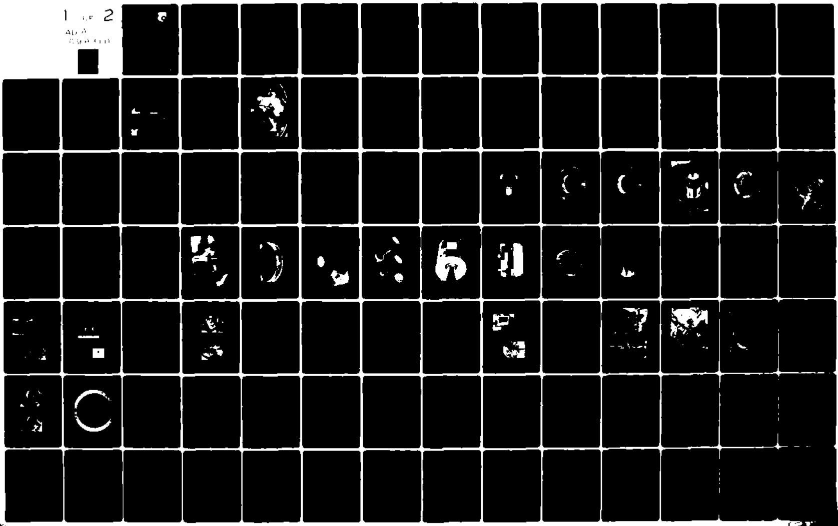
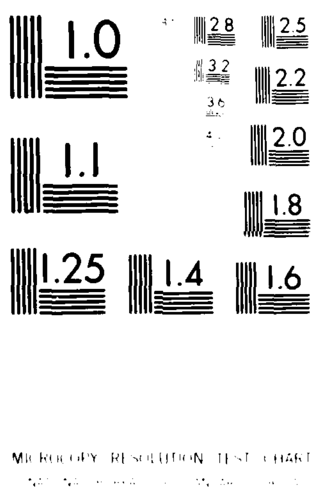
AD-A098 310 ROCKWELL INTERNATIONAL CANOGA PARK CA ROCKETDYNE DIV F/G 21/5
TURBINE WINDAGE TORQUE TESTS.(U)
JAN 81 R F SUTTON F33615-79-C-2073
UNCLASSIFIED RI/RD-80-220 AFWAL-TR-80-2123 NL

1 of 2
AD A
098310




1.0
2.8
2.5
3.2
2.2
3.6
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART

AFWAL-TR-80-2123

TURBINE WINDAGE TORQUE TESTS

R. F. SUTTON
ROCKWELL INTERNATIONAL
CANOGA PARK, CA 91304

JANUARY 1981

TECHNICAL REPORT AFWAL-TR-80-2123
Final Report for period August 1979 — October 1980

Approved for public release; distribution unlimited.

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

PHILLIP G. COLEGROVE
Project Engineer

RICHARD D. FRANKLIN, MAJOR, USAF
Chief, Power Systems Branch

FOR THE COMMANDER

JAMES D. REAMS
Chief, Aerospace Power Division
Aero Propulsion Laboratory

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/POOS, W-PAFB, OH 45433 to help us maintain a current mailing list".

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

(18) AFWAL (19) TR-80-2123

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
2. GOVT ACCESSION NO. AD-A098310
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) TURBINE WINDAGE [redacted] Torque Tests. ~~FINAL REPORT~~
5. TYPE OF REPORT & PERIOD COVERED (9) FINAL rept. (20) Augu[redacted]79 - Oct[redacted]80
6. PERFORMING ORG. REPORT NUMBER (14) RI/RD-80-220
7. AUTHOR(s) (10) R. F. Sutton
8. CONTRACT OR GRANT NUMBER(s) (15) F33615-79-C-2073
9. PERFORMING ORGANIZATION NAME AND ADDRESS
Rocketdyne Division
Rockwell International
6633 Canoga Ave., Canoga Park, CA 91304
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (16) 3145 0141 (17) 01
11. CONTROLLING OFFICE NAME AND ADDRESS
Aero Propulsion Laboratory
Wright Patterson Air Force Base
Ohio 45433
12. REPORT DATE (11) Janu[redacted]81
13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 151
15. SECURITY CLASS (of this report) Unclassified
15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Windage torque, shrouded and unshrouded turbine disc, disc friction, vane pumping, rotary torque transformer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Systems for producing high electrical power on demand include the use of a turbine/gas generator system. The power absorption by turbine windage is an important factor in determining the sizes of the vacuum pump and drive, if the turbine exhaust cavity is to be evacuated, and the size and quality of the vacuum isolation valve on the turbine exhaust system. Rocketdyne conducted windage torque tests on a MK15E3-2 turbine at speeds up to 30,000 RPM where torque contributions of shrouded and unshrouded wheels, single wheel, and bearing and seal power losses were determined at turbine cavity air

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

390199

20. pressure of 0.3 psia to atmospheric pressure (14.3 psia). Windage torque losses of the shrouded two-wheel system at atmospheric conditions represented about 2.6 percent of the overall rated turbine horsepower (155 versus 6,000 HP).

B

PREFACE

The work herein was conducted under Contract F32615-79-C-2073, Project 3145, Task 314501, Work Unit Number 31450141, for the Air Force Wright Aeronautical Laboratories from 20 August 1979 through October 1980 by Rocketdyne, a division of Rockwell International. At Rocketdyne, Mr. R. S. Siegler, Program Manager, and Mr. R. F. Sutton, Project Engineer, were responsible for the overall direction of the Turbine Windage Testing using the MK 15E3-2 turbine. Mr. P. Colegrove of the Air Force Propulsion Laboratory was the focal point for the direction and coordination of the program between the USAF and Rocketdyne.

Important contribution to the conduct of the program and to the preparation of the report material were made by the following Rocketdyne personnel.

Turbomachinery:	Mr. J. Boynton
Rotordynamics:	Mr. B. Rowan Mr. J. Hodges
Development Laboratory:	Mr. D. Butman Mr. C. Brown

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

List of Illustrations

LIST OF TABLES

SUMMARY

The objective of the Turbine Windage Torque Program was to obtain test data on windage losses on various configurations of the MK15E3-2 turbine, and to develop a method of predicting windage losses on other turbines of similar design.

The Rocketdyne Engineering Laboratory rotary dynamics vacuum test chamber, with a 0-60,000 RPM, 300 HP dynamometer, was selected as the test facility. A rotary transformer (brushless) torque sensor, using air/oil mist lubrication for the bearings and mounted between the dynamometer output shaft and the turbine, was selected. For test speeds to 30,000 RPM, the brushless rotary transformer represented the most positive, low risk system to acquire the torque data.

Modifications of the turbine and fabrication of supportive hardware for the windage tester began in September 1979 and ended with the successful accomplishment of all testing during the month of September 1980. A total of twenty-two tests were run encompassing the entire test matrix at turbine cavity pressures of from 0.3 psia to atmospheric conditions. A total of 32,810 seconds turbine run time, including in-place balance spin up, was accumulated on the windage tester system with no major problems. Considerable difficulty was experienced in the alignment of the turbine-torquemeter-dynamometer system; however, final alignment was well within the requirements. Post test examination of the spline teeth showed virtually no scuffing, or wear. Balancing of the torquemeter system also proved difficult since an unusually high residual unbalance was indicated at the normal in-place balance speed of 2,000 RPM. Empirical test results and a re-balance at 5,000 RPM resolved the problem with no further difficulties encountered throughout the test program.

The data acquired during the testing was evaluated and compared with the results of previous analysis and test investigations. Torque predictions for the turbine bearings and oil seal differed from the test values for the

no disc configuration. The previous analytical predictions were updated to more closely agree with the test torque. The turbine floating ring seal torque predictions also differed from the test derived value. Again, the predictions were updated to more closely approximate the test value. For the two-rotor tests, the test torque value averaged 98 percent higher than the updated torque predictions at 14 psia cavity pressure from the 20,000 to 30,000 RPM region. At 7 psia cavity pressure, for the same speed region, the test torque averaged 66 percent higher than the updated predictions. In the case of the single-wheel test, the test torque averaged 33 percent higher than the updated predictions at 14 psia cavity pressure and in the 20,000 to 30,000 RPM speed region. At 7 psia cavity pressure, the recorded torque averaged 11 percent higher than the updated predictions. No observable torque difference was noted between the shrouded E3 second stage wheel and the unshrouded E1 second stage wheel. The unpowered turbine power loss, including disc friction, vane pumping, bearing and seal friction at 30,000 RPM and 14 psia was approximately 2.6 percent of the total designed MK15E3-2 turbine horsepower, or 155 versus 6,000 horsepower. Based on the results of this test program, the experimentally based correlation derived by previous investigators did not adequately predict the actual observed disc friction, vane pumping, and shroud ring friction torque. Predicted torque deviated from the empirical results for the two-wheel configuration. The non-symmetrical, reaction type blading of the second rotor apparently causes greater windage losses than previously calculated when using torque coefficients from tests of symmetrical blading. The effect of the type of blading should be studied in greater detail.

Figure A presents the empirical results of the two-wheel shrouded configuration MK15E3-2 turbine for the initial test series (Tests 1-006, 1-009 and 1-010). At maximum rotor speeds (30,000 RPM), the horsepower requirement for this configuration was 155, 93 and 27 HP at cavity pressures of 14, 8 and 0.3 psia, respectively. Raw test data for the remainder of the test configurations may be found in the appendix. Turbine exhaust pressure level is a strong influence on the total windage power requirements during coast periods of an operational turbine. Methods to lower the cavity pressure, or density, will benefit the overall system operation.

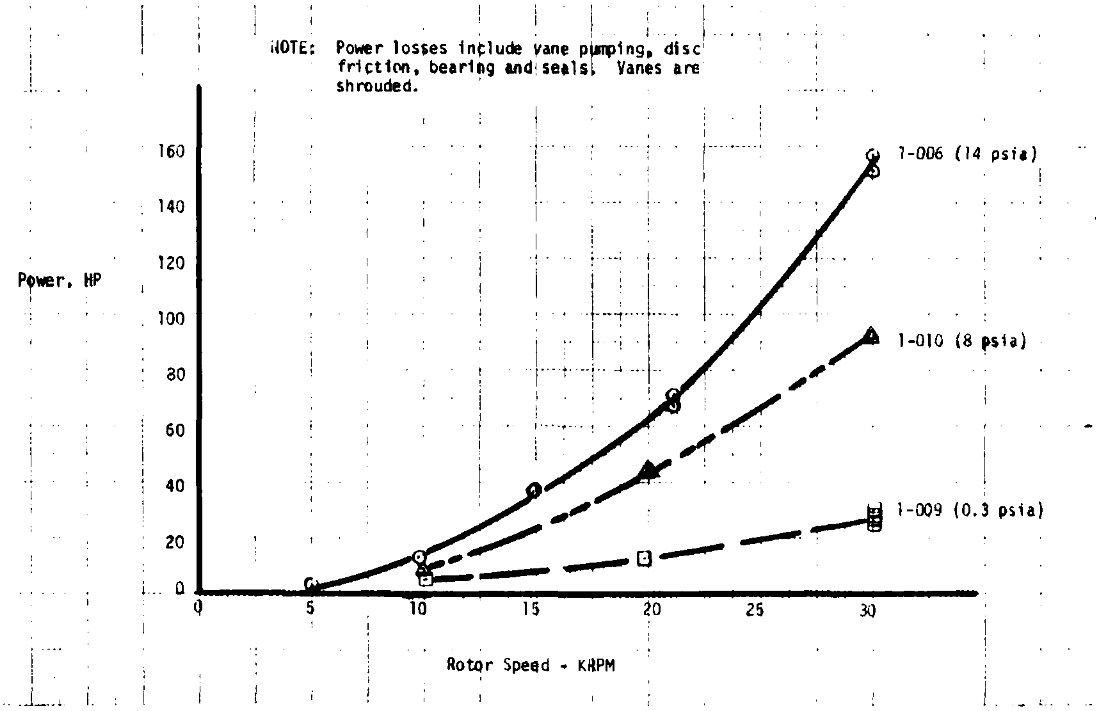


Figure A. MK15E3-2 Power Losses Summary
Horsepower versus Rotor Speed
versus Cavity Pressure

INTRODUCTION

Various methods have been proposed for rapidly producing high electrical power on demand using a turbine/generator system. One scheme is to spin the generator at operating speed, with the turbine at rest and connect the turbine to the generator by means of an overrunning clutch. The turbine can then be brought up to speed very quickly under no-load condition and engage the generator by means of the clutch. This approach requires the development of a high speed, high power overrunning clutch which may be very difficult to accomplish.

Another possibility is the concept of idling the entire turbine/generator as a unit at no-load condition by means of an electric or hydraulic motor. This approach is much more desirable than the overrunning clutch concept if the turbine windage torque is low enough to idle it at full speed. The power required to idle the system is unknown and cannot be accurately calculated analytically. The power absorption by windage is an important factor in determining the feasibility of this approach because it will determine the required size of the idling motor. It will also determine the sizes of the vacuum pump and drive, if the turbine housing is to be evacuated and the size and quality of the vacuum isolation valve in the turbine exhaust.

The objective of the windage torque program was to obtain test data on the windage losses of various configurations of the Mark 15 E3-2 (fast start) turbine and to develop a method of predicting windage losses on other turbines of similar design.

The program was divided into four tasks: Task I - Design/Analysis, Task II - Hardware Preparation 1, Task III - Testing and Task IV - Data Analysis. The program began in September 1979 with all testing conducted in September 1980.

TASK I - DESIGN/ANALYSIS

Design and analytical studies were conducted to support the test of an MK 15E3-2 turbine assembly, P/N XEOR 943562, Unit No. 2, a Government Furnished Part.

Task I effort consisted basically of three major subtasks: (1) a method had to be devised to mount and drive the turbine, (2) because of specific requirements to measure torque as a function of turbine back pressure, a method was necessary to vary and control the turbine exhaust pressure from low partial vacuum levels to atmospheric conditions and (3) incorporate a system to measure torque during turbine spin operations to 31,000 rpm.

Drive Systems and Mounting

A review of the major requirements led to the decision to drive the MK 15E3-2 turbine by an electric motor housed in the Rocketdyne Engineering Laboratory Rotary Dynamics Test facility.

The Rotary Dynamics Test Facility encompasses an area of approximately 1,000 sq. ft. with an enclosed control and instrumentation room and adjoining test cell below factory floor level test area (Fig. 1). The testing is conducted from the control room which also contains the recording equipment and visual display of selected parameters. The console in the Control Room contains the dynamometer control panel and gages and pressure regulators used in operation of the test.

Access to the test area, 12 feet below the factory floor level, is by a stairwell at the northwest corner of the area. The test chamber is cylindrical, 14 feet in diameter by 11 feet tall, with a removable domed cover and has a 2- by 4-foot oval personnel access door. Evacuation of the of the chamber is possible by two mechanical-type vacuum pumps that can reduce the entire chamber pressure to 100 mm Hg absolute in approximately 10 minutes and can maintain 400 mm Hg absolute with 0.5 lb/sec of gaseous nitrogen being injected into the chamber.

