
1	1	3.2246	18.234	-0.23779	3.4653	10385.	9978.8	406.29
2	2	805.48	5.7014	296.51	509.47	46393.	50000.	-3607.3
3	1	1160.7	1.2605	443.00	718.33	59570.	63603.	-4033.4
4	1	1079.1	1.3417	408.71	670.99	56438.	60276.	-3837.9
5	1	1165.0	1.2615	445.89	719.72	59518.	63563.	-4045.2
6	1	1204.6	1.1647	384.65	820.63	61603.	66346.	-4742.7
7	1	1218.4	1.0660	421.53	797.57	63608.	67898.	-4290.2
8	1	1251.9	0.96852	548.91	703.60	65844.	70260.	-4415.9
9	1	1298.4	0.86855	454.05	845.08	68407.	73036.	-4628.6
10	1	1251.4	0.96905	514.58	737.43	65999.	70378.	-4378.4
11	1	1215.0	1.0670	494.65	720.88	63296.	67641.	-4344.2
12	1	1184.8	1.1636	496.38	689.00	61697.	65821.	-4123.4
13	2	1133.4	1.1588	501.54	632.34	52455.	56631.	-4176.6
14	2	1227.0	1.0673	525.11	702.40	64060.	68549.	-4488.2
15	2	1172.5	1.0618	515.90	657.02	52248.	56959.	-4711.2

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P/F ID#		-813	-152	-815	-816	-817	-818	-819
MDS#	TYPE	STAGE T-T HEADRISE	FLOW 1 RATIO IND. #1	XOVR TT HEADRISE #2	PUMP TT HEADRISE	RESULTANT AXIAL LOAD (-)	RESULTANT AXIAL LOAD (+)	NET AXIAL LOAD
16	2	1251.7	0.96851	530.56	721.55	57638.	62801.	-5162.7
17	1	-0.88846	-0.54076	0.61385	-1.5031	10389.	9967.0	421.72

DIRECTORY FILE: RUN NUM: 88A096 , T DATE: 10/ 8/88, N MDS= 37, N CPS= 45
EDF HDR: XOVER HQ CAV TEST

I C P:

1	801	2	228	229	802	803	804	805	230
231	806	807	808	809	810	811	812	813	815
818	120	819	820	821	822	826	7	5	3
838	900	901	903	902	904	905	950	951	952
4	953	850	851	926					

MDS	NSCANS	TYPE	HEADER
1	20	1	PRE STATIC 90
2	158	2	START UP
3	20	1	582 GPM HQ
4	20	1	582 GPM HQ
5	20	1	698 GPM HQ
6	20	1	640 GPM HQ
7	20	1	582 GPM HQ
8	20	1	524 GPM HQ
9	20	1	466 GPM HQ
10	20	1	437 GPM HQ
11	20	1	407 GPM HQ
12	20	1	378 GPM HQ
13	20	1	349 GPM HQ
14	20	1	349 GPM HQ
15	20	1	378 GPM HQ
16	20	1	407 GPM HQ
17	20	1	437 GPM HQ
18	20	1	466 GPM HQ
19	20	1	524 GPM HQ
20	20	1	582 GPM HQ
21	20	1	640 GPM HQ
22	20	1	698 GPM HQ
23	972	2	582 GPM CAV
24	824	2	640 GPM CAV
25	128	2	698 GPM CAV
26	531	2	582 GPM CAV
27	847	2	524 GPM CAV
28	835	2	466 GPM CAV
29	92	2	407 GPM CAV
30	181	2	2ND START UP
31	934	2	582 GPM CAV
32	913	2	407 GPM CAV
33	20	1	POST STATIC 80
34	200	2	3RD START UP
35	20	1	291 GPM HQ
36	1022	2	349 GPM CAV
37	20	1	POST STATIC 90

T S TIME: 7:26:17.20, P DATE: 10/09/88, P TIME: 19:25:39
N WS= 70, N W STAT= 74, N STAT= 37

ID W:

1	801	2	228	229	802	803	804	805	230
231	806	807	808	809	810	811	812	813	815
816	818	120	819	820	821	822	826	7	5
3	838	900	901	903	902	904	905	950	951
952	4	953	850	851	926	-152	-25	-26	-100
-101	-106	-107	-34	-193	-194	-195	-202	-203	-800
-801	-808	-809	-810	-811	-812	-813	-814	-815	-816

I W STAT:

1	801	2	228	229	802	803	804	805	230
231	806	807	808	809	810	811	812	813	802
815	816	818	120	819	820	821	822	826	7
5	3	838	900	901	903	902	904	905	950
951	952	4	953	850	851	926	-152	-25	-26
-100	-101	-106	-107	-34	-152	-193	-194	-195	-202
-203	-800	-801	-152	-808	-809	-810	-811	-812	-813
-814	-152	-815	-816						

M W 1 REC:

3	23	181	201	221	241	261	281	301	321

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID#		1	801	2	228	229	802	803	804	805
		INLET ST ATIC PRE SSURE, P	INLET ST ATIC PR #2	FLOWMETE R #1	D/S STAT . PRESS. IND #1	D/S STAT . PRESS. IND #2	IMP FWD SHROUD P R #1	IMP FWD SHROUD P R #2	IMP AFT SHROUD P R #1	IMP AFT SHROUD P R #2
MDS#	TYPE									
1	1	91.171	93.243	-0.49547E-01	78.957	79.059	77.372	78.349	75.878	79.217
2	2	91.176	92.858	646.44	95.565	95.164	350.39	343.47	395.28	397.15
3	1	91.230	93.257	735.96	96.046	95.806	392.33	385.63	445.69	448.62
4	1	91.161	93.021	688.44	104.14	103.92	405.89	398.33	465.19	467.16
5	1	91.180	92.850	781.27	88.068	87.827	378.31	367.80	426.70	429.06
6	1	91.323	92.969	736.36	96.083	95.774	392.52	377.46	446.28	447.54
7	1	91.212	93.039	688.93	104.15	103.83	405.54	397.70	464.99	465.94
8	1	90.907	92.777	638.89	111.64	111.11	417.68	410.65	481.77	481.94
9	1	91.058	92.725	589.42	119.13	118.42	430.32	421.78	497.63	497.37
10	1	91.256	92.914	571.24	120.39	119.41	436.89	425.72	505.51	504.68
11	1	91.061	93.053	539.98	124.46	123.47	443.67	431.14	514.49	513.37
12	1	91.106	92.892	514.45	127.71	126.45	448.83	442.86	521.90	520.41
13	1	91.022	93.035	485.97	130.73	129.71	451.59	458.29	528.18	525.64
14	1	91.147	92.966	486.33	130.85	129.70	451.97	446.68	528.75	526.41
15	1	91.000	92.875	511.60	128.15	127.75	453.89	447.92	516.84	517.89
16	1	91.197	92.878	538.21	124.43	124.32	448.43	445.07	512.55	513.82
17	1	90.688	91.943	574.01	118.45	117.57	440.54	433.61	510.40	510.34
18	1	91.192	92.474	601.94	114.92	113.82	434.73	433.64	503.27	503.48
19	1	91.304	92.468	655.20	108.66	107.67	417.68	413.62	486.09	486.63
20	1	91.382	92.288	708.92	99.990	99.049	403.22	395.08	467.13	468.14
21	1	91.106	92.267	761.32	91.299	90.400	388.33	380.25	445.31	447.26
22	1	91.430	92.018	792.60	85.580	84.656	378.34	371.22	431.41	433.51
23	2	20.716	21.566	675.32	32.889	32.108	294.17	290.66	349.21	351.76
24	2	23.387	23.584	725.02	27.450	26.981	256.65	245.20	304.47	306.91
25	2	36.869	36.514	773.43	33.510	32.732	257.13	266.60	302.80	304.53
26	2	9.0136	9.0783	761.69	4.9378	5.3683	170.88	175.82	207.98	210.60
27	2	23.450	23.493	630.42	40.536	40.506	334.22	334.54	399.69	398.72
28	2	20.246	20.202	588.54	41.971	42.995	349.66	353.58	419.62	419.80
29	2	68.520	68.588	574.40	95.595	95.704	410.32	414.73	483.50	483.80
30	2	91.318	91.227	607.60	89.773	89.824	321.35	323.50	367.71	369.99
31	2	24.001	23.679	676.92	33.605	34.289	295.54	294.33	351.19	352.80
32	2	24.835	24.714	537.34	52.947	53.475	369.62	368.89	442.31	443.26
33	1	91.181	91.371	4.5953	77.048	77.194	75.661	71.099	74.287	77.233
34	2	91.246	91.165	613.49	90.646	90.727	328.61	302.89	376.20	379.25
35	1	90.146	89.820	429.60	133.00	132.95	461.15	474.59	518.04	537.66
36	2	25.271	25.218	473.56	61.436	61.760	392.43	360.97	453.48	451.48
37	1	90.527	90.742	4.8763	76.518	76.709	75.394	71.275	73.517	76.663

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID# MDS#	TYPE	230 D/S STAT . PRESS. IMP #1	231 D/S STAT . PRESS. IMP #2	806 DWN MID DIFF #1	807 UPC CONS T SEC PR #3	808 UPC CONS T SEC PR #2	809 UPC CONS T SEC PR #4	810 TRANSITI ON ST PR	811 DWN DIFF DISCH P R #1	812 DWN DIFF DISCH P R #2
1	1	80.203	79.408	77.231	78.120	77.583	78.486	77.845	77.482	76.947
2	2	436.34	435.43	524.33	517.05	509.66	516.39	518.09	526.61	525.31
3	1	491.98	487.78	598.62	588.75	580.69	589.51	590.53	601.64	600.21
4	1	509.87	507.28	631.83	623.53	615.71	624.59	624.08	634.58	632.44
5	1	470.89	467.83	564.15	552.75	545.44	554.51	555.85	567.67	566.63
6	1	491.39	488.49	598.62	588.85	581.07	590.30	590.75	601.86	600.64
7	1	509.98	507.50	631.75	623.52	615.64	624.86	624.25	634.45	632.29
8	1	527.45	524.66	658.83	652.31	645.14	654.07	653.03	661.32	658.84
9	1	543.32	541.67	683.81	678.23	671.70	680.52	679.71	685.86	684.47
10	1	550.49	549.15	690.07	684.14	678.04	686.99	685.98	691.70	690.59
11	1	559.51	558.04	703.36	698.17	692.39	701.22	699.20	704.81	703.79
12	1	565.96	564.76	712.87	708.28	702.84	710.76	709.02	714.24	713.23
13	1	570.33	568.76	719.17	715.57	708.48	717.55	715.10	720.11	719.63
14	1	570.95	569.31	718.91	715.21	708.73	717.48	714.82	720.11	719.29
15	1	560.85	559.18	669.20	662.01	655.53	661.49	663.37	671.86	670.25
16	1	556.89	553.39	665.54	658.63	651.22	659.13	658.53	667.93	666.51
17	1	553.55	552.63	690.24	684.12	677.40	687.22	685.51	692.16	691.15
18	1	546.27	544.99	679.23	672.14	665.82	674.77	673.82	681.11	679.84
19	1	526.39	524.45	652.26	644.27	636.64	645.74	645.30	654.66	653.29
20	1	506.72	504.16	621.46	611.96	603.79	613.56	612.72	624.17	622.94
21	1	485.55	482.56	582.99	572.37	564.10	574.03	574.54	586.50	585.67
22	1	471.54	468.71	558.24	546.75	538.11	549.29	549.30	561.95	561.04
23	2	391.34	388.73	502.91	494.66	487.33	497.21	497.62	505.33	504.67
24	2	345.68	342.23	438.79	429.55	422.17	431.46	433.30	442.07	441.37
25	2	342.87	339.46	421.35	410.52	403.42	411.84	415.52	425.24	424.42
26	2	247.17	243.28	304.53	294.93	285.30	294.87	298.03	308.71	308.26
27	2	441.92	439.90	566.93	560.55	552.53	562.46	561.04	569.37	568.01
28	2	462.24	461.63	598.61	593.39	585.67	595.52	593.61	600.64	599.44
29	2	524.83	524.67	665.21	660.12	651.89	661.81	659.69	667.53	665.61
30	2	399.84	397.87	475.63	468.40	461.30	468.58	467.92	478.44	476.71
31	2	392.67	390.19	503.35	495.47	487.67	496.84	497.14	506.00	504.95
32	2	485.12	484.75	629.24	624.79	618.19	626.77	624.89	630.90	630.02
33	1	78.165	76.529	74.308	76.180	75.494	75.829	74.061	75.470	74.502
34	2	408.87	406.85	488.27	480.54	473.42	480.85	480.61	490.87	489.09
35	1	559.20	565.98	675.33	670.91	662.01	666.73	666.66	676.72	676.08
36	2	497.34	494.50	603.87	597.43	590.41	596.93	596.46	605.91	605.26
37	1	77.457	75.838	74.288	75.289	74.791	75.473	73.627	74.994	74.040