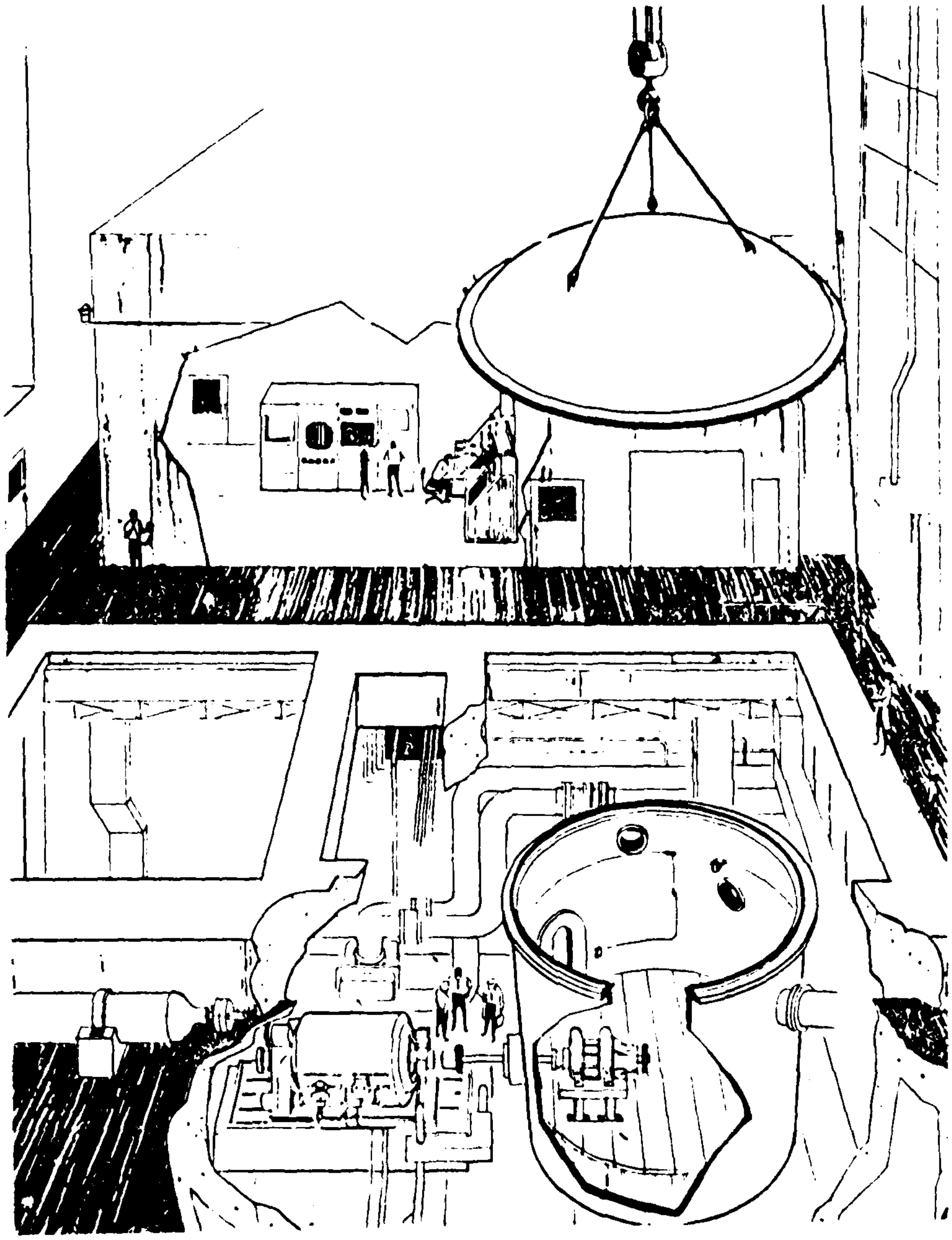


FIGURE 1. Rotary Dynamics Test Facility Schematic

The prime mover for this facility is a 300 hp, 0 to 6000 rpm, d-c dynamometer with its output shaft extended through the test chamber wall and coupled to the input shaft of a 10:1 speed increasing gearbox (Fig. 2). The gearbox output high-speed pinion shaft is coupled to the test rotating assembly with a splined shaft approximately 6 inches long to clear the gearbox assembly. Gearbox lubrication is accomplished with a recirculation system for chamber vacuum levels above 100 mm Hg (11 para) absolute and a single-pass blowdown system for chamber vacuum levels below 100 mm Hg absolute.

The Rotary Dynamics Test Facility had been successfully utilized in 1978 during diagnostic laboratory testing of the Space Shuttle Fuel High Pressure Turbine Blade Evaluation.[1] Similar speed levels and rotor masses were used during that testing.

The tester was designed with the MK15E3-2 turbine mounted with the rotor horizontal, using an in-line rotary transformer for torque measurement mounted between the turbine and the dynamometer output shaft (Figure 3). A discussion of the necessary turbine modifications and design analysis is presented below:

A. Turbine Assembly, P/N XEOR 943562 Modifications

Four basic modifications to the turbine design will be necessary to permit adapting to the Windage Torque Tester (Fig. 3):

1. Front Bearing Carrier, P/N XEOR 939902D3

   Adequate oil lubrication drainage in the tester's horizontal position requires enlargement of one of the existing drain slots. This modification will not cause any future operational problems when tested as a turbine only assembly. Figure 4 shows the modification area of the front bearing carrier.

[1]Rocketdyne Report RSS-8626 High Speed Rotating Diagnostic Laboratory Testing, R. F. Sutton, November 1978, Rockwell International.

Figure 2. Rotary Dynamics Test Chamber

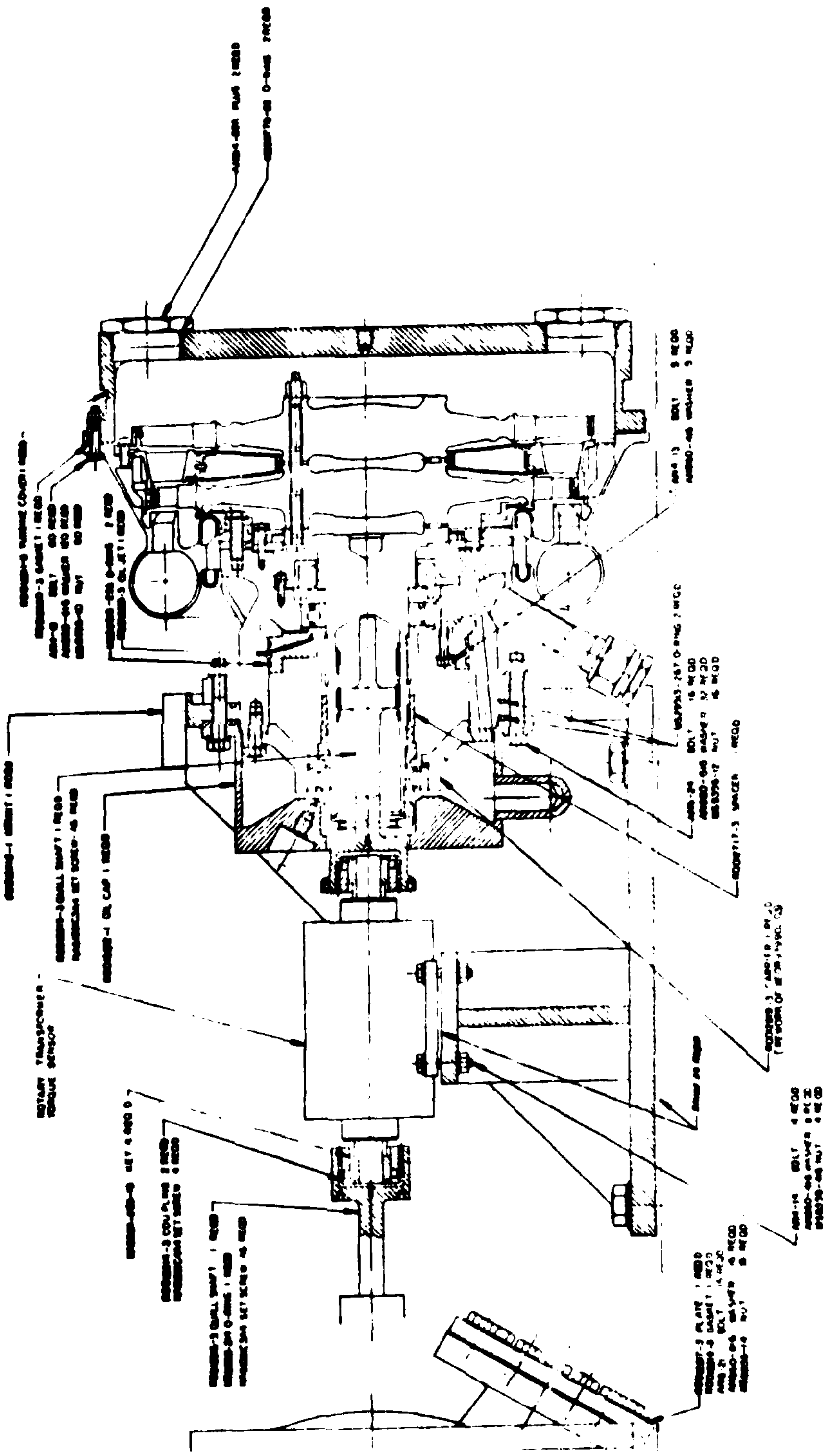


Figure 3. MK15E3-2 Windage Torque Schematic

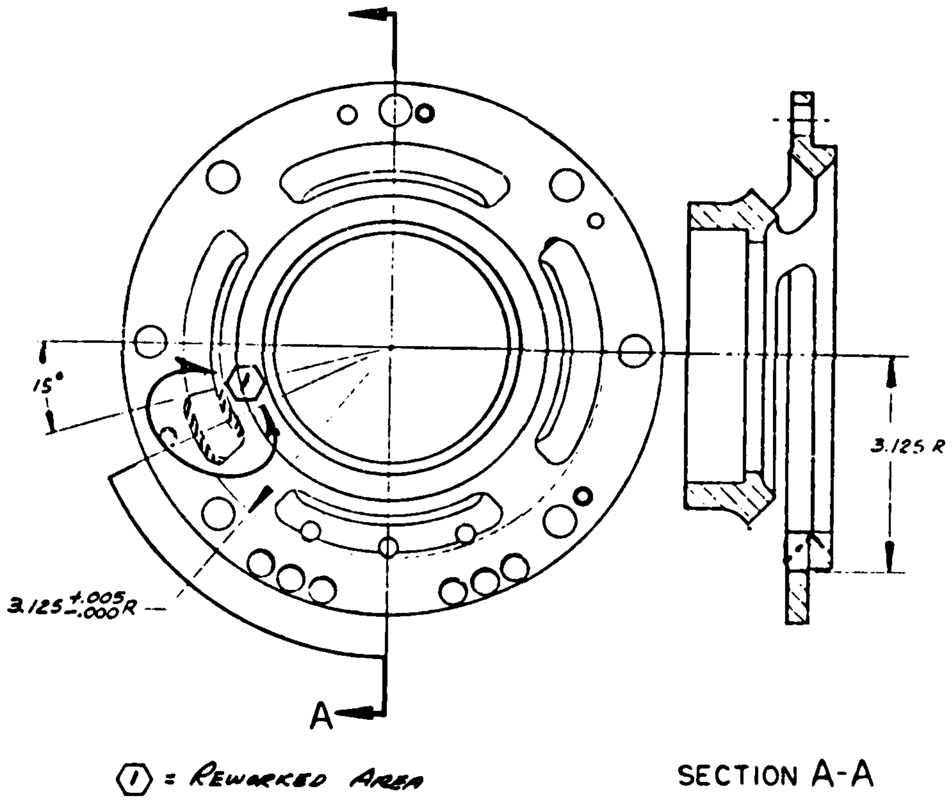


Figure 4: Front Bearing Carrier Modification

2. <u>Bronze Thrust Washer, P/N XEOR 939903D1</u>

The bronze thrust washer must be removed from the assembly to lower the required torque necessary to rotate the turbine. The high torque requirement inherent with the installed bronze thrust washer would mask the actual windage torque caused by the turbine wheels.

3. <u>Turbine Bearing Oil Jet Assembly, P/N XEOR 939902D3</u>

At the same time the bronze thrust washer is removed, a replacement oil jet assembly must be installed. Without the thrust washer, oil lubrication of the bearings would not be effective since leakage from the oil transfer tubes would prevent adequate bearing lubrication flow. The replacement oil jet assembly would be patterned from the original jet assembly except three jets of 0.055 inch diameter in place of the single jet will be used to assure adequate oil lubrication in the horizontal position. Control of the upstream pressure will permit a large variation in the bearing flow (0-2 GPM), as required, to maintain bearing temperatures below 150°F.

4. <u>Runner, P/N XEOR 939902D9</u>

In spite of the drainage modification to the front bearing carrier (see Item 1 above), a possibility exists that oil will accumulate in the runner area and will contact the outer diameter of the runner during operation. Foaming of the oil with additional drag caused by contact with the runner requires the runner to be replaced with a spacer. A design similar to the balance spacer, P/N XEOR 939921D2, will be used to provide the required axial pre-load on the bearings. Actual runner width was measured (2.197 inches) to assure the correct pre-load afforded by the new spacer. The runner can be replaced with a spacer since stack balancing (component by component) procedure was used in the balancing of the MK-15E3-2 turbine. That is, the runner was balanced after installation on the balanced shaft. The turbine wheels were added and the final balance made at the planes of the 1st and 2nd stage turbine wheel.

B. Mount Assembly, P/N R0012810

In order to mount the turbine in the horizontal position, a mount was designed to attach to the 16-hole bolt-circle flange of the XEOR 939902D10 turbine carrier assembly. The mount is attached to a large mass base (Kirtsite) of the test cell by bolting. Shimming, if required, is provided between the base plate and the base. (See assembly drawing, P/N R0012809.) In addition, the rotary transformer torquemeter is mounted at a pad provided on the mount with shimming provided, if required.

C. Front Bearing Oil Cap, P/N R0012812

Lubrication of the front bearing and oil drain provisions from both bearings necessitated the design of the front bearing oil cap. Three lube jets of 0.055 inch diameter each are provided, similar to the turbine bearing oil jet assembly, and will supply about 0.5 gpm per jet at 100 psig supply pressure. The front bearing and turbine bearing oil supply is a common source with individual oil jet flow measurements. A one-inch diameter drain base is provided to drain the estimated 3 gpm maximum lubrication oil flow. To enhance draining, the cavity drain line is attached to a scavenge pump of 5 gpm capacity.

D. Quill Shafts (Drive P/N R0012816; Turbine P/N R0012815)

Each quill shaft has been designed for minimum mass (aluminum) and best fit alignment to minimize wear on the torquemeter bearings (two per torquemeter). Two additional critical speeds appear in the test system with the addition of the torquemeter. A detailed discussion of the system rotordynamics is discussed later.

E. Turbine Cover, P/N R0012311

One of the major design considerations was the ability to control the turbine back pressure and monitor windage heating. A simple solution was to adapt a steel cover to the bolt circle of the turbine exhaust flange. The cover is designed with two large threaded posts (2.2 inch diameter) at the outer diameter. At partial vacuum conditions, one port is capped (bottom) while the other port (top) is connected to the facility vacuum pumping system by a one-inch diameter Cres line through a heat exchanger and then through a flow control valve. Steady partial vacuum levels within the turbine exhaust cavity can be maintained. The heat exchanger was added to cool the heated exhaust air to prevent damage to the soft seat material of the flow control valve. At atmospheric conditions, both large ports are opened to provide free flow of atmospheric air. The steel cover, although very heavy, was chosen to provide adequate stress margin for the expected 1000°F windage heating temperature. Instrumentation bosses were added to permit pressure and temperature profiles across the turbine disc diameter.

Torquemeter Selection

Selection of the torquemeter was made based on analytical calculation of the expected torque which set the required torquemeter range and the most reliable type to withstand the projected high speed operation with minimum risk to operation and data acquisition. In the final selection, two rotary torquemeter transformers (brushless) of 100 and 500 in-lb torque ranges were selected from Lebow Associates, Inc. of Troy, Michigan. Special air/oil mist lubrication for the Model 1604-100 (100 in-lb) and Model 1604-500 (500 in-lb) torquemeter bearings was included with the purchase order. In addition, since prolonged operation at the 30,000 RPM level was anticipated, special thermocouple insertion ports in the outer case of the torquemeter housings were requested to permit installation of 1/16-inch diameter thermocouples. As a speed backup system, the speed sensor option was also requested from Lebow for each torquemeter. A magnetic pickup sensor detects speed by a 60-tooth gear installed on the torquemeter shaft within the housing. Signal conditioning and readout capability is provided by the Lebow Model 7540 signal conditioner which is specifically suited for these torquemeter models. Expected windage torque was calculated to be between 90-150 in-lb plus bearing and seal torque (perhaps 50 in-lb); therefore, the 500-in-lb range model was selected for the tests determining wheel/vane pumping torque while the 100 in-lb range model was selected to monitor tests when bearing and seal torque was to be determined.