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID#		813 DWN CONS T SEC PR #1	802 IMP FWD SHROUD P R #1	815 XOVER DI SCH ST P R #1	818 THRUST D ISK DRAI N PR	120 D/S TOT PRESS. 1 IMP #1	819 TRANSITI ON TOTAL PR	820 XOVER EX IT TOTAL PR #1	821 XOVER EX IT TOTAL PR #2	822 XOVER EX IT TOTAL PR #3
MDS#	TYPE									
1	1	78.280	77.372	79.205	78.652	78.044	77.352	78.033	77.949	78.782
2	2	517.17	350.39	525.86	274.35	326.10	493.00	529.94	532.75	535.32
3	1	588.83	392.33	600.55	457.70	368.45	560.73	612.61	608.41	612.07
4	1	623.56	405.89	633.16	461.95	383.83	597.79	644.30	640.65	643.86
5	1	553.88	378.31	566.73	442.57	352.88	522.55	579.39	575.01	579.00
6	1	589.39	392.52	600.60	461.04	368.34	560.41	612.64	608.44	612.24
7	1	623.44	405.54	633.22	460.61	383.28	597.70	644.59	640.57	643.55
8	1	652.42	417.68	659.97	461.00	393.53	629.57	671.15	667.21	669.87
9	1	679.72	430.32	684.67	460.57	410.62	658.36	695.30	692.14	693.71
10	1	685.73	436.89	690.88	483.73	418.55	663.76	701.34	698.55	699.42
11	1	700.04	443.67	704.31	495.49	423.84	680.44	714.43	711.57	712.60
12	1	709.74	448.83	713.56	503.03	427.47	691.45	723.85	720.80	721.59
13	1	715.77	451.59	719.87	507.87	430.60	700.15	730.49	726.87	727.53
14	1	715.60	451.97	719.52	508.29	429.15	699.11	730.19	726.48	727.47
15	1	662.09	453.89	671.95	487.92	430.92	640.67	681.96	679.13	680.53
16	1	658.93	448.43	667.81	487.19	427.24	637.47	678.39	675.11	677.05
17	1	686.39	440.54	691.49	501.13	404.77	662.45	701.90	698.66	699.83
18	1	674.74	434.73	680.52	493.75	398.47	648.84	691.64	687.73	689.43
19	1	645.59	417.68	653.56	482.02	384.13	618.74	664.98	660.91	663.80
20	1	613.26	403.22	623.07	460.80	371.08	583.26	634.93	631.44	634.16
21	1	573.70	388.33	586.02	438.17	357.03	540.74	598.04	594.44	597.47
22	1	548.22	378.34	561.21	460.58	348.15	513.61	574.04	570.33	573.15
23	2	495.94	294.17	505.23	415.16	258.90	470.26	516.32	512.46	514.27
24	2	431.35	256.65	441.83	366.82	220.74	404.24	453.65	449.90	452.01
25	2	412.79	257.13	424.76	356.31	222.90	383.20	437.00	433.46	435.88
26	2	297.27	170.88	308.33	255.14	135.43	269.94	319.30	315.99	318.00
27	2	560.04	334.22	568.75	455.64	301.74	539.09	579.18	576.07	578.00
28	2	592.88	349.66	600.17	458.45	316.55	575.29	610.17	607.19	608.75
29	2	659.82	410.32	666.16	486.22	376.16	641.76	676.09	673.37	674.80
30	2	467.72	321.35	477.53	373.18	295.89	445.30	486.04	483.99	486.87
31	2	495.39	295.54	505.65	415.95	259.68	471.50	516.72	512.69	515.17
32	2	625.27	369.62	630.72	463.49	331.38	609.33	640.38	636.89	638.01
33	1	76.314	75.661	76.619	77.923	75.816	74.939	75.915	75.919	75.759
34	2	479.94	328.61	489.91	385.69	302.64	456.77	498.72	496.39	499.39
35	1	668.05	461.15	677.30	499.76	408.14	653.21	684.94	683.06	686.44
36	2	597.37	392.43	606.90	460.31	351.50	578.96	615.59	612.53	614.64
37	1	75.179	75.394	76.263	77.400	75.375	74.767	75.626	75.677	75.628

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID#		826 PUMP DEL TA PR	7 IN. TEMP ERATURE	5 TORQUE # 1	3 FLOWMETE R #2	838 THRUST D ISK DRAI N FLOW	900 REAR TOR QUE TEMP	901 FWD TORQ UE TEMP	903 LUBE OIL TEMP #1	902 LUBE OIL TEMP #2
MDS#	TYPE									
1	1	0.26883	66.346	-1.8460	-0.44277E-01	-0.12035E-01	72.844	72.005	88.141	88.967
2	2	434.50	61.300	3741.1	584.37	74.661	76.236	74.100	88.771	99.471
3	1	518.57	58.846	4371.7	653.50	94.924	77.882	77.436	97.957	104.05
4	1	550.92	58.944	4290.8	593.82	106.06	79.048	78.642	87.622	105.38
5	1	485.21	59.187	4407.2	704.24	90.040	80.897	80.777	94.291	105.13
6	1	518.83	59.285	4354.5	652.81	95.822	81.271	81.468	95.435	105.23
7	1	551.19	59.406	4285.8	593.83	106.57	81.683	82.264	91.399	106.88
8	1	577.88	59.541	4164.8	535.96	113.73	81.964	83.088	86.170	107.46
9	1	602.04	59.630	4021.5	479.33	120.05	82.202	83.558	95.395	107.26
10	1	608.07	59.852	3999.2	449.51	131.22	82.935	84.189	112.68	112.58
11	1	621.49	59.987	3909.8	415.22	133.72	83.270	84.820	114.99	112.98
12	1	630.55	60.172	3833.1	388.35	134.64	83.620	85.603	116.45	113.65
13	1	637.35	60.247	3741.1	358.88	135.25	83.963	86.243	117.70	113.94
14	1	637.33	60.338	3741.8	358.78	135.63	84.432	87.054	116.59	114.18
15	1	588.46	60.427	3863.4	388.36	131.74	84.789	87.274	110.92	113.96
16	1	584.90	60.562	3935.7	415.19	131.90	85.457	87.928	113.69	114.05
17	1	609.64	60.702	4027.5	449.47	133.89	85.656	88.791	121.65	114.94
18	1	598.34	60.786	4109.4	479.25	132.50	86.183	89.458	123.44	115.06
19	1	571.54	60.973	4232.0	535.92	130.07	86.854	90.109	95.810	111.01
20	1	541.54	61.058	4350.7	593.84	126.57	87.189	90.067	95.868	109.89
21	1	504.82	61.161	4419.4	653.02	120.83	87.431	90.367	95.161	109.00
22	1	481.15	61.312	4450.7	705.74	100.05	87.784	90.831	97.116	108.60
23	2	494.05	61.968	4073.8	595.57	93.176	90.047	93.098	107.52	106.87
24	2	429.69	62.892	4088.9	654.51	85.049	93.223	95.876	107.72	106.00
25	2	400.59	63.554	4209.4	704.96	82.088	96.015	97.345	110.42	106.09
26	2	310.72	63.766	3908.1	708.31	69.763	96.709	98.238	110.59	106.31
27	2	555.43	64.399	4057.2	535.98	105.60	99.305	99.952	106.48	106.22
28	2	589.80	65.002	3981.3	478.99	119.49	102.16	101.76	105.11	107.58
29	2	608.09	65.393	4001.6	448.89	135.07	103.61	102.63	97.649	108.61
30	2	397.49	65.231	3450.2	523.42	94.207	93.339	91.357	101.54	100.67
31	2	493.00	63.795	4087.6	594.78	94.776	97.696	96.441	115.88	108.98
32	2	615.80	64.790	3859.7	413.56	131.16	100.78	101.34	118.11	114.03
33	1	-0.23896	65.438	-4.6860	-0.25827E-01	4.6179	96.079	98.602	96.305	99.522
34	2	410.13	65.370	3519.3	528.12	95.777	94.056	93.209	103.32	99.989
35	1	597.86	64.894	3610.8	301.48	135.39	97.349	95.820	116.61	110.77
36	2	590.37	65.530	3695.3	355.28	122.87	99.684	99.815	120.00	115.76
37	1	-0.37835	66.040	-3.9760	-0.66416E-01	4.9213	96.208	98.404	99.098	102.11

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID#		904 GEAR CAS E TEMP	905 LUBE OIL SUP T	950 ACCEL X AXIS	951 ACCEL Y AXIS	952 ACCEL Z AXIS	4 SPEED	953 LUBE OIL FLOW	850 FLEX FLO W PR	851 GBOX OIL PR
MDS#	TYPE									
1	1	71.941	83.792	0.42783E-01	0.66199E-01	0.17244E-01	-0.31144	27.668	947.36	46.527
2	2	71.868	84.713	0.19817	0.14734	0.16290	5732.0	26.838	939.84	32.023
3	1	79.708	85.005	0.24620	0.28518	0.25991	6323.2	26.777	937.86	26.844
4	1	82.573	85.103	0.20897	0.14574	0.18550	6323.2	26.754	937.57	25.812
5	1	88.654	85.293	0.44809	0.55748	0.40748	6323.2	26.732	936.27	24.041
6	1	90.724	84.608	0.29548	0.34509	0.28366	6322.5	26.744	936.23	23.405
7	1	93.280	84.746	0.22252	0.14628	0.19356	6322.6	26.772	935.94	22.976
8	1	95.981	85.308	0.25120	0.14860	0.20455	6322.4	26.776	935.44	22.533
9	1	98.453	85.094	0.26146	0.14531	0.21050	6322.8	26.762	934.86	22.104
10	1	102.71	84.968	1.0966	0.54314	0.45076	6323.3	26.782	934.33	21.383
11	1	105.21	85.034	1.1546	0.57229	0.35895	6321.9	26.774	933.79	20.973
12	1	108.14	85.737	1.1521	0.56924	0.44810	6322.9	26.762	933.17	20.540
13	1	109.95	85.617	1.1086	0.55102	0.45039	6322.1	26.769	933.06	20.280
14	1	111.50	85.078	1.1240	0.55678	0.47432	6322.3	26.760	932.55	20.156
15	1	112.86	85.884	0.40793	0.22899	0.25445	6322.5	26.761	932.07	19.829
16	1	114.83	85.991	0.57571	0.30002	0.35654	6322.9	26.770	931.56	19.483
17	1	116.64	85.821	1.1567	0.57323	0.54485	6322.5	26.781	931.40	19.246
18	1	118.16	85.502	1.1233	0.54885	0.57097	6322.8	26.781	930.77	19.052
19	1	120.06	85.514	0.23107	0.14787	0.20412	6324.5	26.789	930.02	18.913
20	1	120.97	86.146	0.22121	0.15059	0.18938	6322.3	26.802	930.00	18.781
21	1	121.86	86.148	0.36558	0.39454	0.35535	6324.6	26.804	929.84	18.635
22	1	122.80	85.648	0.47110	0.55373	0.44895	6325.2	26.856	929.61	18.483
23	2	128.08	86.492	0.20699	0.18005	0.27671	6322.5	26.935	927.51	18.175
24	2	133.89	87.494	0.21844	0.18278	0.29545	6324.3	27.328	924.37	17.574
25	2	136.97	87.439	0.20159	0.15978	0.25789	6322.7	27.296	922.25	17.166
26	2	137.94	88.046	0.34979	0.27073	0.28555	6324.0	27.242	921.65	17.243
27	2	140.35	88.355	0.20060	0.17312	0.26348	6322.5	27.407	919.56	16.980
28	2	142.40	88.925	0.18953	0.14888	0.24430	6322.9	27.161	917.21	16.815
29	2	143.32	88.837	0.22313	0.15698	0.27386	6323.9	27.121	915.73	16.709
30	2	112.71	89.901	0.18653	0.15018	0.13381	5152.9	26.761	901.60	27.855
31	2	109.86	90.075	0.20696	0.17646	0.23437	6322.1	26.638	900.49	22.576
32	2	121.16	90.354	0.70488	0.35120	0.34457	6322.0	26.711	898.12	18.981
33	1	125.76	90.429	0.49253E-01	0.71387E-01	0.16207E-01	1.1290	26.779	895.48	28.319
34	2	112.29	92.248	0.18557	0.14707	0.13040	5238.9	26.704	887.70	27.173
35	1	110.47	91.518	0.23168	0.16756	0.19863	6324.7	26.749	887.40	24.106
36	2	115.48	92.005	0.28278	0.17704	0.33150	6323.5	26.312	885.83	20.097
37	1	121.48	92.556	0.46384E-01	0.71021E-01	0.17397E-01	0.42823	26.945	884.23	27.200

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID# MDS#	TYPE	926 G-BOX TE MP ALARM	-152 FLOW 1 R ATIO IND . #1	-25 NPSH IND . #1	-26 NSS IND. #1	-107 ST-TOT H EAD 2 IM P. #1	-34 D/S PRES S. PIPE #1	-152 FLOW 1 R ATIO IND . #1	-193 SCALED N PSH IND. #1	-194 SCALED F LOW IND. #1
1	1	3.3125	-0.18862	213.86	-0.91270E-03	-1.7815	92.451	-0.18862	0.12459E+12	-50.725
2	2	3.3122	1.2422	214.53	2643.5	533.98	92.742	1.2422	22348.	67.349
3	1	3.3127	1.2643	214.79	3057.4	630.22	92.856	1.2643	7989.5	66.758
4	1	3.3116	1.1827	214.49	2960.1	647.00	92.726	1.1827	7978.5	60.649
5	1	3.3129	1.3421	214.81	3149.9	612.70	92.862	1.3421	7990.2	71.983
6	1	3.3132	1.2651	215.01	3055.6	630.07	92.948	1.2651	7999.4	66.712
7	1	3.3128	1.1836	214.61	2959.7	645.95	92.777	1.1836	7984.4	60.650
8	1	3.3128	1.0977	213.78	2858.4	652.85	92.420	1.0977	7954.0	54.693
9	1	3.3118	1.0126	214.02	2743.3	675.43	92.524	1.0126	7962.0	48.880
10	1	3.3118	0.98131	214.43	2697.1	691.47	92.699	0.98131	7975.9	45.819
11	1	3.3122	0.92781	213.92	2626.3	694.33	92.480	0.92781	7960.4	42.313
12	1	3.3128	0.88381	213.99	2563.3	695.83	92.508	0.88381	7960.4	39.551
13	1	3.3121	0.83499	213.75	2493.2	695.55	92.406	0.83499	7953.7	36.526
14	1	3.3131	0.83558	214.04	2491.6	692.20	92.531	0.83558	7964.0	36.523
15	1	3.3129	0.87896	213.74	2559.0	700.83	92.402	0.87896	7952.1	39.557
16	1	3.3125	0.92462	214.24	2622.1	700.24	92.617	0.92462	7969.8	42.309
17	1	3.3128	0.98620	213.12	2715.7	663.94	92.131	0.98620	7929.0	45.832
18	1	3.3120	1.0341	214.33	2769.3	658.06	92.658	1.0341	7973.6	48.882
19	1	3.3124	1.1253	214.70	2886.3	639.15	92.816	1.1253	7982.8	54.666
20	1	3.3117	1.2180	215.00	2998.1	628.94	92.948	1.2180	7999.7	60.643
21	1	3.3138	1.3076	214.50	3113.4	616.47	92.731	1.3076	7975.5	66.673
22	1	3.3119	1.3612	215.39	3167.3	609.23	93.114	1.3612	8006.7	72.084
23	2	3.3123	1.1602	51.527	12606.	524.48	22.281	1.1602	1916.9	60.614
24	2	3.3131	1.2453	57.843	12117.	448.21	25.011	1.2453	2151.8	66.610
25	2	3.3133	1.3288	89.164	6165.0	439.93	38.551	1.3288	3317.2	71.970
26	2	3.3127	1.3083	24.725	17304.	301.08	10.696	1.3083	919.60	72.015
27	2	3.3128	1.0831	57.727	11033.	604.19	24.961	1.0831	2147.6	54.632
28	2	3.3129	1.0111	50.208	11065.	632.69	21.711	1.0111	1867.9	48.821
29	2	3.3128	0.98664	161.83	3385.3	648.66	69.962	0.98664	6018.0	45.718
30	2	3.3129	2.8127	214.79	2424.7	476.76	92.854	2.8127	0.11589E+11	140.28
31	2	3.3130	1.1631	59.125	11448.	521.34	25.566	1.1631	2200.0	60.607
32	2	3.3132	0.92327	60.717	9519.3	642.75	26.254	0.92327	2259.5	42.284
33	1	3.3130	27.257	213.94	0.43254E-01	-2.6200	92.488	27.257	0.13122E+12	33815.
34	2	3.3125	3.3690	214.63	2467.7	490.28	92.784	3.3690	0.11142E+11	60.234
35	1	3.3131	0.73784	211.65	2362.9	636.48	91.499	0.73784	7869.2	30.614
36	2	3.3124	0.81349	61.645	8684.8	670.14	26.655	0.81349	2292.4	36.496
37	1	3.3124	22.021	212.42	0.16740E-01	-2.5197	91.832	22.021	0.13029E+12	32558.

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID#		-195 SCALED HEAD IND. #1	-800 INDUCER TOT-ST HEAD #1	-801 INDUCER TOT-ST HEAD #2	-152 FLOW 1 RATIO IND. #1	-808 IMP STATIC HEADRISE	-809 XOVR U/S T-T HEADRISE	-810 XOVR D/S TT HEAD RISE #1	-811 XOVR D/S TT HEAD RISE #2	-812 XOVR D/S TT HEAD RISE #3
MDS#	TYPE									
1	1	0.80479E+09	3.4162	3.6517	-0.18862	0.80728	-1.5992	1.8549	1.6601	3.5841
2	2	42279.	41.162	40.236	1.2422	785.94	385.49	85.606	92.094	98.035
3	1	45605.	42.013	41.459	1.2643	905.24	444.05	120.09	110.38	118.84
4	1	48387.	61.047	60.521	1.1827	931.54	494.13	107.71	99.275	106.69
5	1	42737.	23.543	22.984	1.3421	877.62	391.86	131.55	121.42	130.65
6	1	45612.	41.885	41.170	1.2651	906.99	443.58	120.91	111.20	119.98
7	1	48387.	60.952	60.214	1.1836	932.29	495.21	108.59	99.305	106.18
8	1	50709.	79.100	77.864	1.0977	955.14	545.15	96.312	87.204	93.355
9	1	52838.	96.191	94.543	1.0126	977.52	572.17	85.609	78.312	81.920
10	1	53365.	98.700	96.427	0.98131	992.54	566.34	87.083	80.631	82.647
11	1	54527.	108.62	106.32	0.92781	1003.7	592.66	78.788	72.191	74.555
12	1	55302.	116.06	113.16	0.88381	1012.4	609.70	75.117	68.081	69.896
13	1	55847.	123.29	120.92	0.83499	1014.1	622.58	70.360	61.998	63.514
14	1	55799.	123.29	120.63	0.83558	1015.4	623.54	72.064	63.495	65.781
15	1	51737.	117.33	116.40	0.87896	996.51	484.46	95.650	89.111	92.353
16	1	51369.	108.23	107.98	0.92462	991.06	485.58	94.806	87.218	91.699
17	1	53442.	95.526	93.489	0.98620	1004.9	595.19	91.421	83.916	86.636
18	1	52453.	86.124	83.586	1.0341	995.93	578.30	99.143	90.126	94.044
19	1	50108.	71.284	68.999	1.1253	962.70	541.91	107.11	97.705	104.37
20	1	47599.	50.923	48.748	1.2180	935.77	490.10	119.65	111.59	117.85
21	1	44407.	31.320	29.239	1.3076	905.85	424.35	132.65	124.34	131.32
22	1	42295.	17.206	15.068	1.3612	887.14	382.19	139.88	131.31	137.81
23	2	43448.	59.172	57.365	1.1602	823.83	488.25	106.68	97.778	101.94
24	2	37821.	40.275	39.188	1.2453	728.32	423.93	114.44	105.77	110.65
25	2	35263.	22.973	21.172	1.3288	708.68	370.37	124.60	116.41	122.00
26	2	27550.	21.313	22.309	1.3083	549.71	310.78	114.32	106.68	111.32
27	2	48697.	70.662	70.593	1.0831	922.86	548.45	92.899	85.715	90.175
28	2	51648.	81.502	83.872	1.0111	967.38	597.90	80.885	73.994	77.600
29	2	53175.	93.932	94.183	0.98664	991.30	613.78	79.615	73.320	76.630
30	2	-0.12696E+09	27.506	27.624	2.8127	711.84	345.26	94.409	89.675	96.329
31	2	43198.	53.232	54.814	1.1631	822.31	489.41	104.77	95.459	101.18
32	2	53825.	96.385	97.606	0.92327	996.57	642.28	72.015	63.955	66.536
33	1	-0.17930E+10	-1.0867	-0.74895	27.257	-1.5363	-2.0270	2.5367	2.5444	2.1753
34	2	-0.14261E+09	29.688	29.874	3.3690	730.52	356.17	97.234	91.840	98.777
35	1	52141.	130.65	130.52	0.73784	1000.6	566.29	73.613	69.254	77.080
36	2	51676.	115.09	115.84	0.81349	1000.0	525.65	84.929	77.852	82.718
37	1	-0.12340E+10	-0.79349	-0.35118	22.021	-2.0121	-1.4039	2.2646	2.3840	2.2697

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 10/12/88 12:53:52

P/F ID#		-813 STAGE T-T HEADRISE	-152 FLOW 1 RATIO IND . #1	-815 XOVR TT HEADRISE #2	-816 PUMP TT HEADRISE	-817 RESULTANT AXIAL LOAD (-)	-818 RESULTANT AXIAL LOAD (+)	-819 NET AXIAL LOAD
MDS#	TYPE							
1	1	1.9290	-0.18862	0.60861E-01	1.8699	10687.	10145.	541.90
2	2	1051.7	1.2422	477.59	575.05	53056.	48566.	4490.4
3	1	1226.1	1.2643	554.44	672.76	59848.	62081.	-2232.6
4	1	1300.8	1.1827	593.40	708.63	62577.	63968.	-1390.8
5	1	1148.9	1.3421	513.28	636.72	56865.	59546.	-2681.1
6	1	1226.0	1.2651	554.78	672.29	59816.	62246.	-2429.4
7	1	1300.6	1.1836	594.52	707.23	62588.	63898.	-1310.2
8	1	1362.9	1.0977	632.36	731.79	65015.	65456.	-441.23
9	1	1420.3	1.0126	650.48	771.08	67262.	66866.	395.31
10	1	1434.7	0.98131	646.98	789.01	68016.	68658.	-641.98
11	1	1465.3	0.92781	664.85	801.76	69255.	70046.	-791.00
12	1	1486.6	0.88381	677.78	810.10	70137.	71042.	-905.48
13	1	1500.9	0.83499	684.58	817.57	70752.	71767.	-1015.0
14	1	1499.7	0.83558	687.03	813.92	70781.	71839.	-1058.4
15	1	1390.6	0.87896	573.57	818.33	67992.	69873.	-1881.9
16	1	1380.9	0.92462	572.80	809.31	67486.	69445.	-1958.6
17	1	1436.4	0.98620	679.10	758.45	68178.	69827.	-1649.5
18	1	1410.0	1.0341	668.43	742.66	67175.	68813.	-1637.6
19	1	1347.7	1.1253	639.62	709.11	64611.	66593.	-1981.5
20	1	1279.3	1.2180	601.69	678.63	61851.	63811.	-1960.0
21	1	1194.3	1.3076	548.68	646.63	58700.	60776.	-2075.8
22	1	1137.8	1.3612	513.50	625.20	56615.	60630.	-4014.4
23	2	1167.8	1.1602	586.03	582.60	46237.	50899.	-4661.6
24	2	1017.1	1.2453	529.70	488.00	40535.	44630.	-4095.2
25	2	947.86	1.3288	486.78	461.66	40072.	43995.	-3922.9
26	2	740.82	1.3083	417.46	323.76	27643.	30615.	-2972.1
27	2	1308.9	1.0831	634.16	675.49	52435.	57259.	-4824.2
28	2	1388.4	1.0111	671.89	717.27	55042.	59118.	-4076.1
29	2	1429.9	0.98664	687.10	743.54	64222.	66470.	-2248.0
30	2	939.29	2.8127	434.94	504.91	48517.	50647.	-2130.0
31	2	1161.0	1.1631	584.87	576.80	46435.	51087.	-4652.2
32	2	1446.5	0.92327	706.23	741.08	58170.	61425.	-3254.6
33	1	-2.8491	27.257	0.51741	-3.3700	10404.	9933.1	470.44
34	2	968.13	3.3690	448.01	520.68	49646.	52015.	-2369.2
35	1	1402.4	0.73784	635.55	767.72	68207.	70495.	-2287.7
36	2	1389.4	0.81349	603.50	786.69	58081.	62359.	-4277.5
37	1	-1.8889	22.021	0.98010	-2.8719	10316.	9838.7	477.43