Rotordynamic Analysis

Once the turbine mounting, torquemeter selection and coupling arrangements were defined, a rotordynamics analysis was accomplished to determine the critical speed(s) of the system. A series of design-analysis-redesign effort was accomplished to eventually arrive at the most reliable and stable rotor system. An existing rotordynamic analysis model was modified to correspond to the turbine windage tester design (reference Figure 3). Figure 5 shows a schematic of the three test configurations (two discs, end disc replaced and both discs replaced) along with the corresponding system analytical model.

Referring to the Figure 5 schematics, the MK15E3-2 Windage tester in its three configurations will be tested with both turbine discs, with the outer disc replaced with a mass, and with both discs replaced with a mass. The existing model was updated to incorporate these and other minor changes to the shaft. The torquemeter has been modeled in two configurations for comparison. The 500 in-lb torquemeter has a "square" cross-section where strain gages are attached while the 100 in-lb torquemeter has a "squirrel cage" section. The couplings have been modeled as unlocked, utilizing moment releases at appropriate model nodes. This analysis assumes an aluminum quill shaft. Red-line values for the test were chosen on the peak deflections of the torquemeter shaft. This is required because the critical speeds of the torquemeter shaft are the ones which will ultimately damage the torquemeter. Referring to Figure 8, the shaft was analytically loaded statically and maximum displacements were obtained for both assumed bearing spring rates. Figure 9 is a plot of bearing load vs. torquemeter displacement. Actual torquemeter shaft displacement red-line recommendation is 0.016 inch radial displacement. Mode shapes are shown for a typical case in Figures 6 and 7 and remain typical for all cases except for changes in displacement amplitude. Comparative results of the six configurations are tabulated in Tables 1 through 6.

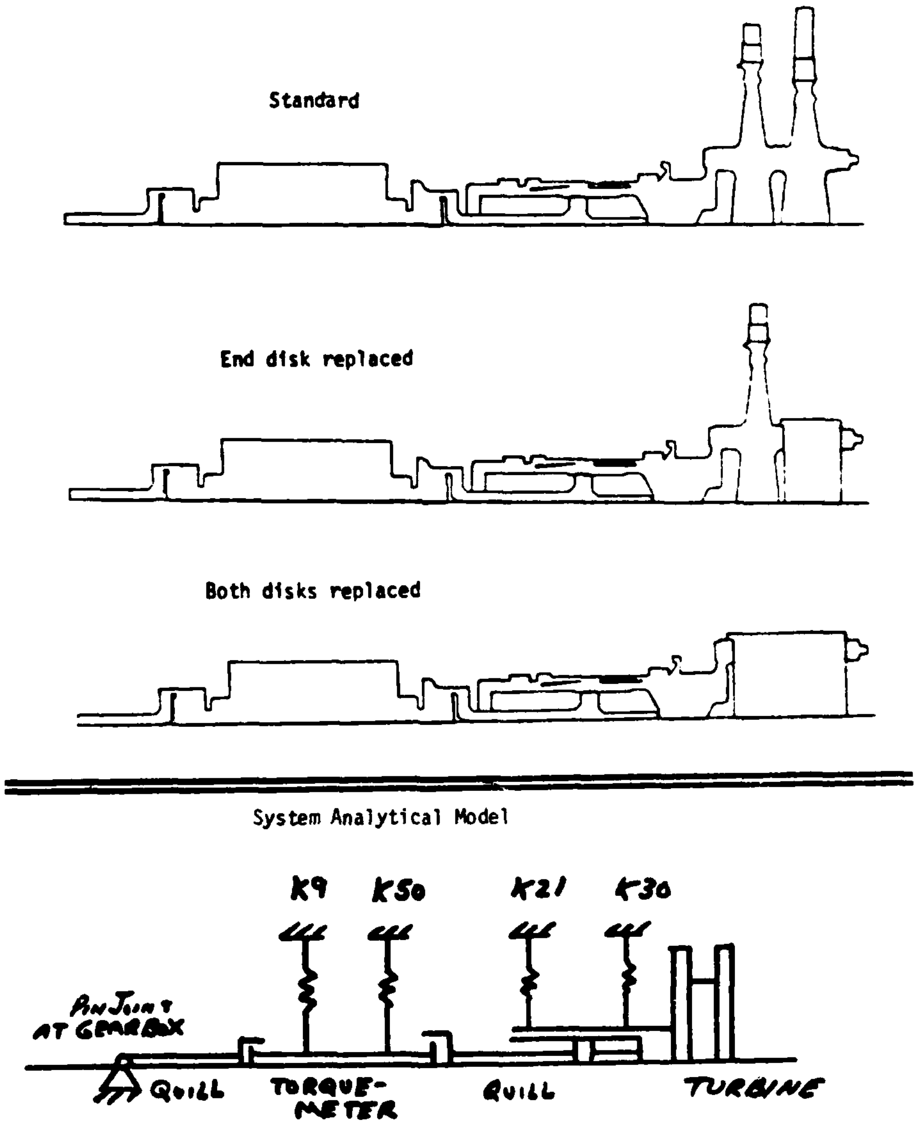


FIGURE 5. MK15E3-2 Windage Test Configurations

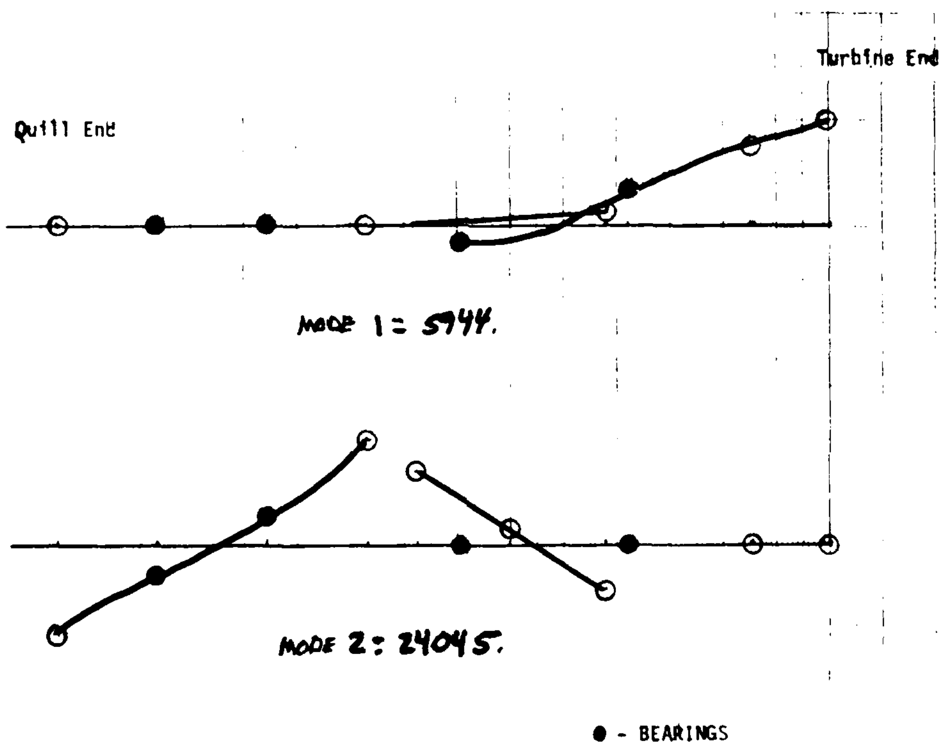


FIGURE 6. MK15E3-2 Mode Shapes

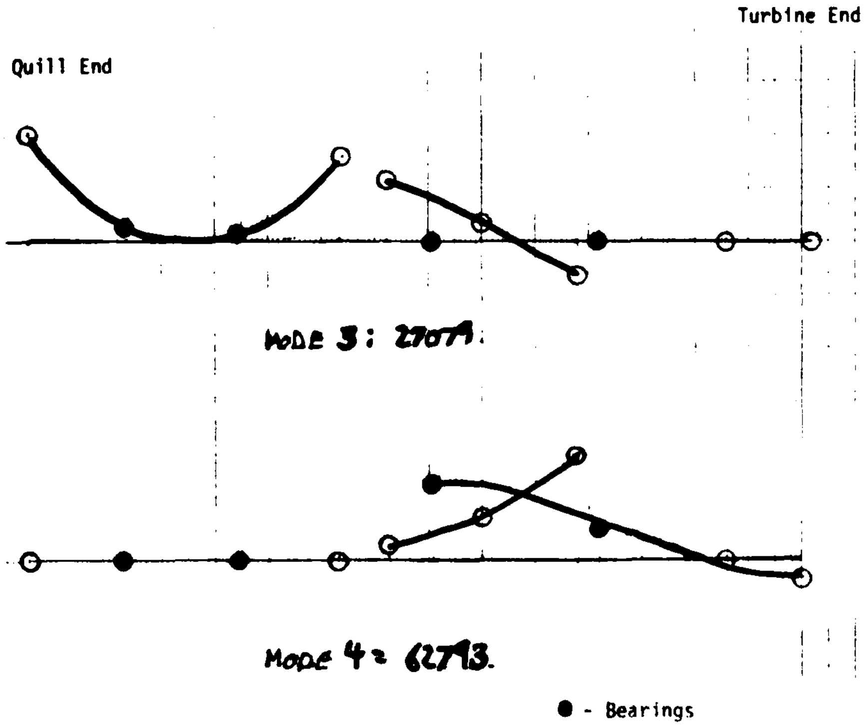


FIGURE 7. MK15E3-2 Mode Shapes

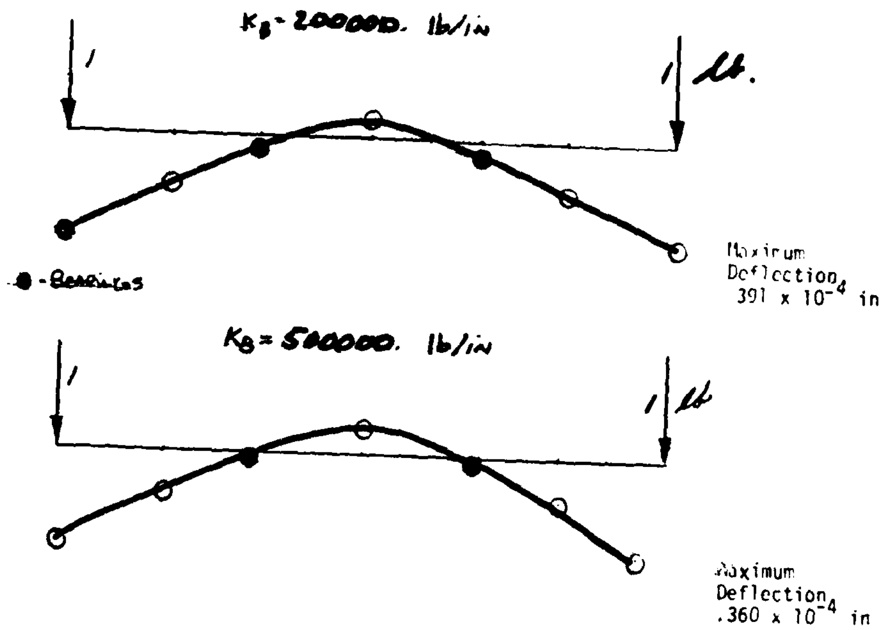


FIGURE 8. MK15E3-2 Quill Shaft Deflection

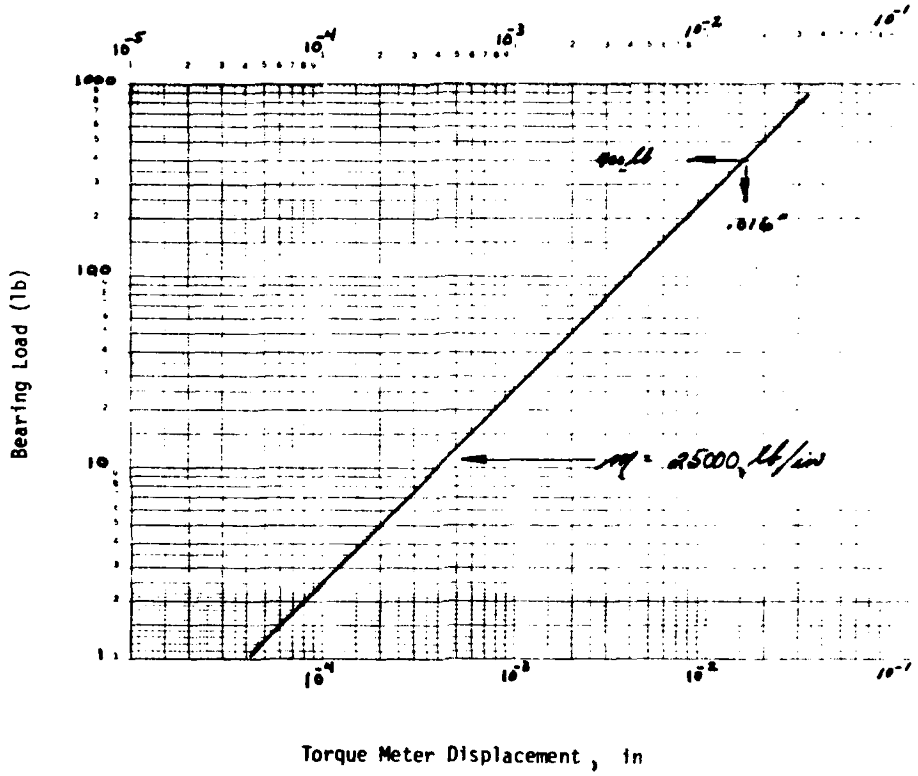


FIGURE 9. MK15E3-2 Torque-Meter Displacement vs Load

BRG STIFFNESS X 10^{-6}				CRITICAL SPEED (RPM)			
K_9	K_{50}	K_{21}	K_{30}	N1	N2	N3	N4
0.2	0.2	0.2	0.2	5157	24045	27079	76680
0.2	0.2	0.5	0.5	7927	24045	27079	82143
0.2	0.2	1.0	1.0	10734	24045	27079	821[illegible]
0.5	0.5	0.2	0.2	5157	28274	34371	76680
0.5	0.5	0.5	0.5	7927	28274	34371	97164
0.5	0.5	1.0	1.0	10734	28274	34371	97985

NOTE: Square TM, alum. quill, unlocked

TABLE 1. Bearing Stiffness versus Critical Speed, Standard Case - 500 in-lb Torquemeter

BRG STIFFNESS X 10^{-6}				CRITICAL SPEED (RPM)			
K_9	K_{50}	K_{21}	K_{30}	N1	N2	N3	N4
0.2	0.2	0.2	0.2	5157	24276	36679	76680
0.2	0.2	0.5	0.5	7927	24276	36679	93[illegible]
0.2	0.2	1.0	1.0	10733	24276	36679	93194
0.5	0.5	0.2	0.2	5157	39904	40855	76680
0.5	0.5	0.5	0.5	7927	39904	40355	97193
0.5	0.5	1.0	1.0	10733	39904	40855	98021

NOTE: Squirrel cage TM, alum. quill, unlocked.

Table 2. Bearing Stiffness versus Critical Speed, Standard Case - 100 in-lb Torquemeter

BRG STIFFNESS X 10^{-6}				CRITICAL SPEED (RPM)			
K_9	K_{50}	K_{21}	K_{30}	N1	N2	N3	N4
0.2	0.2	0.2	0.2	5944	24045	27079	62793
0.2	0.2	0.5	0.5	9140	24045	27079	82149
0.2	0.2	1.0	1.0	12380	24045	27079	82149
0.5	0.5	0.2	0.2	5944	28274	34371	62793
0.5	0.5	0.5	0.5	9140	28274	34371	92135
0.5	0.5	1.0	1.0	12380	28274	34371	97929

NOTE: Square TM, alum. quill, unlocked.

TABLE 3. Bearing Stiffness versus Critical Speed,
End Disc Replaced - 500 in-lb Torquemeter

BRG STIFFNESS X 10^{-6}				CRITICAL SPEED (RPM)			
K_9	K_{50}	K_{21}	K_{30}	N1	N2	N3	N4
0.2	0.2	0.2	0.2	5944	24276	36678	62793
0.2	0.2	0.5	0.5	9140	24276	36672	42078
0.2	0.2	1.0	1.0	12380	24276	36673	93193
0.5	0.5	0.2	0.2	5944	34904	40855	62794
0.5	0.5	0.5	0.5	9140	34904	40855	92133
0.5	0.5	1.0	1.0	12380	34904	40855	97965

NOTE: Squirrel cage TM, alum. quill, unlocked.

TABLE 4. Bearing Stiffness versus Critical Speed,
End Disc Replaced - 100 in-lb Torquemeter

BRG STIFFNESS X 10^{-6}				CRITICAL SPEED (RPM)			
K_9	K_{50}	K_{21}	K_{30}	N1	N2	N3	N4
0.2	0.2	0.2	0.2	6183	24045	27079	44546
0.2	0.2	0.5	0.5	9446	24045	27079	6[illegible]779
0.2	0.2	1.0	1.0	12674	24045	27079	82149
0.5	0.5	0.2	0.2	6183	28274	34371	44546
0.5	0.5	0.5	0.5	9446	28274	34371	63779
0.5	0.5	1.0	1.0	12674	28274	34371	93168

NOTE: Square TM, alum. quill, unlocked.

TABLE 5. Bearing Stiffness versus Critical Speed, Both Discs Replaced - 500 in-lb Torquemeter

BRG STIFFNESS X 10^{-6}				CRITICAL SPEED (RPM)			
K_9	K_{50}	K_{21}	K_{30}	N1	N2	N3	N4
0.2	0.2	0.2	0.2	6183	24276	36678	44546
0.2	0.2	0.5	0.5	9446	24276	36678	6[illegible]
0.2	0.2	1.0	1.0	12674	24276	36679	92920
0.5	0.5	0.2	0.2	6183	34903	40854	44547
0.5	0.5	0.5	0.5	9446	34904	40855	63779
0.5	0.5	1.0	1.0	12674	34904	40855	93171

NOTE: Squirrel cage TM, alum. quill, unlocked

Table 6. Bearing Stiffness versus Critical Speed Both Discs Replaced - 100 in-lb Torquemeter

Referring to Tables 1 through 6, note that the lowest torquemeter mode is slightly above 24,000 RPM. Adhering to a 20% margin on the critical speed to account for magnification factors on bearing loads, the maximum safe running speed is found to be 20,000 RPM. However, this system has been modeled with loose couplings. As bending occurs, the couplings will tend to lock up and stiffen the shaft, perhaps raising this mode above 30,000 RPM. In addition, the relative latitude in bearing stiffness and torquemeter configuration impose a difficulty in characterizing system criterion. Once empirical test data is obtained, more accurate estimations of the bearing support stiffnesses are possible.

Because of the uncertainty of the system bearing support stiffnesses, no attempt would be made to dwell within plus or minus 20 percent of the 1st, 2nd or 3rd critical speed regions during the initial test attempts. Once the critical speeds and bearing stiffnesses are determined (by empirical results and analysis), the test dwell speeds can be closely controlled to reduce operational interference of any system critical speed.

Additional stress analysis was accomplished to define the maximum speed ramps with respect to both torquemeter configurations.

As presented earlier, the maximum allowable radial deflection at the ends of the torquemeter shaft is 0.016 inches. This deflection is measured from the original (non-rotating) shaft axis. This allowable deflection is based on the third mode shape (see Figure 7). The critical failure mode condition is high cycle fatigue of the shaft.

The maximum allowable torque that can be transmitted through the two torquemeter configurations and the corresponding maximum rotating acceleration is presented below. The minimum time to decelerate the turbine from 30,000 RPM to zero RPM, assuming constant deceleration (constant torque), is also presented.

Torquemeter Configuration (in-lb)	Maximum Allowable Torque (in-lb)	Factor of Safety	Maximum Allowable Acceleration (RPM/sec)	Maximum Allowable Deceleration Time (sec)
100	200	2.2	380	34.
500	2100	4.2	8400	3.7

Maximum possible deceleration of the facility dynamometer from 30,000 to zero is about 7 seconds. No problem is anticipated with the 500 in-lb torquemeter in the event of an emergency stop command, but caution must be exercised in the acceleration or deceleration of the 100 in-lb torquemeter.

TASK II - HARDWARE PREPARATIONS

Hardware preparations for the program began in September 1979 with the retrieval of the MK15E3-2 turbine assembly, P/N XEOR 943562, from storage. Previous history of this assembly included testing in 1977 as part of the Fast Start Turbine Project using a hydrazine gas generator to power the turbine. The turbine incorporated 37 inlet nozzles in place of the previously tested 41 to raise the turbine blade torsional mode resonance speed. A total test time of 9 tests for 37.4 seconds was accumulated during the Fast Start Project at a maximum speed of 31,800 RPM. Following that test program, the turbine was placed in storage at Rocketdyne without being disassembled.

The turbine assembly was partially disassembled for the Windage test program to remove the thrust washer and runner and to replace the oil jet assembly which becomes inoperative due to the removal of the washer and runner. A close examination of the turbine end bearing revealed some flaking of the bearing cartridge silver plate. The silver flakes were removed by flushing with oil. The relatively soft silver acts as a seating agent as the balls run-in, and the amount of flaking observed is not sufficient to impair the operation of the bearing.

The turbine was re-assembled using the replacement bearing spacer, P/N R0012717 (Figure 10), the oil jet, P/N R0012813 (Figures 11 through 13), and the modified front bearing carrier, P/N R0012819 (Figure 15). During the ambient push-pull bearing load versus travel tests (Figure 15), an additional shaft travel of about 0.008 inch was noted toward the turbine that had not been recorded during the previous build (Fast Start Program). The resulting total shaft travel was recorded at 0.024 inch for a $\pm$ 1000 pound applied load. The additional travel is attributed to the removal of the thrust washer and runner which controls total travel of the shaft to limit the load on the turbine end bearing. The amount of travel experienced on this build (Windage torque testing) will not damage or limit use of the bearings. The results of the push-pull tests are shown in Figure 16. Complete build records were maintained during the assembly, including dimensional stacks. The turbine rotational