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 01/04/89 17:23:31

P/F ID#		-813	-152	-815	-816	-817	-818	-819	-814	-820
MDS#	TYPE	STAGE T-T HEADRISE	FLOW 1 RATIO IND . #1	XOVR TT HEADRISE #2	PUMP TT HEADRISE	RESULTANT AXIAL LOAD (-)	RESULTANT AXIAL LOAD (+)	NET AXIAL LOAD	STAGE EFFICIENCY	CMOMENTL
1	1	1.9290	-0.18862	0.60861E-01	1.8699	10687.	10145.	541.90	-0.11455	0.51631E-06
2	2	1051.7	1.2422	477.59	575.05	53056.	48566.	4490.4	0.45537	25.738
3	1	1226.1	1.2643	554.44	672.76	59848.	62081.	-2232.6	0.51964	31.937
4	1	1300.8	1.1827	593.40	708.63	62577.	63968.	-1390.8	0.52546	27.928
5	1	1148.9	1.3421	513.28	636.72	56865.	59546.	-2681.1	0.51275	35.969
6	1	1226.0	1.2651	554.78	672.29	59816.	62246.	-2429.4	0.52198	31.954
7	1	1300.6	1.1836	594.52	707.23	62588.	63898.	-1310.2	0.52636	27.968
8	1	1362.9	1.0977	632.36	731.79	65015.	65456.	-441.23	0.52641	24.065
9	1	1420.3	1.0126	650.48	771.08	67262.	66866.	395.31	0.52409	20.481
10	1	1434.7	0.98131	646.98	789.01	68016.	68658.	-641.98	0.51588	19.227
11	1	1465.3	0.92781	664.85	801.76	69255.	70046.	-791.00	0.50956	17.179
12	1	1486.6	0.88381	677.78	810.10	70137.	71042.	-905.48	0.50228	15.593
13	1	1500.9	0.83499	684.58	817.57	70752.	71767.	-1015.0	0.49087	13.919
14	1	1499.7	0.83558	687.03	813.92	70781.	71839.	-1058.4	0.49073	13.935
15	1	1390.6	0.87896	573.57	818.33	67992.	69873.	-1881.9	0.46361	15.421
16	1	1380.9	0.92462	572.80	809.31	67486.	69445.	-1958.6	0.47536	17.062
17	1	1436.4	0.98620	679.10	758.45	68178.	69827.	-1649.5	0.51538	19.400
18	1	1410.0	1.0341	668.43	742.66	67175.	68813.	-1637.6	0.51990	21.334
19	1	1347.7	1.1253	639.62	709.11	64611.	66593.	-1981.5	0.52508	25.284
20	1	1279.3	1.2180	601.69	678.63	61851.	63811.	-1960.0	0.52478	29.585
21	1	1194.3	1.3076	548.68	646.63	58700.	60776.	-2075.8	0.51777	34.136
22	1	1137.8	1.3612	513.50	625.20	56615.	60630.	-4014.4	0.50985	37.012
23	2	1167.8	1.1602	586.03	582.60	46237.	50899.	-4661.6	0.48708	27.046
24	2	1017.1	1.2453	529.70	488.00	40535.	44630.	-4095.2	0.45308	31.177
25	2	947.86	1.3288	486.78	461.66	40072.	43995.	-3922.9	0.43815	35.303
26	2	740.82	1.3083	417.46	323.76	27643.	30615.	-2972.1	0.36293	34.502
27	2	1308.9	1.0831	634.16	675.49	52435.	57259.	-4824.2	0.51179	23.468
28	2	1388.4	1.0111	671.89	717.27	55042.	59118.	-4076.1	0.51642	20.415
29	2	1429.9	0.98664	687.10	743.54	64222.	66470.	-2248.0	0.51634	19.433
30	2	939.29	2.8127	434.94	504.91	48517.	50647.	-2130.0	-0.48905	25.136
31	2	1161.0	1.1631	584.87	576.80	46435.	51087.	-4652.2	0.48363	27.107
32	2	1446.5	0.92327	706.23	741.08	58170.	61425.	-3254.6	0.50684	16.915
33	1	-2.8491	27.257	0.51741	-3.3700	10404.	9933.1	470.44	-18.538	0.12027E-02
34	2	968.13	3.3690	448.01	520.68	49646.	52015.	-2369.2	-0.53618	25.384
35	1	1402.4	0.73784	635.55	767.72	68207.	70495.	-2287.7	0.41975	10.876
36	2	1389.4	0.81349	603.50	786.69	58081.	62359.	-4277.5	0.44800	13.045
37	1	-1.8889	22.021	0.98010	-2.8719	10316.	9838.7	477.43	-11.587	0.13436E-02

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 01/04/89 17:23:31

P/F ID#		-821 TDFWDL	-822 FIMPL	-823 TDUAFTL	-824 TDLAFTL	-825 AIMPL
MDS#	TYPE					
1	1	3085.0	2790.1	1307.7	1014.5	6607.3
2	2	20482.	24388.	5471.5	6477.7	35205.
3	1	23391.	27761.	9372.7	11597.	39694.
4	1	24661.	28846.	9463.2	11715.	41277.
5	1	22074.	26482.	9050.9	11174.	37997.
6	1	23393.	27725.	9443.9	11690.	39694.
7	1	24664.	28853.	9434.7	11678.	41273.
8	1	25706.	29913.	9443.0	11689.	42723.
9	1	26668.	30875.	9433.8	11677.	44066.
10	1	26910.	31310.	9926.6	12323.	44703.
11	1	27433.	31857.	10177.	12652.	45465.
12	1	27793.	32248.	10337.	12862.	46052.
13	1	28039.	32513.	10440.	12998.	46503.
14	1	28025.	32551.	10449.	13009.	46553.
15	1	26172.	31938.	10016.	12441.	45621.
16	1	26011.	31698.	10000.	12420.	45272.
17	1	26933.	31496.	10297.	12809.	45040.
18	1	26506.	31054.	10140.	12603.	44430.
19	1	25456.	29848.	9890.3	12276.	42861.
20	1	24268.	28656.	9438.8	11683.	41225.
21	1	22825.	27372.	8957.3	11052.	39406.
22	1	21859.	26522.	9434.2	11677.	38224.
23	2	19679.	21659.	8467.7	10409.	31349.
24	2	17209.	18890.	7439.1	9059.6	27523.
25	2	16544.	18719.	7215.6	8766.4	27333.
26	2	12009.	12915.	5062.9	5941.7	19267.
27	2	22153.	24727.	9329.0	11540.	35628.
28	2	23377.	25959.	9388.9	11618.	37332.
29	2	25947.	29755.	9979.7	12393.	42685.
30	2	18600.	22174.	7574.5	9237.5	32492.
31	2	19695.	21740.	8484.6	10432.	31490.
32	2	24566.	27346.	9496.2	11759.	39261.
33	1	2984.3	2666.3	1292.2	994.06	6453.7
34	2	19082.	22722.	7840.7	9586.7	33234.
35	1	26381.	31839.	10268.	12771.	45602.
36	2	23639.	28088.	9428.6	11670.	40251.
37	1	2970.4	2623.5	1281.1	979.55	6391.1

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 01/05/89 13:05:42

P/F ID# MDS#	TYPE	-813 STAGE T-T HEADRISE	-152 FLOW 1 RATIO IND . #1	-815 XOVR TT HEADRISE #2	-816 PUMP TT HEADRISE	-817 RESULTANT AXIAL LOAD (+)	-818 RESULTANT AXIAL LOAD (-)	-819 NET AXIAL LOAD	-814 STAGE EFFICIENCY	-820 CMOMENTL
1	1	1.9290	-0.18862	0.60861E-01	1.8699	6639.7	9647.2	-3007.5	-0.11455	0.51631E-06
2	2	1051.7	1.2422	477.59	575.05	49007.	48067.	939.13	0.45537	25.738
3	1	1226.1	1.2643	554.44	672.76	55798.	61582.	-5784.7	0.51964	31.937
4	1	1300.8	1.1827	593.40	708.63	58527.	63470.	-4942.9	0.52546	27.928
5	1	1148.9	1.3421	513.28	636.72	52814.	59047.	-6233.1	0.51275	35.969
6	1	1226.0	1.2651	554.78	672.29	55766.	61747.	-5981.3	0.52198	31.954
7	1	1300.6	1.1836	594.52	707.23	58538.	63400.	-4862.1	0.52636	27.968
8	1	1362.9	1.0977	632.36	731.79	60964.	64957.	-3993.1	0.52641	24.065
9	1	1420.3	1.0126	650.48	771.08	63212.	66368.	-3156.5	0.52409	20.481
10	1	1434.7	0.98131	646.98	789.01	63966.	68159.	-4193.8	0.51588	19.227
11	1	1465.3	0.92781	664.85	801.76	65205.	69548.	-4342.7	0.50956	17.179
12	1	1486.6	0.88381	677.78	810.10	66087.	70544.	-4457.1	0.50228	15.593
13	1	1500.9	0.83499	684.58	817.57	66702.	71269.	-4566.6	0.49087	13.919
14	1	1499.7	0.83558	687.03	813.92	66731.	71341.	-4610.0	0.49073	13.935
15	1	1390.6	0.87896	573.57	818.33	63942.	69375.	-5433.4	0.46361	15.421
16	1	1380.9	0.92462	572.80	809.31	63436.	68946.	-5510.1	0.47536	17.062
17	1	1436.4	0.98620	679.10	758.45	64128.	69329.	-5201.0	0.51538	19.400
18	1	1410.0	1.0341	668.43	742.66	63125.	68314.	-5189.1	0.51990	21.334
19	1	1347.7	1.1253	639.62	709.11	60562.	66095.	-5532.9	0.52508	25.284
20	1	1279.3	1.2180	601.69	678.63	57802.	63313.	-5511.4	0.52478	29.585
21	1	1194.3	1.3076	548.68	646.63	54650.	60278.	-5627.1	0.51777	34.136
22	1	1137.8	1.3612	513.50	625.20	52566.	60131.	-7565.7	0.50985	37.012
23	2	1167.8	1.1602	586.03	582.60	42188.	50401.	-8212.7	0.48708	27.046
24	2	1017.1	1.2453	529.70	488.00	36486.	44132.	-7645.9	0.45308	31.177
25	2	947.86	1.3288	486.78	461.66	36023.	43497.	-7473.4	0.43815	35.303
26	2	740.82	1.3083	417.46	323.76	23594.	30117.	-6522.5	0.36293	34.502
27	2	1308.9	1.0831	634.16	675.49	48387.	56761.	-8374.4	0.51179	23.468
28	2	1388.4	1.0111	671.89	717.27	50994.	58620.	-7626.0	0.51642	20.415
29	2	1429.9	0.98664	687.10	743.54	60175.	65972.	-5797.8	0.51634	19.433
30	2	939.29	2.8127	434.94	504.91	44470.	50149.	-5679.8	-0.48905	25.136
31	2	1161.0	1.1631	584.87	576.80	42386.	50589.	-8202.6	0.48363	27.107
32	2	1446.5	0.92327	706.23	741.08	54122.	60927.	-6804.7	0.50684	16.915
33	1	-2.8491	27.257	0.51741	-3.3700	6355.8	9435.1	-3079.3	-18.538	0.12027E-02
34	2	968.13	3.3690	448.01	520.68	45598.	51517.	-5919.0	-0.53618	25.384
35	1	1402.4	0.73784	635.55	767.72	64159.	69997.	-5837.7	0.41975	10.876
36	2	1389.4	0.81349	603.50	786.69	54033.	61861.	-7827.2	0.44800	13.045
37	1	-1.8889	22.021	0.98010	-2.8719	6268.6	9340.7	-3072.1	-11.587	0.13436E-02

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: XOVER HQ CAV TEST
TEST 88A096 TEST START TIME 10/ 8/88 7:26:17.20 PROCESS TIME 01/05/89 13:05:42