4LC43-10/25/79-C1A

Figure 10. Runner Replacement

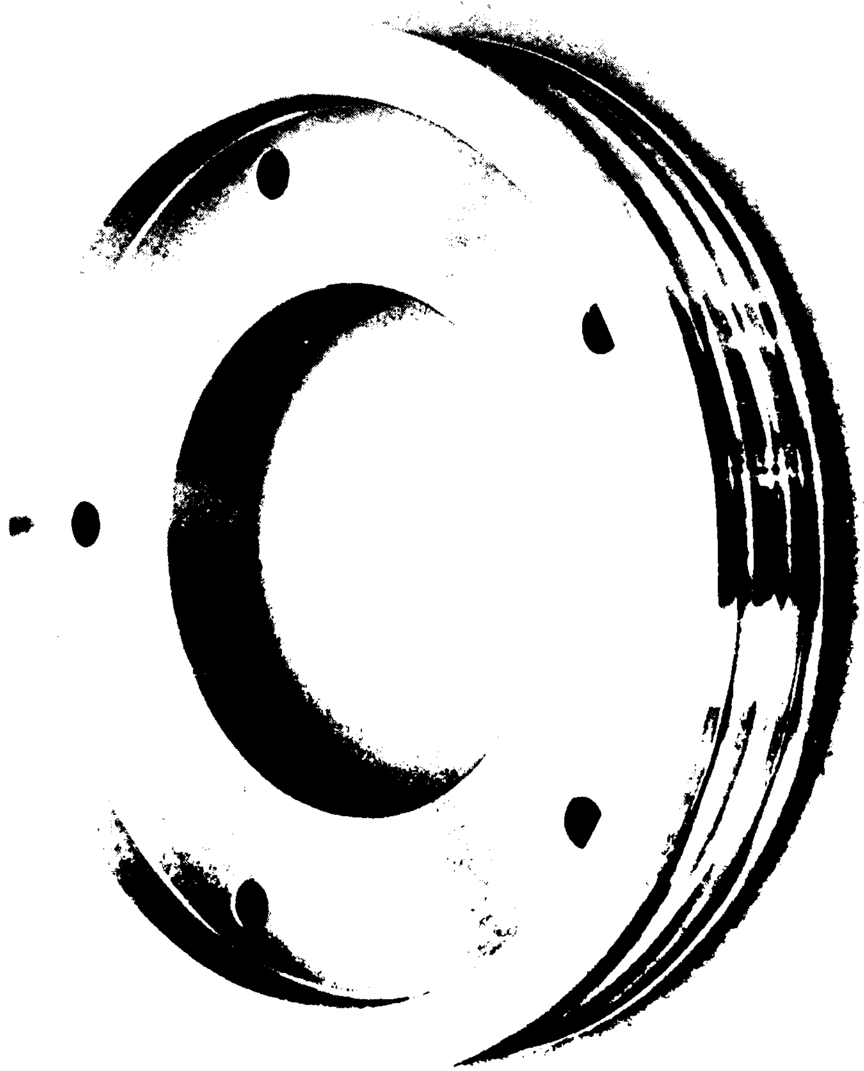


Figure 11. Turbine Bearing Oil Jet, View A

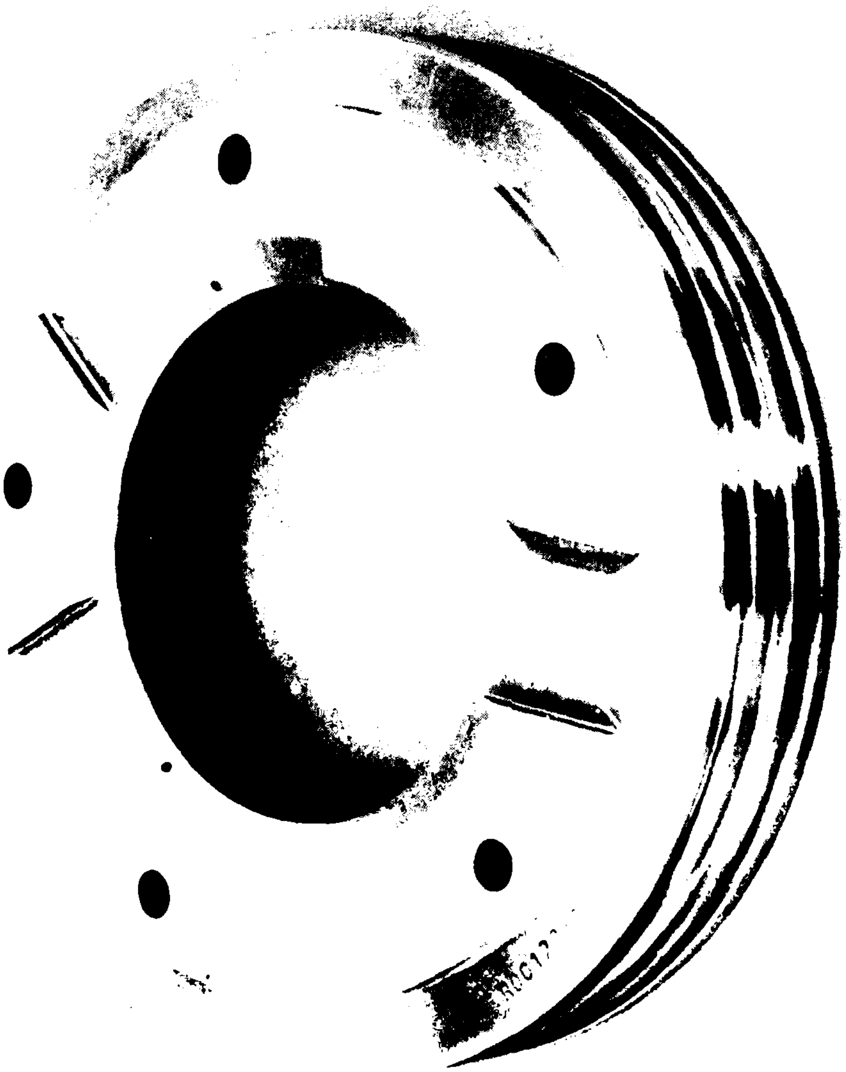


Figure 12. Turbine Bearing Oil Jet, View B

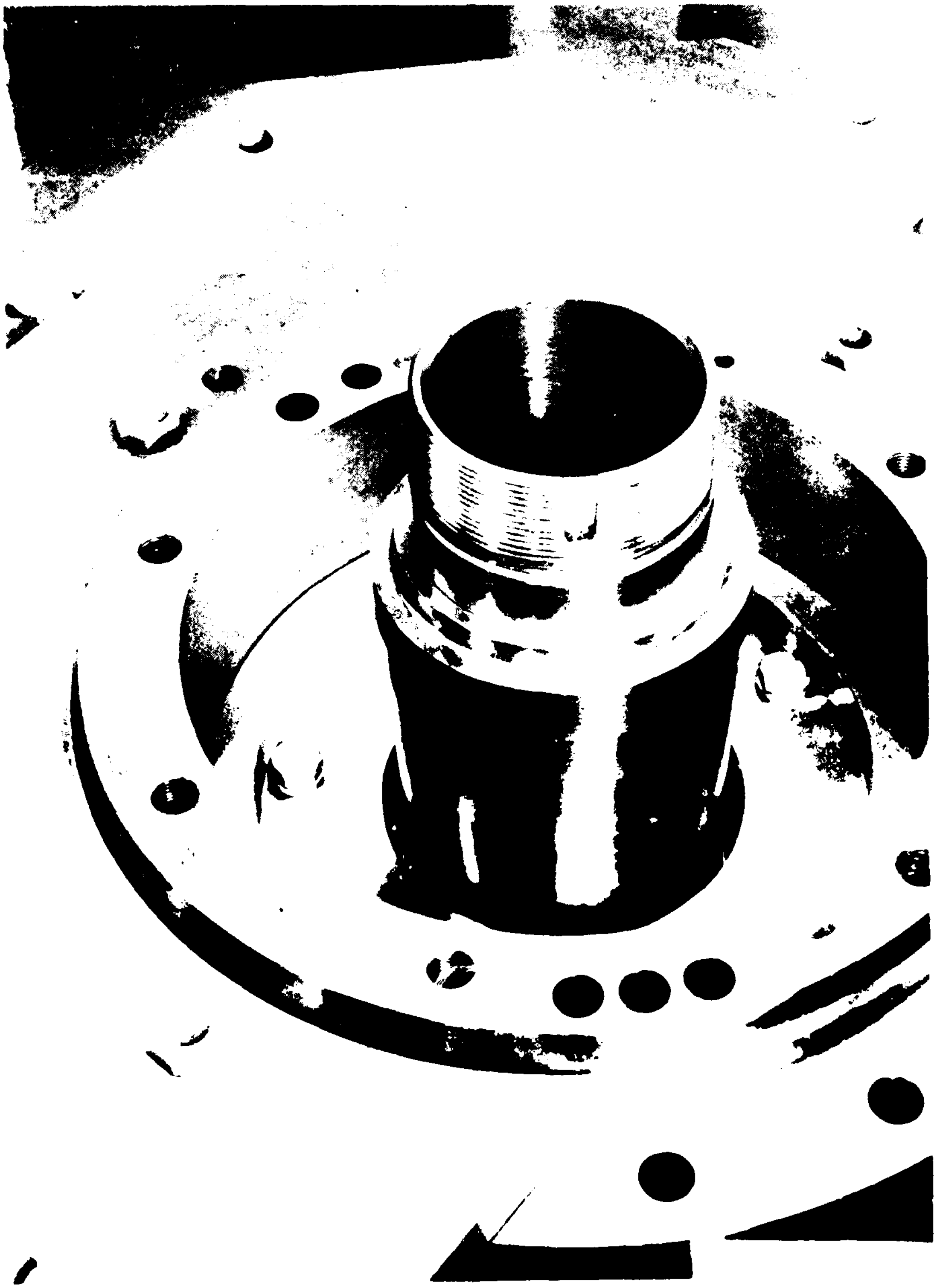


Figure 13. Runner/Turbine Bearing Oil Jet Installation

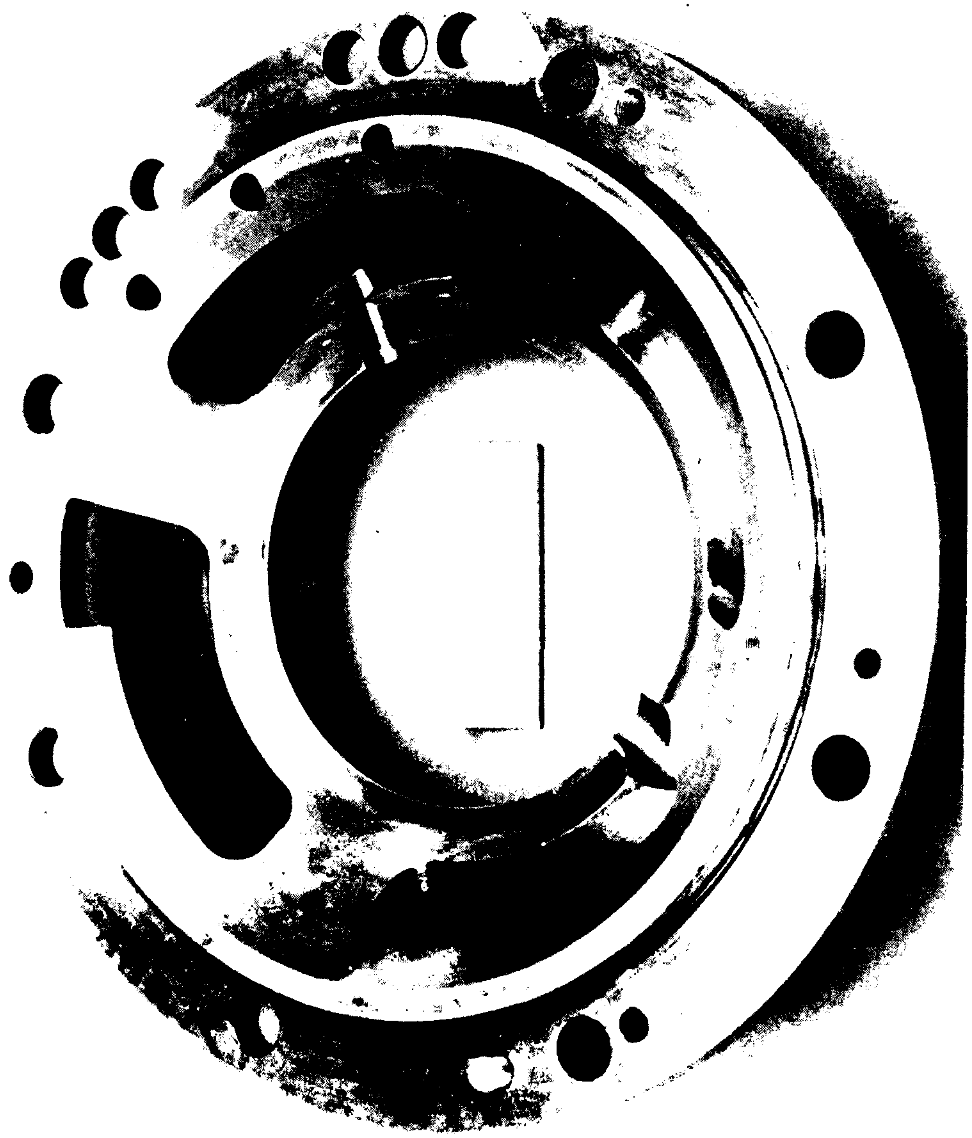


Figure 14. Rear Bearing Carrier

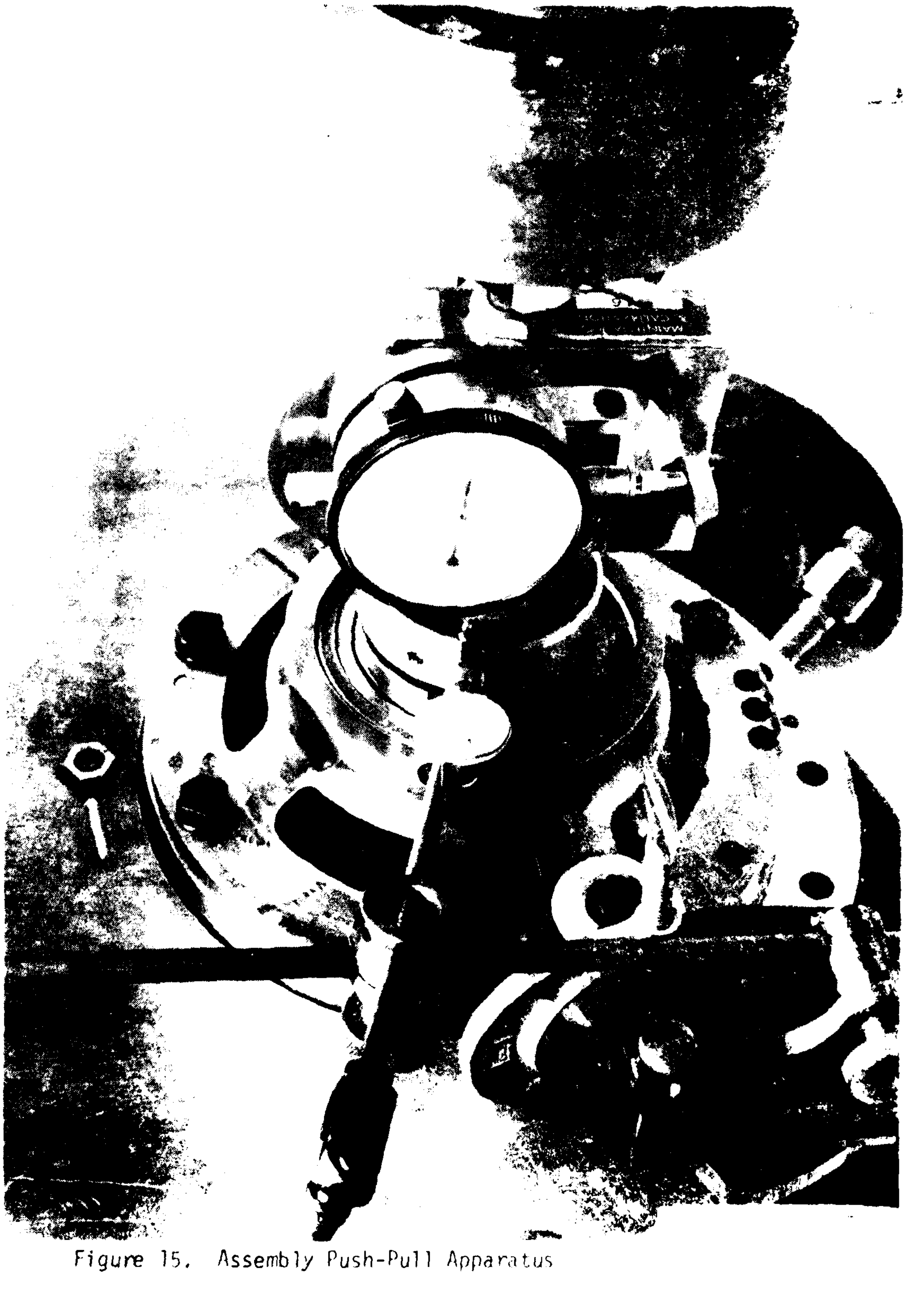


Figure 15. Assembly Push-Pull Apparatus

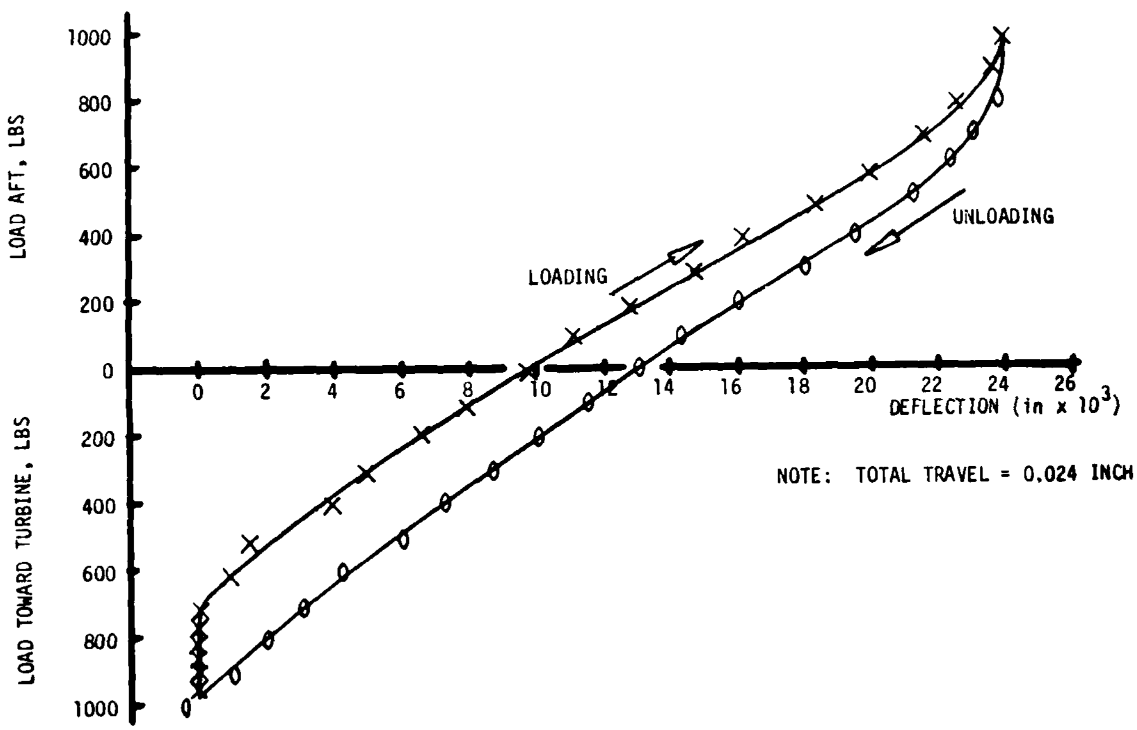


FIGURE 16. Turbine Assembly Push-Pull Results

breakaway torque was 10-20 in-lbs with a running torque of 5-10 in-lbs.

Hardware to support the Windage torque testing was ordered from three outside vendors: APV Manufacturing (majority of the tester hardware), Grove Gear (quill shafts and quill shaft adapters) and Lebow Associates, Inc. (torquemeters and Signal Conditioning Unit). Delivery of all the hardware on time was the only significant problem experienced during the program. The quill shafts and quill adapters were received only ten days behind schedule, but dimensional discrepancies precluded their use without rework by the vendor.

The quill shafts and spline adapters were re-machined by Grove Gear to correct out of tolerance pilot fits between the quill shafts and the spline adapters. Actual dimensions of the pilots (see drawings P/N R0012814, R0012815 and R0012816) were not per print but the fit-up dimensions were held (i.e., diametral clearance dimension was maintained).

No problems were anticipated with the change in actual diameters as long as the same pilot fit was maintained.

Table 7 presents the Windage torque tester hardware manufactured for the program. The assembly drawing is supplied as Appendix A of this report with actual photographs shown in Figures 10 through 24. Copies of the individual drawings are available at Rocketdyne.[2]

---

[2]Copies available from Rocketdyne Division of Rockwell International, 6633 Canoga Ave., Canoga Park, CA 91304, Attention: R. F. Sutton

Part Number	Part Name	Manufactured by	Figure (Photograph)
R0012717	Spacer	Rocketdyne	10
R0012810	Mount	APV	17
R0012811	Turbine Cover	APV	18
R0012812	Oil Cap	APV	19
R0012813	Oil Jet	APV	11 & 12
R0012814	Couplings	Grove Gear	20
R0012815	Foward Quill	Grove Gear	20
R0012816	Drive Quill	Grove Gear	20
R0012817	Cover Plate	APV	No photo
R0012819	Bearing Carrier	Rocketdyne	14
Model 1604-500	Torquemeter	Lebow Associates	21 & 22
Model 1604-100	Torquementer	Lebow Associates	See Figures 21 & 22
Model 7540-104	Signal Conditioner	Lebow Associates	No photo
EWR 405602D1	2nd Stage Disc Replacement	Rocketdyne	23
EWR 405602D2	1st 2nd Stage Disc Replacement	Rocketdyne	24
EWR 341813	Accelerometer Mounts	Rocketdyne	No photo

TABLE 7. MK15E3-2 Turbine Windage Torque Hardware

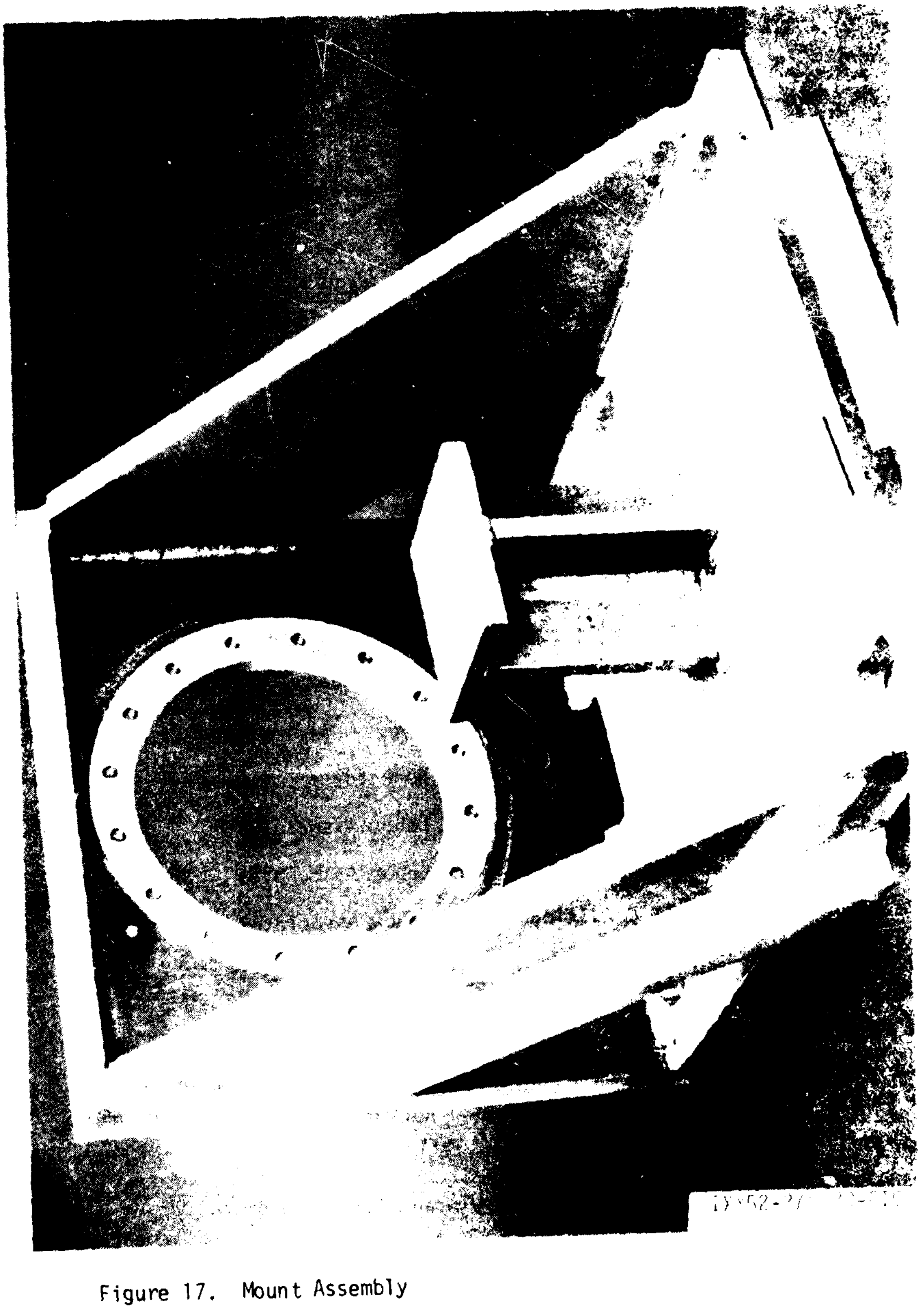
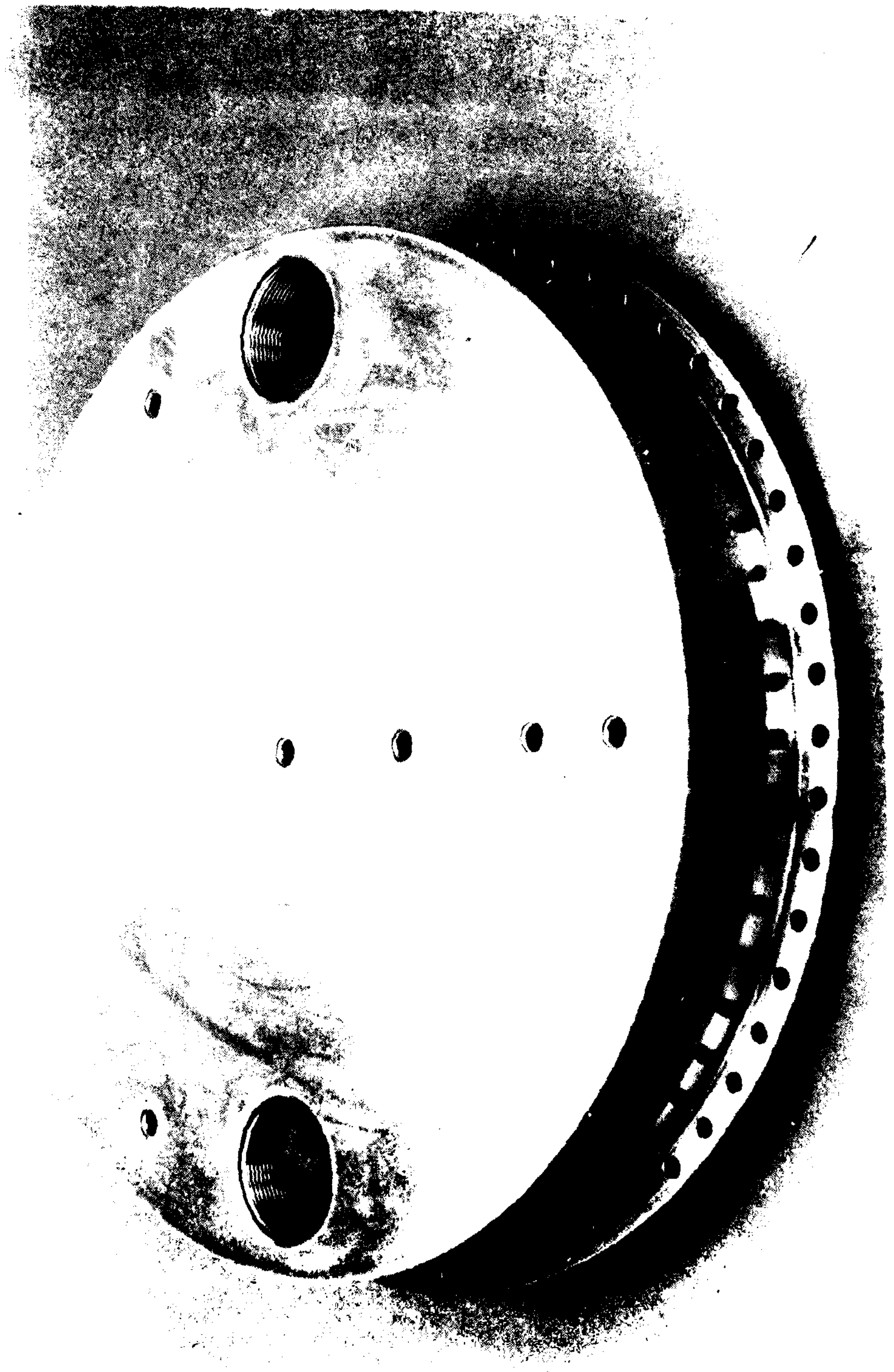