P/F ID#		-821 TDFWDL	-822 FIMPL	-823 TDUAFTL	-824 TDLAFTL	-825 AIMPL
MDS#	TYPE					
1	1	3085.0	-1006.4	1304.8	593.62	6607.3
2	2	20482.	20589.	5468.6	6056.5	35205.
3	1	23391.	23962.	9369.8	11175.	39694.
4	1	24661.	25047.	9460.3	11294.	41277.
5	1	22074.	22683.	9048.0	10753.	37997.
6	1	23393.	23926.	9441.0	11269.	39694.
7	1	24664.	25054.	9431.8	11257.	41273.
8	1	25706.	26114.	9440.1	11268.	42723.
9	1	26668.	27076.	9430.9	11256.	44066.
10	1	26910.	27511.	9923.7	11902.	44703.
11	1	27433.	28058.	10174.	12231.	45465.
12	1	27793.	28449.	10334.	12441.	46052.
13	1	28039.	28715.	10437.	12576.	46503.
14	1	28025.	28752.	10446.	12588.	46553.
15	1	26172.	28139.	10013.	12019.	45621.
16	1	26011.	27899.	9997.4	11999.	45272.
17	1	26933.	27697.	10294.	12388.	45040.
18	1	26506.	27255.	10137.	12182.	44430.
19	1	25456.	26050.	9887.4	11855.	42861.
20	1	24268.	24857.	9436.0	11262.	41225.
21	1	22825.	23573.	8954.4	10630.	39406.
22	1	21859.	22724.	9431.3	11256.	38224.
23	2	19679.	17860.	8464.9	9988.2	31349.
24	2	17209.	15092.	7436.2	8638.5	27523.
25	2	16544.	14921.	7212.7	8345.4	27333.
26	2	12009.	9117.8	5060.0	5520.7	19267.
27	2	22153.	20929.	9326.1	11119.	35628.
28	2	23377.	22162.	9386.0	11197.	37332.
29	2	25947.	25958.	9976.9	11973.	42685.
30	2	18600.	18378.	7571.6	8816.5	32492.
31	2	19695.	17942.	8481.7	10011.	31490.
32	2	24566.	23550.	9493.3	11338.	39261.
33	1	2984.3	-1130.5	1289.3	573.11	6453.7
34	2	19082.	18926.	7837.8	9165.7	33234.
35	1	26381.	28042.	10265.	12350.	45602.
36	2	23639.	24291.	9425.7	11249.	40251.
37	1	2970.4	-1173.1	1278.2	558.63	6391.1

DIRECTORY FILE: RUN NUM: 88A097 , T DATE: 10/10/88, N MDS= 46, N CPS= 45
EDF HDR: CROSSOVER TEST

I C P:

1	801	2	228	229	802	803	804	805	230
231	806	807	808	809	810	811	812	813	815
818	120	819	820	821	822	826	7	5	3
838	900	901	903	902	904	905	950	951	952
4	953	850	851	926					

MDS	NSCANS	TYPE	HEADER
1	20	1	PRE STATIC @ 90 PSIA
2	139	2	START UP
3	132	2	
4	20	1	463
5	20	1	582
6	20	1	524 GPM
7	20	1	495 GPM
8	20	1	466 GPM
9	20	1	437 GPM
10	20	1	407 GPM
11	189	2	2ND START UP
12	20	1	442
13	20	1	400
14	20	1	375
15	20	1	359
16	20	1	331
17	20	1	302
18	20	1	272
19	20	1	243
20	20	1	
21	97	2	3RD START UP
22	252	2	4TH START UP
23	300	2	5TH START UP
24	183	2	6TH STARTUP
25	20	1	441
26	20	1	400
27	20	1	375
28	20	1	359
29	20	1	331
30	20	1	302
31	20	1	272
32	20	1	243
33	20	1	243
34	20	1	272
35	20	1	302
36	20	1	331
37	20	1	359
38	20	1	375
39	20	1	400
40	20	1	442
41	681	2	442 GPM
42	14	2	
43	188	2	7TH START UP
44	182	2	START UP
45	175	2	START UP
46	717	2	375 CAV

T S TIME: 14:37:48.70, P DATE: 10/11/88, P TIME: 07:42:58
N WS= 70, N W STAT= 74, N STAT= 46
ID W:

1	801	2	228	229	802	803	804	805	230
231	806	807	808	809	810	811	812	813	815
816	818	120	819	820	821	822	826	7	5
3	838	900	901	903	902	904	905	950	951
952	4	953	850	851	926	-152	-25	-26	-100
-101	-106	-107	-34	-193	-194	-195	-202	-203	-800
-801	-808	-809	-810	-811	-812	-813	-814	-815	-816

PRECEDING PAGE BLANK NOT FILMED

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID# MDS#	TYPE	1 INLET STATIC PRESSURE, P	801 INLET STATIC PR #2	2 FLOWMETER #1	228 D/S STAT. PRESS. IND #1	229 D/S STAT. PRESS. IND #2	802 IMP FWD SHROUD PR #1	803 IMP FWD SHROUD PR #2	804 IMP AFT SHROUD PR #1	805 IMP AFT SHROUD PR #2
1	1	90.861	91.100	0.13083	77.011	77.060	76.880	74.766	73.596	77.950
2	2	91.203	91.424	50.122	76.495	76.539	78.714	76.834	75.339	79.847
3	2	91.236	91.127	739.30	91.131	90.700	372.29	349.32	418.49	418.19
4	1	90.871	90.672	711.82	97.562	97.676	411.67	390.37	469.85	467.79
5	1	90.799	90.881	578.53	116.03	115.32	447.60	427.51	512.05	511.36
6	1	90.895	90.876	513.55	124.13	123.20	456.98	434.67	526.44	525.29
7	1	90.797	91.080	502.19	124.78	124.10	458.34	435.81	528.20	526.91
8	1	90.735	90.709	466.67	128.24	127.54	461.98	424.72	534.16	532.68
9	1	89.850	90.420	435.40	132.34	132.08	467.48	471.95	529.10	533.12
10	1	90.108	89.349	402.81	135.14	134.24	476.12	434.51	539.15	534.22
11	2	90.181	90.054	526.59	101.92	102.03	357.84	338.37	409.37	411.48
12	1	89.610	89.491	578.67	115.62	115.65	440.93	438.33	508.79	509.91
13	1	91.024	90.886	539.61	120.23	119.65	451.86	448.82	519.36	519.03
14	1	90.702	90.684	513.52	123.12	122.28	455.38	417.86	524.57	524.21
15	1	90.902	90.796	500.01	124.48	123.74	457.36	427.78	527.30	526.74
16	1	90.072	90.814	467.00	129.92	129.33	466.41	436.65	524.75	521.05
17	1	91.782	90.795	438.88	132.12	132.01	470.31	436.98	527.55	530.17
18	1	89.589	90.454	407.83	135.45	134.30	477.65	440.49	535.50	533.43
19	1	88.508	91.430	382.17	140.88	139.62	485.13	443.28	543.81	539.48
20	1	89.793	89.874	4.6583	75.545	75.821	75.713	70.419	72.707	76.241
21	2	92.355	92.440	257.98	95.248	95.031	224.07	212.21	242.40	244.42
22	2	90.855	95.260	75.663	119.63	120.09	295.09	276.31	319.00	322.25
23	2	90.635	90.711	189.45	79.439	79.565	140.89	130.85	149.75	153.08
24	2	91.202	91.007	687.50	90.252	89.825	351.77	321.68	399.33	401.16
25	1	90.026	90.222	579.66	115.47	115.38	440.54	390.10	508.60	509.62
26	1	90.898	90.947	539.59	119.65	118.93	450.79	399.19	518.77	519.17
27	1	91.251	90.970	514.97	122.69	121.84	454.32	402.27	524.08	524.24
28	1	91.011	90.874	502.06	124.28	123.43	455.55	435.96	526.61	526.47
29	1	90.374	90.083	473.07	126.04	125.36	458.43	436.11	530.55	529.74
30	1	89.499	90.996	443.85	130.00	129.36	462.07	440.46	536.29	535.25
31	1	89.909	90.477	409.27	134.30	134.16	469.58	460.05	533.66	535.40
32	1	87.368	91.733	381.51	140.25	139.98	479.17	445.04	540.63	543.16
33	1	89.041	90.771	383.83	139.57	138.41	480.49	429.53	540.97	539.07
34	1	95.944	90.393	408.46	134.28	133.00	474.12	422.97	533.67	534.46
35	1	90.909	90.332	439.69	130.99	130.39	469.31	417.72	528.14	529.44
36	1	90.548	91.012	467.47	129.06	128.45	466.28	411.43	525.74	524.36
37	1	90.397	90.771	496.53	125.63	125.59	458.21	411.05	520.41	522.77
38	1	90.671	90.296	511.06	123.54	123.64	456.56	405.78	517.32	519.82
39	1	90.579	90.757	536.48	121.50	120.70	455.97	399.49	513.33	515.61

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID#		1	801	2	228	229	802	803	804	805
MDS#	TYPE	INLET ST ATIC PRE SSURE, P	INLET ST ATIC PR #2	FLOWMETE R #1	D/S STAT . PRESS. IND #1	D/S STAT . PRESS. IND #2	IMP FWD SHROUD P R #1	IMP FWD SHROUD P R #2	IMP AFT SHROUD P R #1	IMP AFT SHROUD P R #2
40	1	90.968	90.812	579.49	115.95	115.61	443.36	396.21	508.66	507.33
41	2	27.024	26.766	576.55	48.157	48.606	364.69	326.05	430.52	431.05
42	2	90.963	92.504	4.2102	78.256	78.433	78.537	70.438	75.239	79.112
43	2	91.296	92.632	534.29	107.13	106.96	367.94	326.41	421.68	421.90
44	2	91.112	92.159	544.94	110.78	110.73	394.96	364.34	453.78	453.93
45	2	91.071	92.015	579.32	106.36	106.41	389.38	353.51	446.16	446.62
46	2	61.197	61.703	380.89	81.473	81.361	321.12	311.86	365.75	366.30

P/F ID#		230	231	806	807	808	809	810	811	812
MDS#	TYPE	D/S STAT . PRESS. IMP #1	D/S STAT . PRESS. IMP #2	DWN MID DIFF #1	UPC CONS T SEC PR #3	UPC CONS T SEC PR #2	UPC CONS T SEC PR #4	TRANSITI ON ST PR	DWN DIFF DISCH P R #1	DWN DIFF DISCH P R #2
1	1	78.274	77.140	75.908	76.705	76.108	76.984	75.402	76.868	76.758
2	2	80.554	79.175	77.190	78.094	77.420	78.048	76.433	78.271	78.153
3	2	461.25	460.27	532.69	519.54	514.78	521.26	523.75	535.75	534.95
4	1	510.79	507.99	625.40	615.43	609.41	616.52	616.14	628.35	627.12
5	1	556.66	555.71	693.58	687.10	681.49	689.00	687.36	695.54	694.55
6	1	570.01	570.13	714.11	709.47	704.16	711.80	709.08	716.29	715.25
7	1	571.85	571.87	716.57	712.74	707.94	714.54	711.86	719.00	717.96
8	1	577.47	577.71	725.69	722.93	717.48	724.06	721.23	728.02	727.06
9	1	571.75	569.59	679.30	672.11	666.07	673.11	671.55	681.91	681.24
10	1	578.20	575.37	681.70	674.05	669.92	675.85	674.54	684.48	683.00
11	2	442.59	441.07	545.19	539.62	534.43	540.45	539.03	547.55	546.20
12	1	550.58	549.54	689.42	683.85	677.53	685.62	683.90	691.99	690.73
13	1	563.76	563.37	706.19	700.90	695.54	703.19	701.44	708.47	707.25
14	1	568.77	568.69	713.68	709.09	704.12	711.14	708.74	715.89	714.67
15	1	571.22	571.47	718.04	713.78	709.36	716.07	713.35	720.50	719.53
16	1	571.53	567.04	675.96	668.51	663.44	669.33	668.55	678.85	677.80
17	1	569.62	573.61	678.27	671.86	666.94	672.63	670.02	680.94	680.04
18	1	579.87	577.24	680.63	674.43	669.83	673.88	672.03	684.16	683.02
19	1	587.07	582.42	685.43	679.26	675.76	679.30	677.51	689.03	687.77
20	1	76.730	75.403	73.054	74.814	74.197	74.811	72.820	75.103	74.448
21	2	258.96	258.43	285.53	283.40	281.01	283.83	281.79	287.70	287.21
22	2	339.11	337.31	375.69	374.37	372.31	374.23	371.22	377.26	376.56
23	2	161.00	159.04	178.70	178.09	176.14	178.11	176.06	180.92	180.43
24	2	436.52	434.34	517.91	508.38	502.76	509.30	510.07	521.43	520.47
25	1	550.52	549.06	689.11	683.25	677.35	684.98	682.83	691.76	690.54