Figure 17. Mount Assembly



IXY52-2/8/80-CIB

Figure 18. Turbine Exhaust Cover

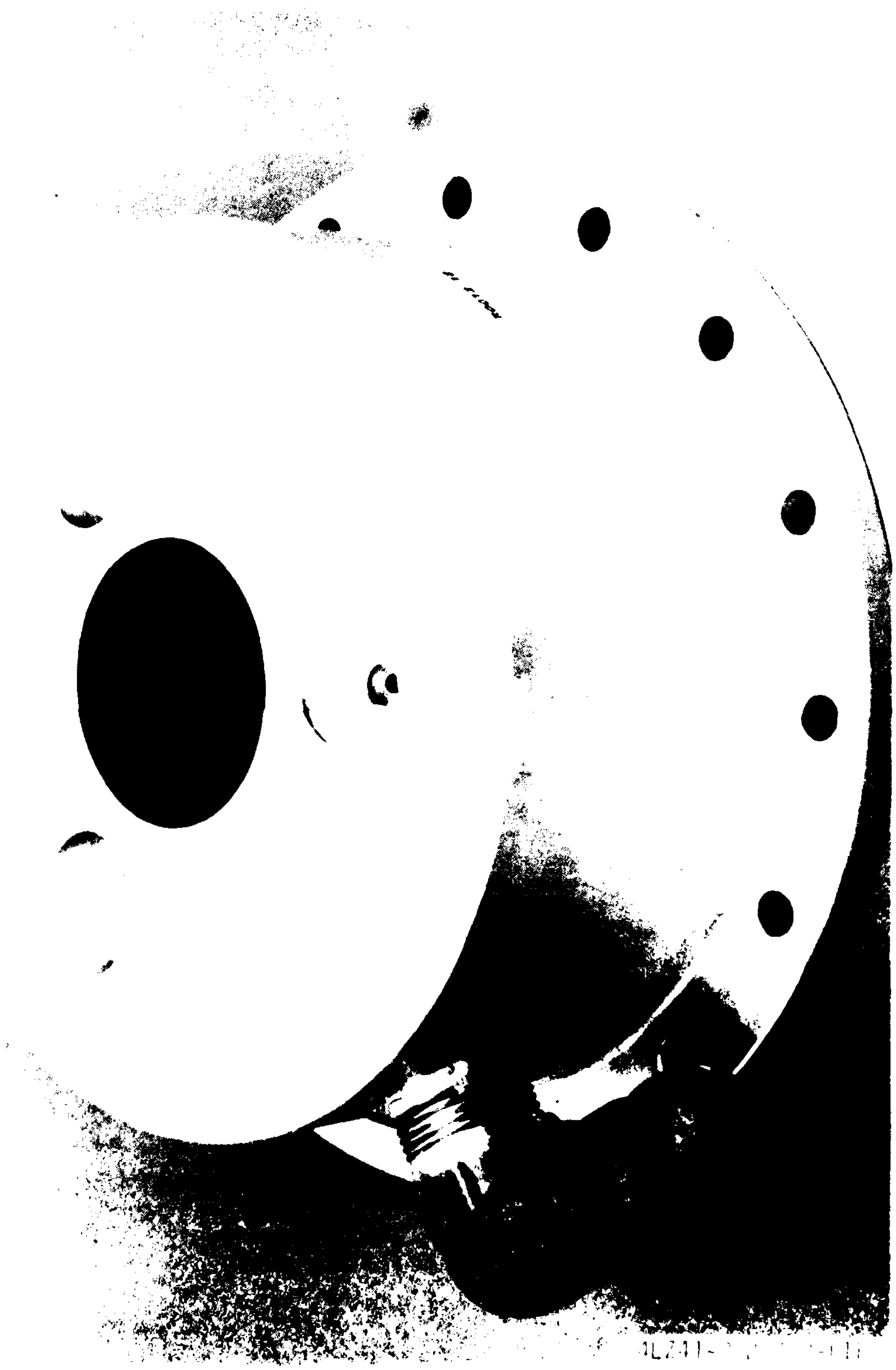


Figure 19. Rear Bearing Cover/Oil Jet

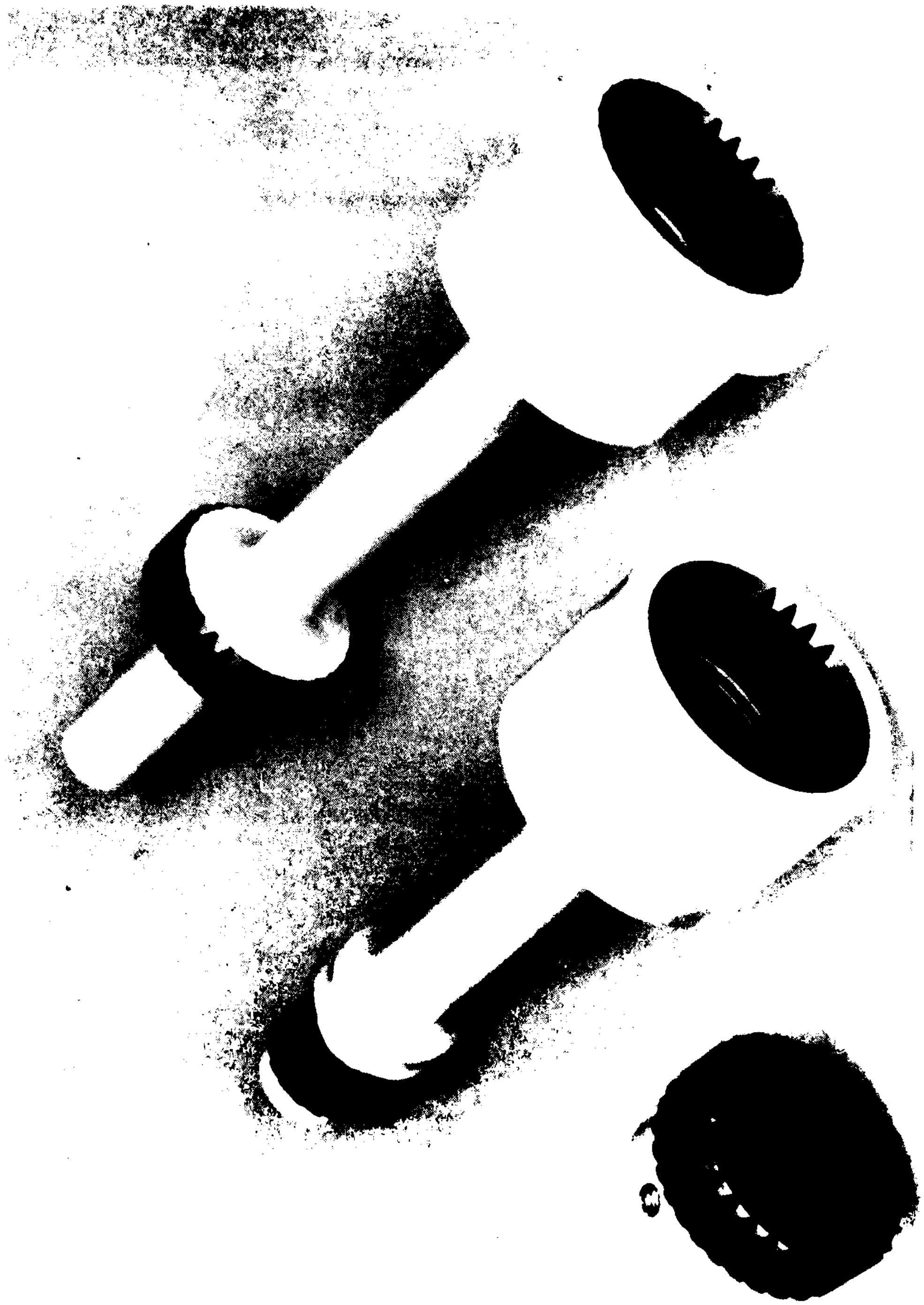


Figure 20. Quill Shafts and Quill Adapter

Figure 21. Model 1604-116 (500 in-lb) Torquemeter, View [illegible]

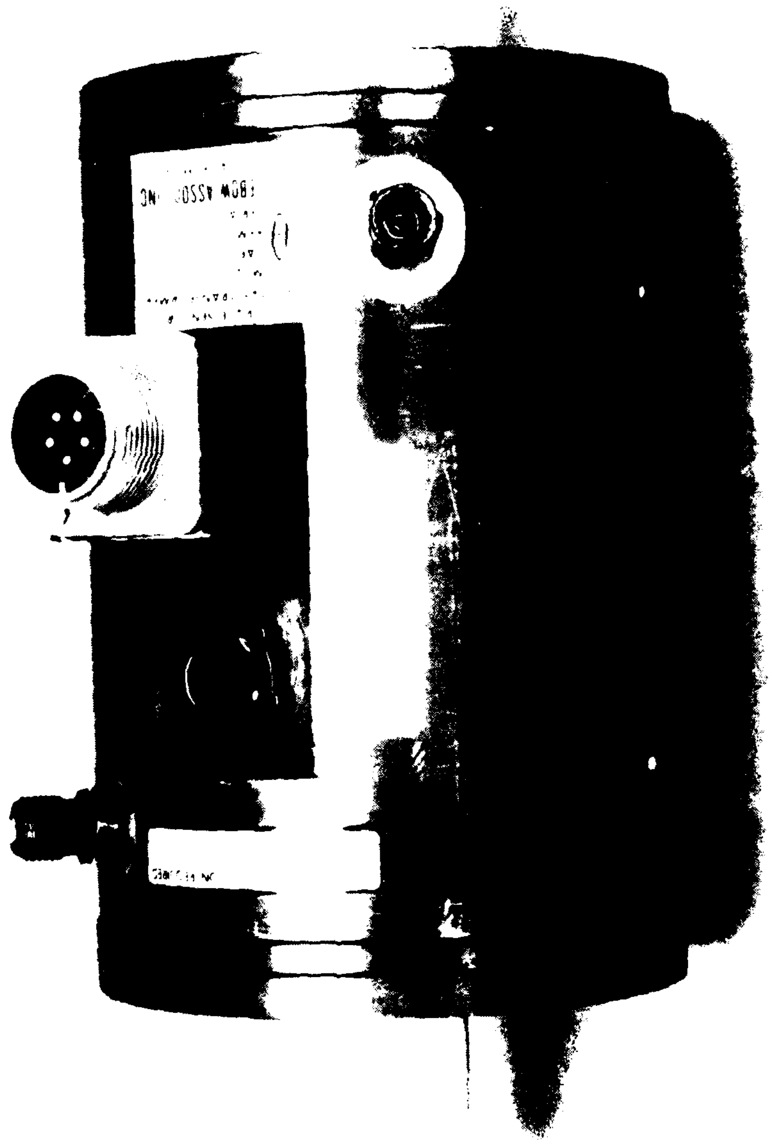
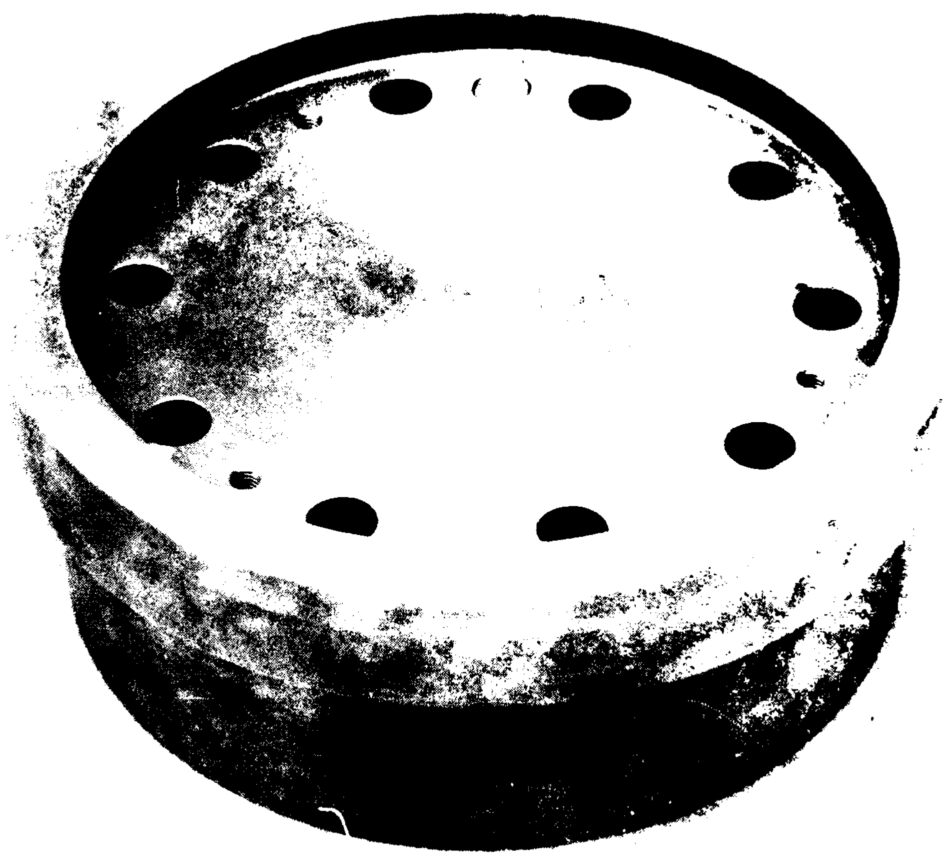


Figure 22. Model 1604-116 (500 in-lb) Torquemeter, View B



IXY52-2/21/80-C1

Figure 23. Second Stage Wheel Replacement Disc

Figure 24. First and Second Stage Wheel [illegible]

Effort conducted during Task III, although generally classified under Test, included facility mechanical and instrumentation preparations, turbine system balancing, actual data runs (tests), disassembly of the tester and final storage preparations. The following sections discuss each sub-task effort conducted during the MK15E3-2 Turbine Windage Torque Program.