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P/F ID#		230 D/S STAT . PRESS. IMP #1	231 D/S STAT . PRESS. IMP #2	806 DWN MID DIFF #1	807 UPC CONS T SEC PR #3	808 UPC CONS T SEC PR #2	809 UPC CONS T SEC PR #4	810 TRANSITI ON ST PR	811 DWN DIFF DISCH P R #1	812 DWN DIFF DISCH P R #2
MDS#	TYPE									
26	1	562.64	562.10	702.89	697.48	692.52	699.77	697.61	705.33	704.04
27	1	567.66	567.36	711.38	706.44	701.69	708.63	706.10	713.65	712.43
28	1	569.95	569.69	715.31	710.63	706.29	712.82	710.19	717.52	716.47
29	1	574.08	574.48	722.44	718.82	714.38	719.97	716.93	724.38	723.62
30	1	579.27	579.04	729.91	727.96	721.68	727.50	724.81	731.53	731.18
31	1	572.57	569.10	679.15	672.57	667.63	673.56	671.68	681.78	681.05
32	1	579.33	580.49	683.11	676.82	671.97	675.83	676.50	686.02	684.89
33	1	582.61	580.63	682.21	675.48	672.14	675.35	675.13	685.52	684.51
34	1	573.87	575.49	678.93	672.13	666.75	672.63	671.36	681.55	680.77
35	1	571.30	571.58	677.01	670.03	665.51	669.58	669.42	679.87	679.29
36	1	566.13	568.36	676.03	668.63	663.01	670.06	668.51	679.17	678.53
37	1	562.67	562.51	673.40	666.76	660.35	666.35	665.80	676.08	675.64
38	1	559.78	559.35	670.85	663.55	658.14	663.43	664.10	673.90	673.42
39	1	557.89	553.52	667.24	659.66	653.87	659.12	658.36	670.28	669.65
40	1	550.78	549.13	675.98	669.11	661.76	671.59	668.08	678.97	677.73
41	2	474.81	472.89	614.64	610.38	604.79	611.50	610.11	617.59	617.08
42	2	79.528	77.562	75.980	77.549	77.213	77.392	75.298	77.932	77.552
43	2	456.26	455.49	561.95	556.99	551.85	558.10	556.07	564.53	563.45
44	2	491.36	490.38	609.15	603.94	598.42	605.29	603.16	611.69	610.56
45	2	484.43	483.59	598.32	591.95	586.42	592.84	591.07	600.80	599.72
46	2	398.80	396.36	482.47	477.98	474.15	478.54	476.64	484.92	484.44

P/F ID#		813 DWN CONS T SEC PR #1	802 IMP FWD SHROUD P R #1	815 XOVER DI SCH ST P R #1	818 THRUST D ISK DRAI N PR	120 D/S TOT PRESS. 1 IMP #1	819 TRANSITI ON TOTAL PR	820 XOVER EX IT TOTAL PR #1	821 XOVER EX IT TOTAL PR #2	822 XOVER EX IT TOTAL PR #3
MDS#	TYPE									
1	1	77.195	76.880	76.757	76.647	75.778	74.832	74.306	75.278	75.319
2	2	78.439	78.714	78.410	77.879	77.235	75.538	75.972	76.971	76.774
3	2	524.82	372.29	533.44	420.65	327.41	493.29	543.60	541.10	543.60
4	1	617.17	411.67	626.15	472.74	371.93	587.15	636.58	632.98	635.74
5	1	689.83	447.60	693.45	514.41	402.43	667.98	702.47	693.55	700.10
6	1	711.95	456.98	714.41	527.49	405.69	696.57	723.40	715.35	720.16
7	1	714.91	458.34	717.18	530.21	406.99	699.68	726.62	718.52	723.09
8	1	724.36	461.98	726.18	536.23	409.10	713.56	735.61	727.93	731.65
9	1	673.62	467.48	681.16	507.36	422.86	654.91	688.82	686.36	687.55
10	1	676.30	476.12	684.23	508.97	442.50	655.01	691.53	688.59	688.87
11	2	540.34	357.84	545.07	416.57	322.60	519.79	552.14	550.14	551.74

AVERAGED DATA ON MEASUREMENT DATA SETS

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P/F ID# MDS#	TYPE	813 DWN CONS T SEC PR #1	802 IMP FWD SHROUD P R #1	815 XOVER DI SCH ST P R #1	818 THRUST D ISK DRAI N PR	120 D/S TOT PRESS. 1 IMP #1	819 TRANSITI ON TOTAL PR	820 XOVER EX IT TOTAL PR #1	821 XOVER EX IT TOTAL PR #2	822 XOVER EX IT TOTAL PR #3
12	1	685.52	440.93	689.54	519.88	395.18	662.85	698.42	694.76	696.43
13	1	702.91	451.86	706.21	523.23	402.98	683.76	715.24	711.06	712.33
14	1	710.75	455.38	713.80	528.31	405.52	693.42	722.63	718.38	719.24
15	1	715.70	457.36	718.09	531.17	405.67	699.32	727.37	722.63	723.67
16	1	669.89	466.41	677.92	506.13	426.58	648.64	686.17	683.25	683.67
17	1	672.63	470.31	680.16	507.36	422.86	653.26	686.70	684.78	686.57
18	1	676.52	477.65	683.23	509.56	434.34	655.67	690.19	687.97	688.29
19	1	681.36	485.13	687.42	512.89	442.84	660.61	694.40	692.55	692.95
20	1	75.615	75.713	75.079	75.095	74.133	73.035	72.600	73.660	72.530
21	2	284.30	224.07	287.44	229.39	209.02	274.40	290.39	288.87	288.73
22	2	374.97	295.09	377.44	293.35	278.47	367.55	378.35	378.11	377.71
23	2	178.50	140.89	180.71	153.22	131.37	170.53	180.91	180.80	180.59
24	2	510.47	351.77	519.15	403.41	314.39	482.79	528.28	525.79	527.71
25	1	684.90	440.54	689.38	527.24	393.08	663.08	698.32	694.38	695.94
26	1	699.73	450.79	703.34	527.99	399.70	679.48	711.96	707.98	708.96
27	1	708.46	454.32	711.49	534.90	402.74	691.52	720.14	715.77	717.14
28	1	712.84	455.55	715.70	537.85	403.58	696.99	724.76	719.89	720.85
29	1	720.15	458.43	722.28	542.26	404.15	706.55	731.24	726.52	727.59
30	1	728.03	462.07	729.77	547.95	408.68	718.30	738.34	734.61	734.67
31	1	673.62	469.58	681.22	514.45	426.84	654.92	688.44	685.58	686.97
32	1	677.75	479.17	685.32	517.34	436.53	660.08	692.80	690.03	690.80
33	1	677.60	480.49	684.76	517.30	439.39	656.65	692.11	689.47	689.38
34	1	673.28	474.12	681.39	515.41	428.03	652.98	689.09	685.80	686.66
35	1	671.34	469.31	679.11	513.82	422.63	650.86	686.70	683.79	684.77
36	1	670.78	466.28	678.13	514.25	417.93	649.22	686.37	683.10	684.21
37	1	667.13	458.21	675.10	512.35	412.48	646.43	682.66	680.50	682.15
38	1	664.53	456.56	672.96	511.35	408.83	643.02	680.64	678.22	679.65
39	1	660.76	455.97	669.12	508.91	404.14	638.38	677.30	674.48	675.97
40	1	670.75	443.36	677.05	517.26	398.66	647.87	686.76	682.87	684.17
41	2	612.03	364.69	616.58	458.99	313.10	592.93	625.29	621.22	621.51
42	2	77.557	78.537	77.982	77.960	76.311	75.823	75.462	76.391	75.452
43	2	558.17	367.94	562.63	438.26	329.88	538.93	569.41	566.60	567.69
44	2	605.22	394.96	609.56	473.67	352.19	585.26	616.59	613.88	615.01
45	2	593.05	389.38	598.76	465.92	346.57	571.18	606.14	603.38	604.97
46	2	479.12	321.12	484.73	369.03	285.40	463.53	490.07	487.32	487.67

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID# MDS#	TYPE	826 PUMP DEL TA PR	7 IN. TEMP ERATURE	5 TORQUE # 1	3 FLOWMETE R #2	838 THRUST D ISK DRAI N FLOW	900 REAR TOR QUE TEMP	901 FWD TORQ UE TEMP	903 LUBE OIL TEMP #1	902 LUBE OIL TEMP #2
1	1	1.1449	68.464	8.0963	-0.11805	-0.15470E-01	75.662	75.707	90.640	96.498
2	2	0.84515	67.578	52.482	40.986	5.7271	75.879	75.845	103.03	106.89
3	2	451.86	65.773	4254.5	644.70	106.75	79.538	77.673	100.31	108.12
4	1	547.88	65.270	4374.6	593.86	129.75	83.019	80.260	107.24	112.86
5	1	613.80	65.943	4039.4	451.01	137.64	86.180	85.537	115.30	121.41
6	1	635.07	66.420	3838.0	383.02	139.40	88.479	88.447	117.83	123.49
7	1	637.95	67.182	3810.8	371.46	139.43	91.118	93.827	118.70	124.97
8	1	646.77	67.316	3688.4	333.80	140.88	91.921	95.256	121.14	124.91
9	1	600.30	67.631	3630.8	305.52	136.03	93.174	96.766	120.54	124.14
10	1	603.08	67.835	3536.0	273.07	136.41	94.186	97.626	125.50	124.56
11	2	465.81	67.802	3365.4	424.68	110.21	85.877	84.584	101.66	110.34
12	1	611.68	65.603	4025.5	450.25	137.13	88.653	86.353	108.21	114.27
13	1	626.86	65.530	3930.8	409.46	138.24	89.640	87.628	114.69	118.97
14	1	634.81	65.610	3849.2	382.77	138.67	90.216	89.155	114.51	120.66
15	1	639.29	65.694	3812.3	367.99	139.46	90.805	90.371	115.84	122.43
16	1	598.40	65.721	3733.1	338.04	135.82	91.120	91.204	116.39	123.51
17	1	597.23	65.811	3652.2	309.12	136.20	91.498	91.830	117.65	123.73
18	1	602.35	65.889	3549.0	277.19	136.34	91.840	92.474	129.57	124.89
19	1	606.41	65.962	3486.0	250.44	136.68	92.426	93.322	125.23	125.45
20	1	-0.10951	66.051	-0.42611	-0.95914E-01	4.5120	89.378	90.213	106.82	113.70
21	2	204.54	66.685	1399.5	195.56	62.476	85.689	85.454	100.61	107.63
22	2	291.55	66.885	1386.3	-0.12355	74.913	84.845	84.584	110.63	111.72
23	2	103.57	65.583	899.32	158.52	32.103	83.673	83.601	103.12	107.32
24	2	439.79	65.239	3873.4	587.36	111.78	82.357	82.599	103.32	105.52
25	1	610.98	65.264	4044.0	451.12	138.17	84.315	84.388	104.89	111.74
26	1	624.12	65.260	3931.7	410.04	138.35	85.316	85.282	114.01	116.39
27	1	632.15	65.289	3846.5	383.62	139.97	86.264	86.581	113.69	117.45
28	1	636.42	65.354	3795.7	369.15	141.08	86.779	87.139	111.28	118.53
29	1	643.94	65.405	3713.6	339.15	141.49	86.796	88.391	110.40	121.32
30	1	651.08	65.480	3607.9	309.63	141.36	87.465	89.220	111.19	122.00
31	1	600.79	65.521	3559.6	279.14	136.59	87.532	89.450	112.05	122.48
32	1	604.95	65.632	3498.3	249.75	137.45	87.986	90.009	117.20	123.72
33	1	604.39	65.721	3512.7	251.76	138.14	88.198	90.460	110.43	123.06
34	1	597.50	65.843	3573.0	277.07	137.73	88.552	91.141	114.14	123.57
35	1	597.73	65.936	3655.9	309.97	136.77	88.730	91.613	123.90	124.16
36	1	597.20	65.972	3746.0	339.15	135.99	89.018	92.013	123.20	123.76
37	1	594.10	66.060	3829.9	368.81	135.87	89.209	92.387	118.24	124.00
38	1	591.89	66.125	3867.8	383.76	135.97	89.431	92.788	116.93	123.81
39	1	588.24	66.192	3929.9	410.12	135.03	89.661	93.155	112.40	123.08