Facility Preparations

Preparations of the facility to adapt the MK15E3-2 Windage Torque Test Article began by adapting the existing Brayoil 1015/DTE797 bearing lube oil system to the specific requirements of the MK15E3-2. Figure 25 presents a schematic of the required operational system including the air/oil mist lubrication for the torquemeter bearings. The heat exchanger at the exhaust cavity was added to prevent damaging the soft seat of the vacuum flow control valve. The system was sized for a maximum exhaust flow of about 0.03 lb/sec (air) or nearly ten times the expected rate. Instrumentation necessary to obtain windage data and turbine system operational data is listed in Table 8. As testing progressed, however, two additional radial accelerometers were mounted on the torquemeter housing to monitor housing displacement or a red-line backup system for the quill shaft(s) orbital displacement. Figure 26a shows the dynamometer control panel with lube oil system controls. Figure 26b shows the instrumentation systems which recorded the various windage torque data, including the DORIC analyzer. Figure 27a shows the three dual beam oscilloscopes used for turbine accelerometer, drive end and turbine end Bently orbital display. Figure 27b shows an actual example of the system drive end Bently orbital trace. In this photo, one centimeter equals 0.005 inch. The two spikes represent the 0.004 inch pre-machined calibration marks on the outside diameter of the quill shaft. For the display shown, shaft total deflection of only [illegible] inch is indicated, or well within the 0.016 inch radial deflection red-line. The Doric analyzer system scanned the applicable parameters continuously but was programmed to print out the data on paper tape only once in every eight seconds, which is the instrument limit. The eight-second break in instrumentation acquisition proved to be of no consequence since during the testing, the

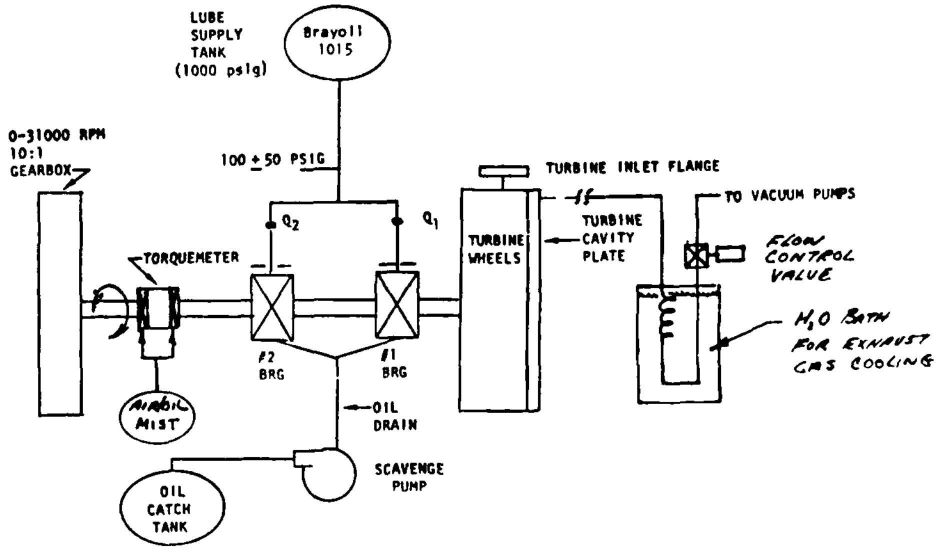


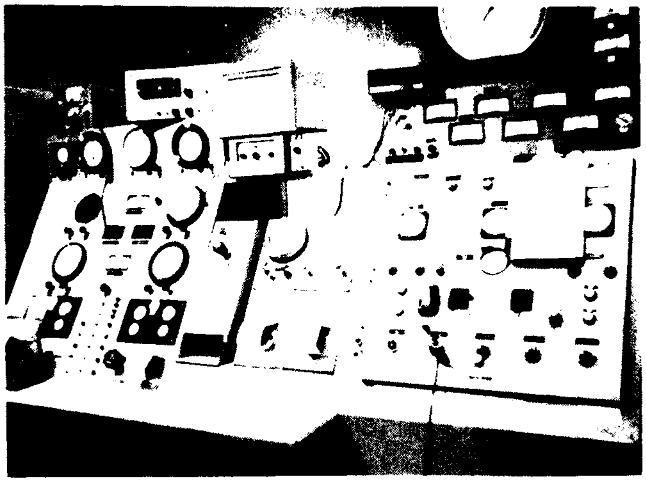
FIGURE 25. MK15E3-2 System Requirement Schematic

PARAMETER	RANGE	ID	GAUGE IDENT.	DORIC CHANNEL	FM TAPE CHANNEL	REDLINE VALUE	REMARKS
RPM	0-50,000	N1	Panel Mtr	6	6	>33,000	
Torque	0-500 in-lb or 0-100 in-lb	T	Lebow Model 7540	7	4	—	Max speed change: 500 in lb = 8400 RPM/sec 100 in lb = 88[illegible] RPM/sec
Turbine Cav. Press #1	15 psia	TCP1	—	1	—	—	
Turbine Cav. Press #4	15 psia	TCP4	Gauge	2	—	—	
Stg 1 Stat Out Pr.	15 psia	P2	—	3	—	—	
Turbine Jet In Pr.	200 psig	PLS2	Gauge	—	—	—	
Turbine Cav. temp	1200F	TCT4	Doric	11	—	>1000°F	
Turbine Inlet temp	1200F	TT1	—	13	—	—	
Turbine Outb'd Brg temp	200F	TBT2	Doric	12	—	> 200°F	150°F blueline
Lube Oil Flow, Thrust	0-2 GPM	Q1	Panel Mtr	4	—	—	
Lube Oil Flow, Outb'd	0-2 GPM	Q2	Panel Mtr	5	—	—	
Turbine Radial Accel	20 GRMS	TR	OSC	—	1	>10 GRMS	
Torque Mtr, Bently	0-0.02"	BT1	OSC**	—	3	>.016'	Orbital radius
Torque Mtr, Bently	0-0.02"	BT2	OSC**	—	5	>.016"	Orbital radius
Torque Mtr, Bently	0-0.02"	BD1	OSC**	—	7	>.016"	Orbital radius
Torque Mtr, Bently	0-0.02"	BD2	OSC**	—	9	>.016"	Orbital radius
IRIG		IRIG	—	—	13	.	

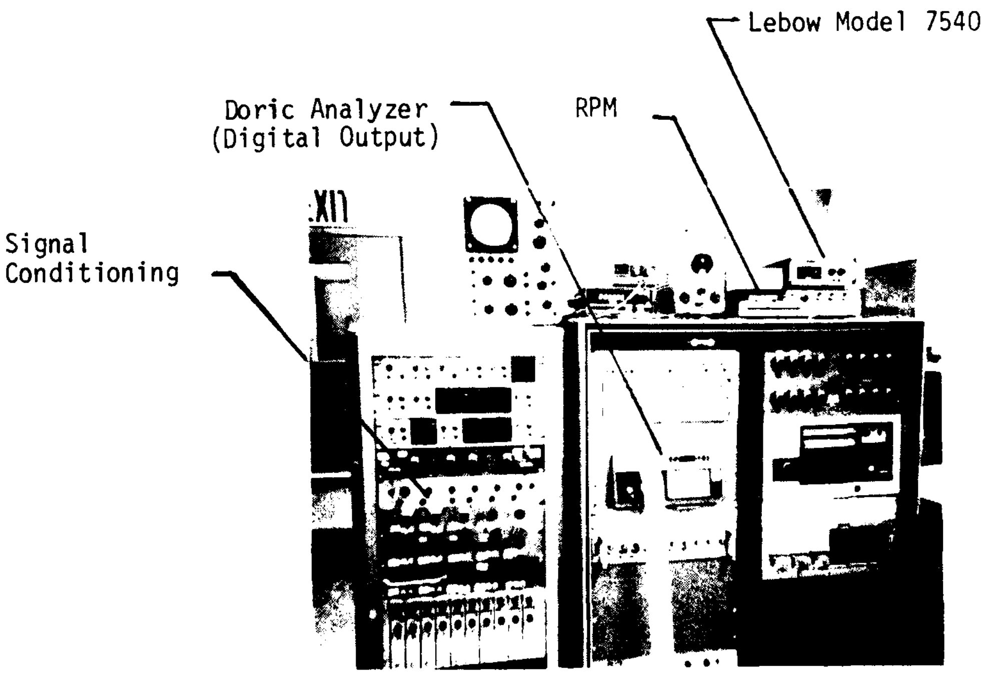
*Low pass filter req'd, 1000 Hz
**Orbital display

8/25/80

TABLE 8. MK15E3-2 Turbine Windage Torque Test Instrumentation List

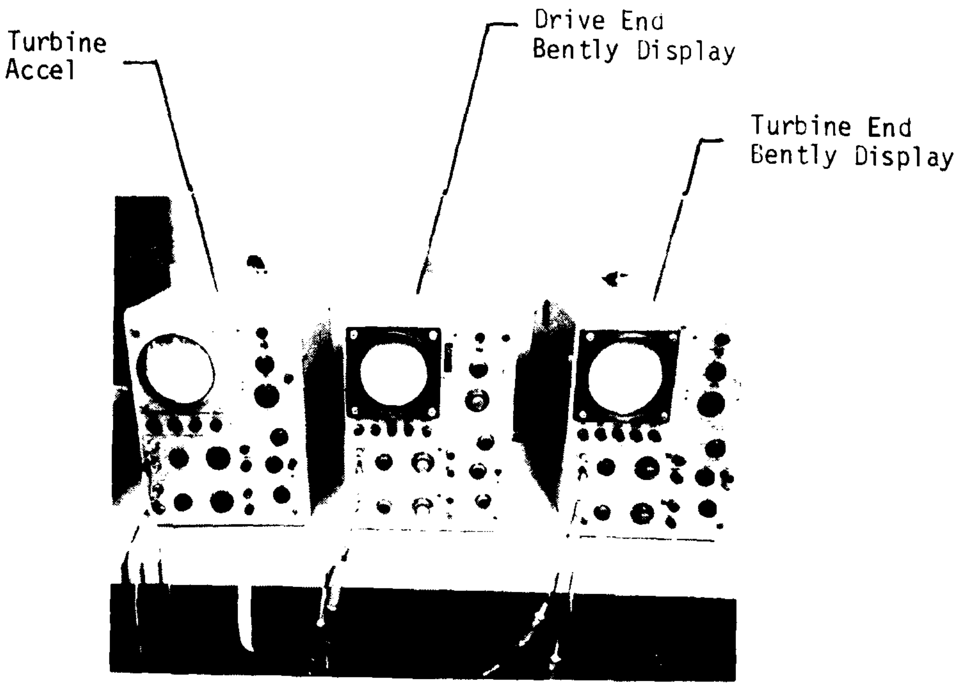


a) MK15E3-2 Control Panel



b) Data Acquisition System

FIGURE 26. MK15E3-2 Instrumentation and Controls



a) Observer Oscilloscopes

b) Typical Bently Orbital Display - Photographed during 5000 RPM Steady State

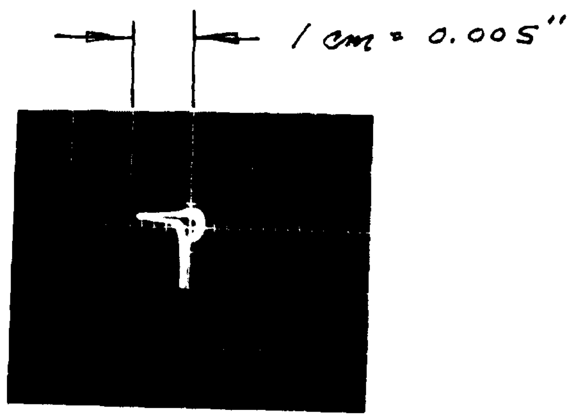


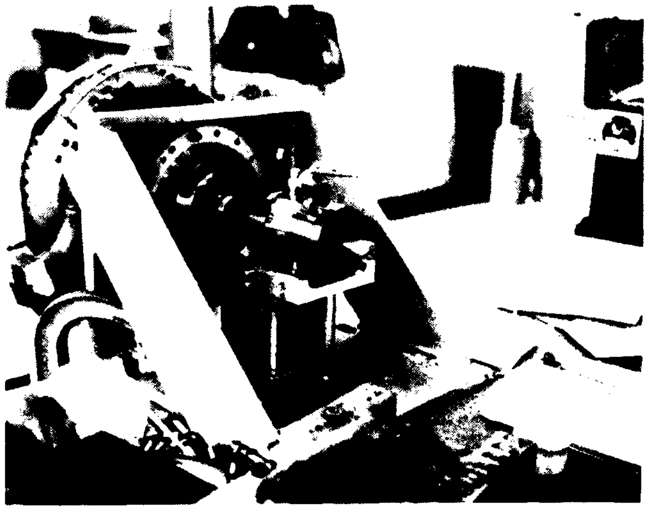
FIGURE 27. Bently and Turbine Accelerometer Oscilloscope Systems

turbine speed was allowed to stabilize for a minimum of 30 seconds, or at least three stabilized level printouts on the Doric tape.

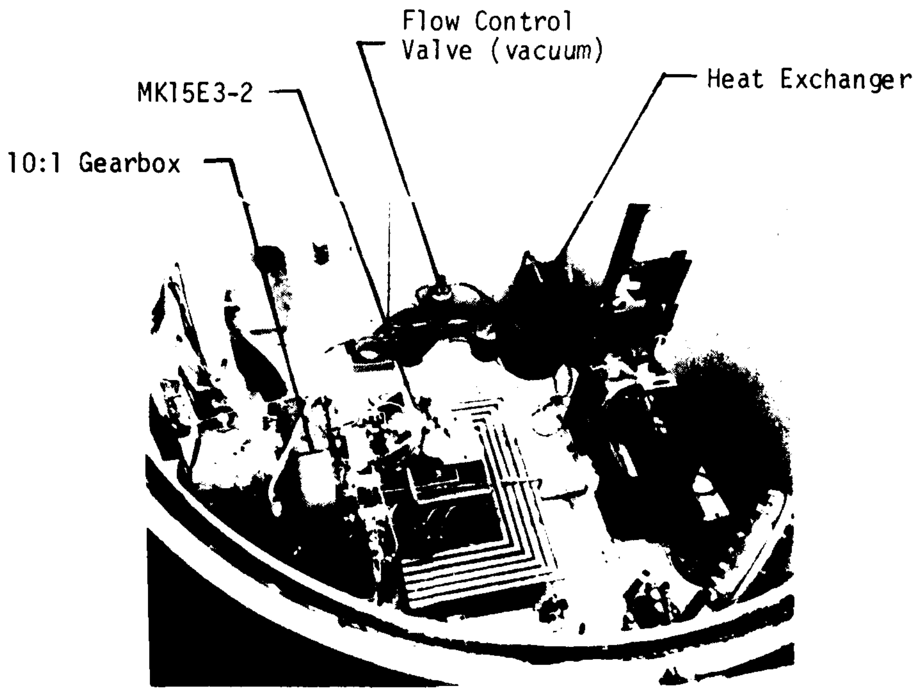
System Alignment

Alignment of the torquemeter to the turbine (before installation in the test cell) and to the dynamometer output shaft proved to be very difficult. The two quill shafts (drive end, P/N R0012816 and turbine end, P/N R0012815) were designed with uncoupled (∿0.001 inch maximum loose fit) splines to withstand the rotordynamic conditions expected. An alignment tolerance of 0.002 inch per inch length was required in both parallelism and concentricity. Actual turbine end alignment was done on the bench with a maximum of 0.0006 inch/inch alignment achieved. A special alignment tool was fabricated to aid in the alignment procedure (Figure 28a). Once the torquemeter was aligned, the torquemeter foot mount was pinned to the turbine mount pedestal. The assembly (turbine, mount, torquemeter) was then lowered into the rotary test cell for mounting (Figure 28b).