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID#		826 PUMP DEL TA PR	7 IN. TEMP ERATURE	5 TORQUE # 1	3 FLOWMETE R #2	838 THRUST D ISK DRAI N FLOW	900 REAR TOR QUE TEMP	901 FWD TORQ UE TEMP	903 LUBE OIL TEMP #1	902 LUBE OIL TEMP #2
MDS#	TYPE									
40	1	597.93	66.284	4029.9	452.91	136.24	89.906	93.438	109.48	121.46
41	2	600.12	66.978	3936.1	449.99	135.61	91.459	94.911	108.84	115.87
42	2	-0.24178	67.400	12.378	-0.10540	4.0012	89.609	93.498	102.78	107.31
43	2	480.08	67.411	3332.6	426.25	116.90	88.066	89.450	104.91	110.96
44	2	527.04	66.307	3571.4	429.73	124.69	86.442	86.736	106.22	106.48
45	2	517.11	64.927	3697.4	465.62	123.15	81.472	82.246	104.68	103.89
46	2	434.96	62.522	2801.0	284.83	101.26	84.366	86.936	109.00	114.58

P/F ID#		904 GEAR CAS E TEMP	905 LUBE OIL SUP T	950 ACCEL X AXIS	951 ACCEL Y AXIS	952 ACCEL Z AXIS	4 SPEED	953 LUBE OIL FLOW	850 FLEX FLO W PR	851 GBOX OIL PR
MDS#	TYPE									
1	1	75.804	94.559	0.48280E-01	0.71320E-01	0.19869E-01	1.0119	26.372	945.06	42.860
2	2	75.558	93.954	0.69023E-01	0.82350E-01	0.19538E-01	249.41	19.059	942.51	39.736
3	2	75.560	93.591	0.18474	0.15219	0.16262	6287.8	19.114	942.40	28.292
4	1	81.341	93.629	0.14673	0.13095	0.15160	6321.6	19.006	941.32	25.701
5	1	100.22	93.823	1.1335	0.51368	0.50419	6322.1	19.008	939.66	21.236
6	1	110.45	93.866	1.0934	0.61155	0.43272	6322.1	18.936	938.23	19.777
7	1	121.67	93.735	1.0208	0.69419	0.38306	6322.8	19.106	936.73	18.594
8	1	123.97	93.632	0.95253	0.70893	0.44264	6320.9	19.401	936.41	18.419
9	1	127.94	94.429	0.17099	0.12522	0.23754	6322.3	19.682	935.29	18.098
10	1	130.26	93.851	0.16529	0.12445	0.19853	6323.8	19.763	934.87	17.913
11	2	89.155	93.856	0.16812	0.13518	0.12475	5262.4	20.282	912.95	28.499
12	1	89.330	93.590	0.17069	0.13678	0.14949	6321.7	20.231	912.81	26.548
13	1	90.149	93.792	0.96467	0.70985	0.44193	6322.0	20.405	912.83	25.561
14	1	91.251	94.458	0.93617	0.73585	0.47071	6321.7	20.343	912.67	24.637
15	1	93.053	94.097	0.88731	0.75212	0.55483	6321.5	20.201	912.55	23.878
16	1	94.843	94.160	0.23499	0.13620	0.23992	6321.8	20.052	912.13	23.250
17	1	97.269	94.147	0.21964	0.12228	0.22445	6322.0	20.207	911.82	22.659
18	1	99.556	94.070	0.18628	0.11939	0.19713	6322.4	20.139	911.63	22.142
19	1	102.54	94.354	0.17060	0.11167	0.23366	6321.6	20.194	911.37	21.582
20	1	105.02	94.121	0.39399E-01	0.64607E-01	0.16847E-01	0.97300	20.454	911.17	28.991
21	2	94.400	91.134	0.11413	0.11322	0.11458	3233.4	25.231	901.90	31.074
22	2	85.477	90.959	0.12001	0.11104	0.16216	3373.7	27.741	688.47	31.537
23	2	84.030	92.641	0.74525E-01	0.88176E-01	0.51559E-01	1532.2	26.744	686.73	34.747
24	2	78.355	93.678	0.20683	0.16696	0.28566	5834.3	31.084	723.17	27.774
25	1	79.139	93.783	0.17365	0.14209	0.16597	6321.7	26.121	739.53	27.077

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TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID#		904 GEAR CAS E TEMP	905 LUBE OIL SUP T	950 ACCEL X AXIS	951 ACCEL Y AXIS	952 ACCEL Z AXIS	4 SPEED	953 LUBE OIL FLOW	850 FLEX FLO W PR	851 GBOX OIL PR
MDS#	TYPE									
26	1	80.359	93.432	1.1544	0.57591	0.54543	6321.6	24.084	736.57	26.547
27	1	81.968	94.061	1.0835	0.56001	0.52028	6322.3	19.848	734.41	25.909
28	1	83.444	93.492	1.0208	0.52522	0.55724	6321.2	19.167	733.64	25.260
29	1	85.671	94.226	1.0932	0.61378	0.36002	6321.8	26.318	732.85	24.501
30	1	87.837	93.446	1.0395	0.56642	0.30059	6321.5	26.820	732.30	23.842
31	1	90.290	94.193	0.18839	0.12265	0.21764	6321.5	26.279	731.71	23.236
32	1	92.944	94.455	0.17801	0.12970	0.29812	6320.7	28.876	731.28	22.815
33	1	94.541	93.831	0.19815	0.10779	0.21407	6320.2	31.084	731.27	22.510
34	1	97.331	93.556	0.19214	0.11572	0.23076	6321.5	31.084	731.17	21.987
35	1	99.299	94.267	0.23206	0.11432	0.25286	6321.6	28.517	713.83	21.697
36	1	100.99	93.655	0.20942	0.12555	0.22085	6321.1	28.532	715.61	21.390
37	1	102.61	94.444	0.21756	0.13150	0.24831	6322.0	28.456	716.95	21.120
38	1	104.24	93.863	0.28400	0.13495	0.32321	6321.7	27.844	717.36	20.863
39	1	106.14	94.419	0.21265	0.14081	0.24401	6321.3	27.833	717.68	20.570
40	1	107.62	93.665	0.19184	0.10883	0.20537	6321.8	27.314	718.10	20.297
41	2	118.88	94.248	0.19672	0.13763	0.19769	6321.8	29.509	718.09	19.050
42	2	123.97	94.373	0.43641E-01	0.69450E-01	0.21626E-01	1.3900	19.805	748.73	26.942
43	2	108.74	93.758	0.11767	0.85801E-01	0.18386	5471.7	27.045	740.98	27.088
44	2	94.306	93.149	0.17509	0.13562	0.14257	5776.3	23.945	736.47	27.776
45	2	78.946	91.488	0.17369	0.13628	0.14816	5797.8	24.026	777.37	28.817
46	2	84.829	91.086	0.34418	0.21998	0.25562	4646.8	26.065	768.92	27.508

P/F ID#		926 G-BOX TE MP ALARM	-152 FLOW 1 R ATIO IND . #1	-25 NPSH IND . #1	-26 NSS IND. #1	-107 ST-TOT H EAD 2 IM P. #1	-34 D/S PRES S. PIPE #1	-152 FLOW 1 R ATIO IND . #1	-193 SCALED N PSH IND. #1	-194 SCALED F LOW IND. #1
MDS#	TYPE									
1	1	3.3134	0.19632	213.14	0.38851E-02	-2.4010	92.141	0.19632	0.55227E+11	49.669
2	2	3.3134	9.2647	213.95	63.316	2.1726	92.490	9.2647	0.34463E+11	476.61
3	2	3.3134	1.2772	214.80	3044.5	547.59	92.859	1.2772	8080.9	66.204
4	1	3.3131	1.2231	213.82	3016.3	634.32	92.435	1.2231	7957.3	60.594
5	1	3.3137	0.99403	213.37	2723.8	664.10	92.242	0.99403	7939.6	45.891
6	1	3.3137	0.88237	213.49	2565.2	653.44	92.292	0.88237	7943.8	38.941
7	1	3.3134	0.86276	213.25	2539.1	654.42	92.188	0.86276	7933.0	37.749
8	1	3.3130	0.80198	213.05	2448.7	651.36	92.104	0.80198	7930.5	33.911
9	1	3.3134	0.74808	210.97	2383.9	672.69	91.205	0.74808	7849.9	31.154
10	1	3.3142	0.69193	211.53	2293.9	713.10	91.447	0.69193	7867.0	27.716
11	2	3.3132	1.3537	211.95	2314.1	510.42	91.628	1.3537	0.44960E+10	64.392

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID# MDS#	TYPE	926 G-BOX TE MP ALARM	-152 FLOW 1 R ATIO IND . #1	-25 NPSH IND . #1	-26 NSS IND. #1	-107 ST-TOT H EAD 2 IM P. #1	-34 D/S PRES S. PIPE #1	-152 FLOW 1 R ATIO IND . #1	-193 SCALED N PSH IND. #1	-194 SCALED F LOW IND. #1
12	1	3.3138	0.99432	210.62	2750.6	646.55	91.054	0.99432	7838.1	45.963
13	1	3.3132	0.92717	213.83	2626.3	655.34	92.439	0.92717	7956.7	41.780
14	1	3.3133	0.88239	213.04	2569.0	655.11	92.100	0.88239	7928.4	39.022
15	1	3.3132	0.85919	213.48	2531.0	652.10	92.291	0.85919	7945.2	37.533
16	1	3.3138	0.80243	211.53	2463.5	687.49	91.444	0.80243	7871.7	34.474
17	1	3.3138	0.75409	215.45	2358.3	672.71	93.139	0.75409	8016.9	31.506
18	1	3.3136	0.70070	210.34	2319.0	693.97	90.931	0.70070	7826.1	28.258
19	1	3.3135	0.65669	207.81	2293.7	701.32	89.838	0.65669	7733.6	25.554
20	1	3.3133	11.953	210.67	0.37962E-01	-3.3381	91.073	11.953	0.57438E+11	51.799
21	2	3.3135	1.3372	216.76	1058.8	264.02	93.708	1.3372	0.86463E+06	69.737
22	2	3.3134	2.1195	213.13	672.13	366.62	92.135	2.1195	0.87440E+10	11.232
23	2	3.3134	6.7096	212.76	662.27	120.30	91.979	6.7096	0.28413E+11	79.551
24	2	3.3134	1.2907	214.63	2755.3	519.51	92.787	1.2907	21374.	65.881
25	1	3.3136	0.99601	211.58	2743.5	642.29	91.469	0.99601	7873.9	45.958
26	1	3.3135	0.92719	213.54	2628.8	649.39	92.313	0.92719	7947.0	41.771
27	1	3.3137	0.88479	214.31	2561.5	649.70	92.649	0.88479	7974.1	39.034
28	1	3.3138	0.86277	213.74	2534.4	647.96	92.401	0.86277	7955.5	37.582
29	1	3.3136	0.81286	212.23	2474.6	644.81	91.747	0.81286	7897.7	34.517
30	1	3.3130	0.76268	210.17	2416.2	646.06	90.856	0.76268	7821.6	31.489
31	1	3.3136	0.70327	211.08	2325.9	676.92	91.251	0.70327	7855.8	28.387
32	1	3.3132	0.65564	205.17	2333.1	685.88	88.698	0.65564	7637.8	25.410
33	1	3.3132	0.65968	209.05	2260.6	696.13	90.372	0.65968	7783.3	25.581
34	1	3.3132	0.70188	225.04	2215.6	682.40	97.286	0.70188	8375.3	28.182
35	1	3.3135	0.75553	213.43	2374.8	675.92	92.266	0.75553	7942.9	31.533
36	1	3.3133	0.80334	212.63	2455.2	669.57	91.920	0.80334	7914.4	34.508
37	1	3.3134	0.85315	212.32	2534.1	663.60	91.786	0.85315	7900.6	37.540
38	1	3.3133	0.87815	212.97	2563.9	659.68	92.069	0.87815	7925.7	39.043
39	1	3.3136	0.92189	212.80	2628.2	655.61	91.994	0.92189	7920.2	41.790
40	1	3.3134	0.99573	213.77	2722.3	654.73	92.412	0.99573	7955.0	46.137
41	2	3.3134	0.99068	65.836	10090.	611.89	28.467	0.99068	2450.1	45.893
42	2	3.3141	12.559	213.37	0.51056E-01	-4.3423	92.243	12.559	0.49889E+11	65.432
43	2	3.3138	1.0965	214.50	2311.4	515.83	92.728	1.0965	26826.	52.755
44	2	3.3136	1.0292	214.07	2451.4	558.63	92.545	1.0292	27455.	48.447
45	2	3.3135	1.0838	214.05	2538.3	555.51	92.534	1.0838	27493.	51.995
46	2	3.3134	1.9613	144.72	2582.6	471.94	62.564	1.9613	0.57776E+10	49.069

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID# MDS#	TYPE	-195 SCALED H EAD IND. #1	-800 INDUCER TOT-ST H EAD #1	-801 INDUCER TOT-ST H EAD #2	-152 FLOW 1 R ATIO IND . #1	-808 IMP STAT IC HEADR ISE	-809 XOVR U/S T-T HEA DRISE	-810 XOVR D/S TT HEAD RISE #1	-811 XOVR D/S TT HEAD RISE #2	-812 XOVR D/S TT HEAD RISE #3
1	1	-0.90213E+09	-0.36951	-0.25512	0.19632	0.18367	-2.1876	-0.93450	1.3120	1.4070
2	2	-0.56928E+09	-2.3700	-2.2676	9.2647	6.0927	-3.9228	1.2831	3.5935	3.1387
3	2	40289.	30.635	29.639	1.2772	854.07	383.35	116.54	110.76	116.55
4	1	47806.	46.494	46.757	1.2231	948.18	497.35	114.50	106.20	112.58
5	1	53028.	89.659	88.017	0.99403	1017.8	613.70	79.983	59.369	74.501
6	1	54901.	108.28	106.14	0.88237	1032.9	672.26	62.300	43.695	54.808
7	1	55175.	110.04	108.46	0.86276	1034.9	676.51	62.558	43.835	54.399
8	1	56025.	118.24	116.62	0.80198	1040.5	703.72	51.240	33.502	42.098
9	1	52506.	129.80	129.19	0.74808	1011.3	536.38	78.670	72.983	75.744
10	1	52653.	135.71	133.64	0.69193	1019.7	491.22	84.705	77.902	78.560
11	2	-0.98844E+08	58.432	58.685	1.3537	783.70	455.80	75.054	70.424	74.142
12	1	53238.	91.465	91.532	0.99432	1002.7	618.57	82.476	74.024	77.896
13	1	54516.	98.917	97.570	0.92717	1025.4	648.85	73.041	63.392	66.319
14	1	55180.	106.40	104.46	0.88239	1031.6	665.33	67.769	57.955	59.935
15	1	55532.	109.10	107.40	0.85919	1034.7	678.63	65.088	54.136	56.533
16	1	52215.	123.63	122.29	0.80243	1011.5	513.18	87.009	80.273	81.231
17	1	52197.	124.81	124.56	0.75409	1020.6	532.47	77.563	73.120	77.248
18	1	52655.	137.62	134.96	0.70070	1023.7	511.50	80.051	74.910	75.655
19	1	53156.	152.71	149.80	0.65669	1023.3	503.28	78.366	74.094	75.026
20	1	-0.15136E+10	-1.2878	-0.65082	11.953	-0.96464	-2.5363	-0.72593	1.7236	-0.88656
21	2	15410.	38.196	37.694	1.3372	377.66	151.12	37.224	33.722	33.387
22	2	-0.16918E+09	98.230	99.300	2.1195	502.07	205.90	25.246	24.693	23.764
23	2	-0.60252E+09	5.6248	5.9160	6.7096	183.67	90.495	24.260	24.015	23.530
24	2	42041.	28.768	27.781	1.2907	796.13	389.14	105.40	99.643	104.09
25	1	53167.	90.162	89.955	0.99601	1002.2	623.93	81.727	72.602	76.219
26	1	54267.	97.868	96.197	0.92719	1024.1	646.54	75.351	66.146	68.405
27	1	54896.	104.13	102.17	0.88479	1029.5	667.32	66.435	56.322	59.503
28	1	55292.	108.38	106.41	0.86277	1031.3	678.04	64.466	53.204	55.421
29	1	55907.	113.96	112.40	0.81286	1037.9	698.83	57.327	46.424	48.911
30	1	56684.	125.18	123.71	0.76268	1039.2	715.49	46.595	37.971	38.126
31	1	52435.	134.22	133.91	0.70327	1005.1	527.07	77.750	71.131	74.351
32	1	53051.	153.90	153.26	0.65564	1018.0	516.63	75.875	69.474	71.274
33	1	52868.	148.44	145.76	0.65968	1022.0	502.10	82.221	76.126	75.903
34	1	51937.	120.22	117.25	0.70188	1022.6	519.86	83.739	76.118	78.109
35	1	52195.	124.21	122.84	0.75553	1019.6	527.46	83.112	76.376	78.659
36	1	52174.	120.56	119.14	0.80334	1016.6	534.51	86.137	78.593	81.154
37	1	51947.	112.92	112.83	0.85315	1009.8	540.67	84.015	79.011	82.820
38	1	51732.	107.44	107.66	0.87815	1007.0	541.23	87.220	81.630	84.936
39	1	51423.	102.89	101.04	0.92189	1000.3	541.36	90.234	83.719	87.171

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID#		-195	-800	-801	-152	-808	-809	-810	-811	-812
		SCALED H EAD IND. #1	INDUCER TOT-ST H EAD #1	INDUCER TOT-ST H EAD #2	FLOW 1 R ATIO IND . #1	IMP STAT IC HEADR ISE	XOVR U/S T-T HEA DRISE	XOVR D/S TT HEAD RISE #1	XOVR D/S TT HEAD RISE #2	XOVR D/S TT HEAD RISE #3
MDS#	TYPE									
40	1	52102.	89.079	88.305	0.99573	1001.9	575.97	90.155	81.164	84.167
41	2	52304.	80.183	81.222	0.99068	980.65	646.77	75.082	65.671	66.354
42	2	-0.33952E+09	2.2762	2.6857	12.559	-2.0128	-1.1276	-0.55441	1.5934	-0.57587
43	2	50255.	67.942	67.559	1.0965	805.60	483.20	70.747	64.231	66.753
44	2	51807.	76.810	76.693	1.0292	877.43	538.66	72.688	66.404	69.017
45	2	50405.	66.612	66.737	1.0838	871.56	519.01	81.067	74.700	78.370
46	2	-0.22251E+09	78.376	78.117	1.9613	727.72	411.51	61.599	55.248	56.045

P/F ID#		-813	-152	-815	-816	-817	-818	-819
		STAGE T-T HEADRI SE	FLOW 1 R ATIO IND . #1	XOVR TT HEADRISE #2	PUMP TT HEADRISE	RESULTAN T AXIAL LOAD (-)	RESULTAN T AXIAL LOAD (+)	NET AXIA L LOAD
MDS#	TYPE							
1	1	-3.5303	0.19632	-0.87555	-2.6567	10409.	9845.8	562.85
2	2	-0.42128	9.2647	-0.32930	-0.92199E-01	10622.	10070.	551.10
3	2	1071.3	1.2772	494.11	577.80	54862.	57749.	-2886.8
4	1	1284.6	1.2231	603.55	681.76	62178.	64659.	-2480.7
5	1	1425.1	0.99403	673.07	752.79	68410.	70654.	-2244.6
6	1	1475.4	0.88237	715.96	760.21	70346.	72568.	-2222.4
7	1	1483.1	0.86276	720.35	763.45	70594.	72862.	-2267.9
8	1	1505.1	0.80198	737.23	768.54	71416.	73689.	-2273.1
9	1	1411.1	0.74808	609.36	802.43	69142.	71861.	-2718.9
10	1	1415.8	0.69193	569.13	847.31	69748.	72672.	-2924.1
11	2	1095.3	1.3537	526.22	569.52	54403.	56499.	-2095.4
12	1	1430.6	0.99432	692.59	738.76	67819.	70523.	-2704.6
13	1	1465.1	0.92717	712.24	753.60	69512.	71748.	-2236.2
14	1	1482.8	0.88239	723.28	760.26	70214.	72464.	-2250.5
15	1	1492.1	0.85919	732.76	760.17	70590.	72840.	-2250.2
16	1	1403.1	0.80243	593.46	810.49	68939.	71578.	-2638.9
17	1	1402.7	0.75409	605.59	797.96	69006.	71702.	-2695.9
18	1	1415.2	0.70070	586.41	829.64	69803.	72620.	-2817.6
19	1	1428.3	0.65669	577.37	851.82	70530.	73504.	-2974.4
20	1	-4.7994	11.953	-0.81272	-3.9907	10179.	9648.8	530.44
21	2	486.53	1.3372	184.84	301.96	31450.	32370.	-920.03
22	2	696.42	2.1195	230.59	466.25	40928.	42440.	-1511.9
23	2	240.72	6.7096	114.51	126.33	20222.	20367.	-144.62
24	2	1036.0	1.2907	488.78	547.85	52660.	55032.	-2371.5
25	1	1428.7	0.99601	696.53	732.94	67815.	70874.	-3058.7

AVERAGED DATA ON MEASUREMENT DATA SETS

HEADER: CROSSOVER TEST
TEST 88A097 TEST START TIME 10/10/88 14:37:48.70 PROCESS TIME 10/12/88 12:39:00

P/F ID#		-813	-152	-815	-816	-817	-818	-819
MDS#	TYPE	STAGE T-T HEADRISE	FLOW 1 RATIO IND #1	XOVR TT HEADRISE #2	PUMP TT HEADRISE	RESULTANT AXIAL LOAD (-)	RESULTANT AXIAL LOAD (+)	NET AXIAL LOAD
26	1	1458.2	0.92719	712.69	746.29	69299.	71903.	-2603.6
27	1	1475.4	0.88479	723.64	752.57	70047.	72716.	-2669.4
28	1	1485.5	0.86277	731.24	755.06	70404.	73084.	-2680.3
29	1	1502.3	0.81286	745.25	757.90	70974.	73663.	-2689.1
30	1	1523.1	0.76268	753.46	770.45	71694.	74453.	-2758.7
31	1	1408.9	0.70327	598.20	811.54	69239.	72460.	-3221.5
32	1	1425.1	0.65564	586.10	839.86	69911.	73254.	-3342.9
33	1	1420.0	0.65968	578.22	842.60	70118.	73397.	-3279.3
34	1	1395.5	0.70188	595.98	800.34	69474.	72563.	-3088.7
35	1	1402.5	0.75553	603.83	799.45	69020.	72103.	-3083.0
36	1	1401.7	0.80334	613.11	789.38	68603.	71781.	-3178.3
37	1	1396.0	0.85315	619.68	777.09	68175.	71275.	-3099.7
38	1	1390.1	0.87815	622.86	767.99	67861.	70948.	-3086.6
39	1	1381.6	0.92189	625.08	757.30	67528.	70555.	-3026.9
40	1	1400.1	0.99573	657.13	743.67	67322.	70401.	-3079.3
41	2	1405.5	0.99068	712.44	693.66	56852.	60211.	-3359.3
42	2	-1.1918	12.559	0.46576	-1.6590	10571.	10048.	523.25
43	2	1130.8	1.0965	547.44	583.82	56174.	58728.	-2553.8
44	2	1240.3	1.0292	605.06	635.86	60516.	63357.	-2841.7
45	2	1215.9	1.0838	593.71	622.88	59510.	62308.	-2798.1
46	2	1016.7	1.9613	466.76	550.71	47840.	50219.	-2378.5

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Report Documentation Page

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15. Supplementary Notes

Project Manager, G.P. Richter, Space Propulsion Technology Division, NASA-Lewis Research Center

16. Abstract

High speed, high efficiency head rise multistage pumps require continuous passage diffusing crossovers to effectively convey the pumped fluid from the exit of one impeller to the inlet of the next impeller. On Rocketdyne's Orbital Transfer Vehicle (OTV), the MK49-F, a three stage high pressure liquid hydrogen turbopump, utilizes a 6.23 velocity ratio diffusing crossover. This velocity ratio approaches the diffusion limits for stable and efficient flow over the operating conditions required by the OTV system. The design of the high velocity ratio diffusing crossover was based on advanced analystical techniques anchored by previous tests of stationary two-dimensional diffusers with steady flow. To secure the design and the analytical techniques, tests were required with the unsteady whirling characteristics produced by an impeller. A tester was designed and fabricated using a 2.85 times scale model of the MK49-F turbopumps first stage, including the inducer, impeller, and the diffusing crossover.

Water and air tests were completed to evaluate the large scale turbulence, non-uniform velocity, and non-steady velocity on the pump and crossover head and efficiency. Suction performance tests from 80% to 124% of design flow were completed in water to assess these pump characteristics. Pump and diffuser performance from the water and air tests were compared with the actual MK49-F test data in liquid hydrogen.

17. Key Words (Suggested by Author(s)) Orbital transfer Vehicle Engine; OTV; OTVE; Liquid Hydrogen Turbopump; Multi-stage pump; Diffuser; Crossover.	18. Distribution Statement Unclassified - Unlimited Subject Category 20

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