During the alignment of the turbine (and torquemeter) to the gearbox, several problems were encountered. First, an alignment fixture similar to the bench alignment fixture had to be fabricated to move the massive assembly, both in yaw and pitch. Second, because of gearbox shaft centerline growth (about 0.006 inch upward), when at operating oil temperature (∿100 F), the gearbox lube system heaters had to be turned on while performing the alignment. Third, an output shaft aligning head had to be fabricated to locate the center of the drive shaft perpendicular to the torquemeter (and turbine) shaft. Lastly, the gearbox shaft rotational centerline centers within about 0.002 inch at speeds above 1000 RPM. The aligning procedure accounted for all of these variables, and as can be expected, proved to be very laborious. Nevertheless, final alignment to 0.0004 inch/inch was achieved. It is recommended that particular care be taken during future alignments since spline wear or failure can be the result of an improper alignment.



a) Turbine to Torquemeter Alignment



b) MK15E3-2 Test Cell Installation

FIGURE 28. MK15E3-2 Alignment and Installation

Lube System Flow Checks

After alignment, the lube oil systems were checked to determine bearing lube flowrate versus tank and lube jet pressure. Two 3/8-inch lines were plumbed in parallel to each turbine jet manifold. In one leg (turbine end bearing), a hand valve served as a variable orifice. The tank was pressurized until the unobstructed lube supply line (rear bearing) flowed about one GPM. The hand valve was then adjusted to also flow about one GPM, thus providing similar hydraulic resistances in the two systems. A series of pressure versus flowrates were then run to construct a bearing lube flowrate curve (Figure 29). The purpose of this blowdown test was to aid in determining required bearing flowrate during a test, depending on the temperature of the bearing. Each system resistance proved to be slightly different (see Figure 29). Only the outboard bearing temperature was monitored for the test series, it having the lowest flowrate. No problems were encountered during any of the testing with a lube jet pressure of about 180 psig (1.0 to 1.2 GPM) setting. As can be seen in the raw test data compilation, flowrates above 1.2 GPM were recorded, but generally this is attributed to the type of test conducted - usually vacuum conditions in the exhaust cavity.

System Dynamic Balancing

The quill shafts and turbine were dynamically balanced prior to the first test. A Hofmann in-place balance system was used to balance the systems to less than one gram-inch unbalance. Considerable difficulty was experienced in the first balance operation when balancing at about 2000 RPM. The turbine single plane unbalance was reduced to 0.25 gram-inch, or well within the 1.0 gram inch required by the assembly drawing. The torquemeter on the other hand indicated a balance correction at each end of the shaft of about 12 gram-inches. The magnitude of the suggested correction could not be accounted for in either misalignment, torquemeter residual unbalance or fit-up within the splines. The corrections were made, however, and the first three tests were conducted using the Hofmann balance accelerometers at the radial position of each torquemeter bearing as a red-line monitor. Housing displacement in micrometers was closely monitored as a red-line. On the third test, an unacceptable torque-

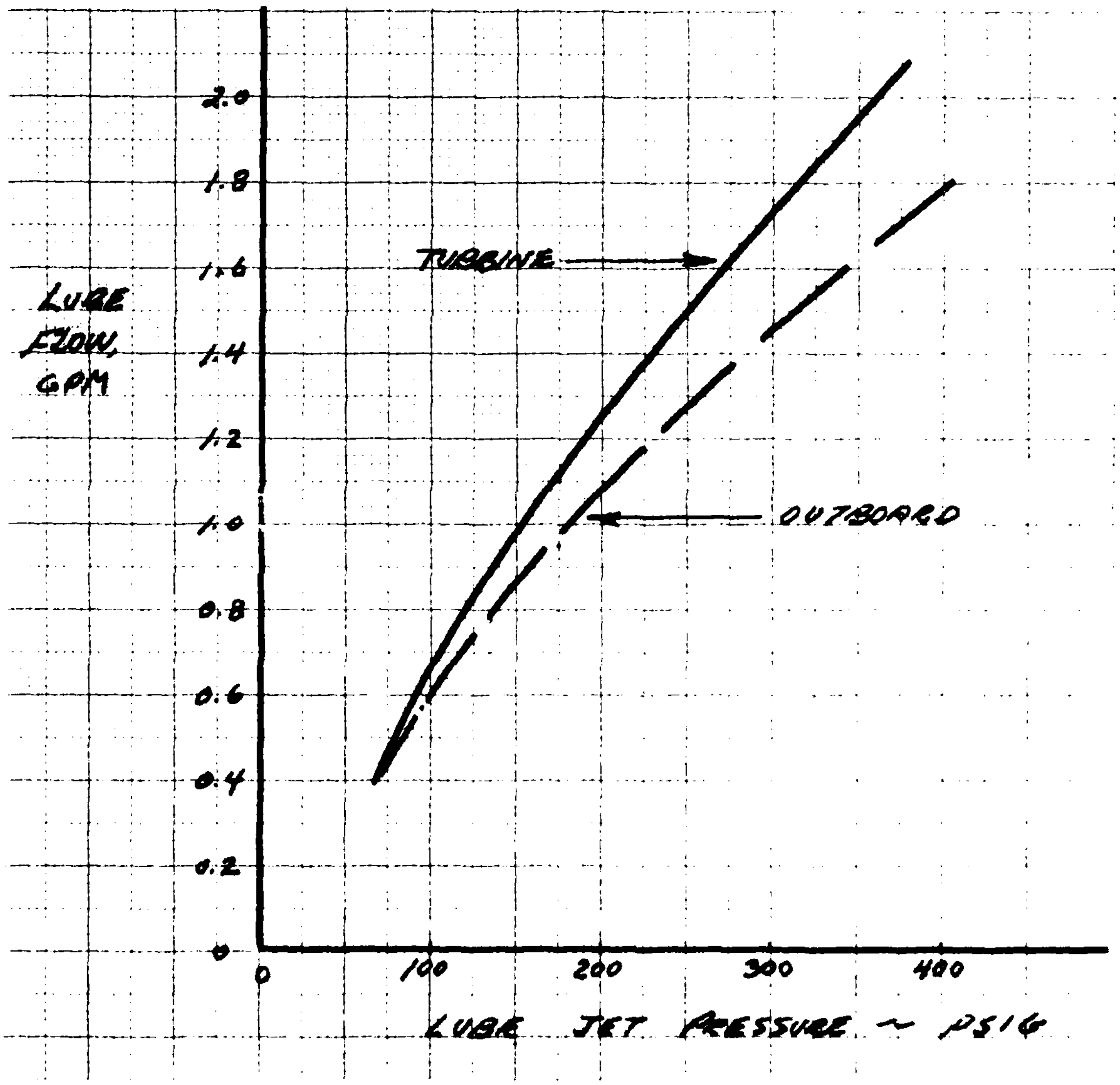


FIGURE 29. MK15E3-2 Turbine Windage Outboard and Inboard Bearing Flow versus Lube Jet Pressure

meter housing displacement of about 30 micrometers was obtained at about 12,000 RPM. A decision was made to balance the torquemeter system (quill shaft plus torquemeter) at 9500 RPM. The balance speed of 9500 RPM was selected after reviewing the high speed FM data or the minimum G-level resonance value below the anticipated first critical system speed (Figure 30). After balancing at 9500 RPM, the residual unbalance was only about one gram-inch. Set screw correction weights were installed with no further problem with the torquemeter accelerations. For data analysis backup, two radial accelerometers were installed to monitor the torquemeter. Figure 31 shows the Hofmann UGA2000 analyzer and the location of the balance accelerometers while balancing the turbine end.

Windage Tests

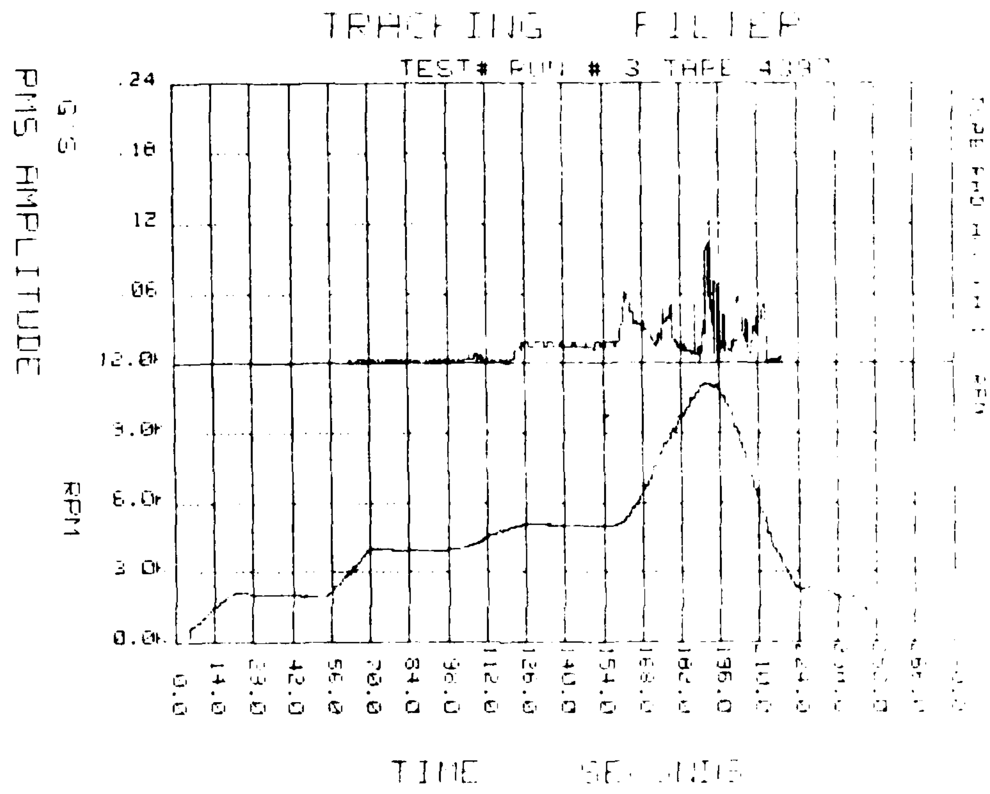
The MK15E3-2 was readied for the first test on 8 September 1980 after completing all necessary preparatory checkouts. Testing continued until 26 September 1980, accumulating 25 tests, 5 balance operations and approximately 32,810 seconds of rotor operation. During the test series, another turbine cavity test media (helium) was used to gain additional empirical windage data on six tests for 2213 seconds on two different turbine configurations. The helium testing was sponsored by Rocketdyne and the results are available to the Air Force Aero Propulsion Laboratory.[3] The total turbine time mentioned above includes the helium media testing.

The test matrix presented in Table 9 was successfully accomplished in a total of 19 tests. Of these tests, ten were necessary to satisfy the requirements of the first series, while three each completed the next three series.

Figures 32 and 33 show the MK15E3-2 turbine windage tester with the exhaust cover installed for partial vacuum conditions. For the atmospheric tests, the two large plugs in the cover were removed (see Figure 32). Figure 34 shows the shrouded E3 second stage wheel which represents test series #1. Figure

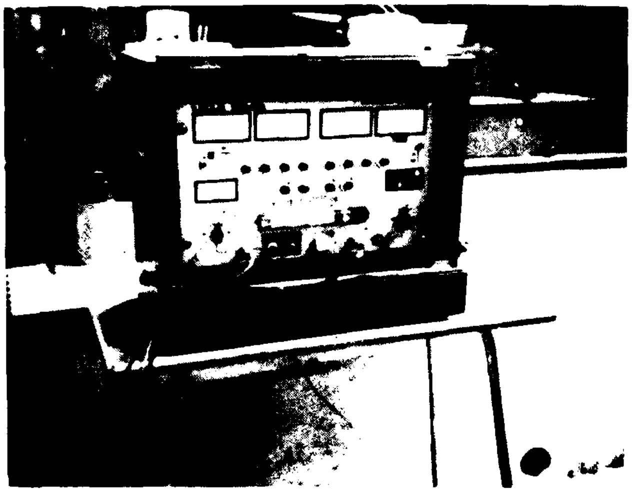
---

[3]ITR-80-076, available through Rocketdyne Division of Rockwell International, 6633 Canoga Ave., Canoga Park, CA 91304, Attention: R. F. Sutton

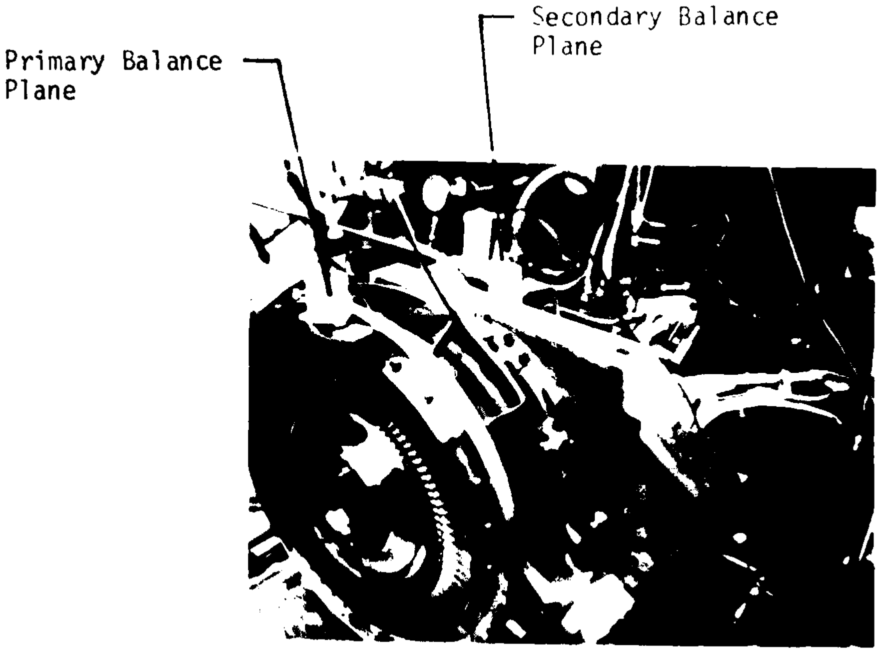


DATA CHANNEL TURB RAD ACC CH 1
KEY NUMBER= 28 GPP
CAL VOLTS= .604 V RMS
TIME BASE EXPANSION= 1 1
DB GAIN= 30 db

FIGURE 30. Test 1-003 RPM and Turbine Radial Acceleration versus Test Time



a) Hofmann UGA2000 Balance Analyzer



b) Balance Accelerometer Locations

FIGURE 31. MK15E3-2 Balance Equipment

TEST SERIES	TEST #	CONFIGURATION (WHEELS)	TURBINE CAVITY PRESSURE	SPEED RPM
1	1-001	E3 1st & 2nd stages	Ambient	15,000
	1-002		Ambient	31,000
	1-003		7 psia	31,000
	1-004		1 psia	31,000
2	2-005	E3 1st stage - Replacement Disc - 2nd stage	Ambient	31,000
	2-006		7 psia	31,000
	2-007		1 psia	31,000
3	3-008	Replacement Disc - 1st & 2nd stage	Ambient	31,000
	3-009		7 psia	31,000
	3-010		1 psia	31,000
4	4-011	E3 1st stage - E1 2nd stage	Ambient	31,000
	4-012		7 psia	31,000
	4-013		1 psia	31,000

TABLE 9. MK15E3-2 Test Matrix

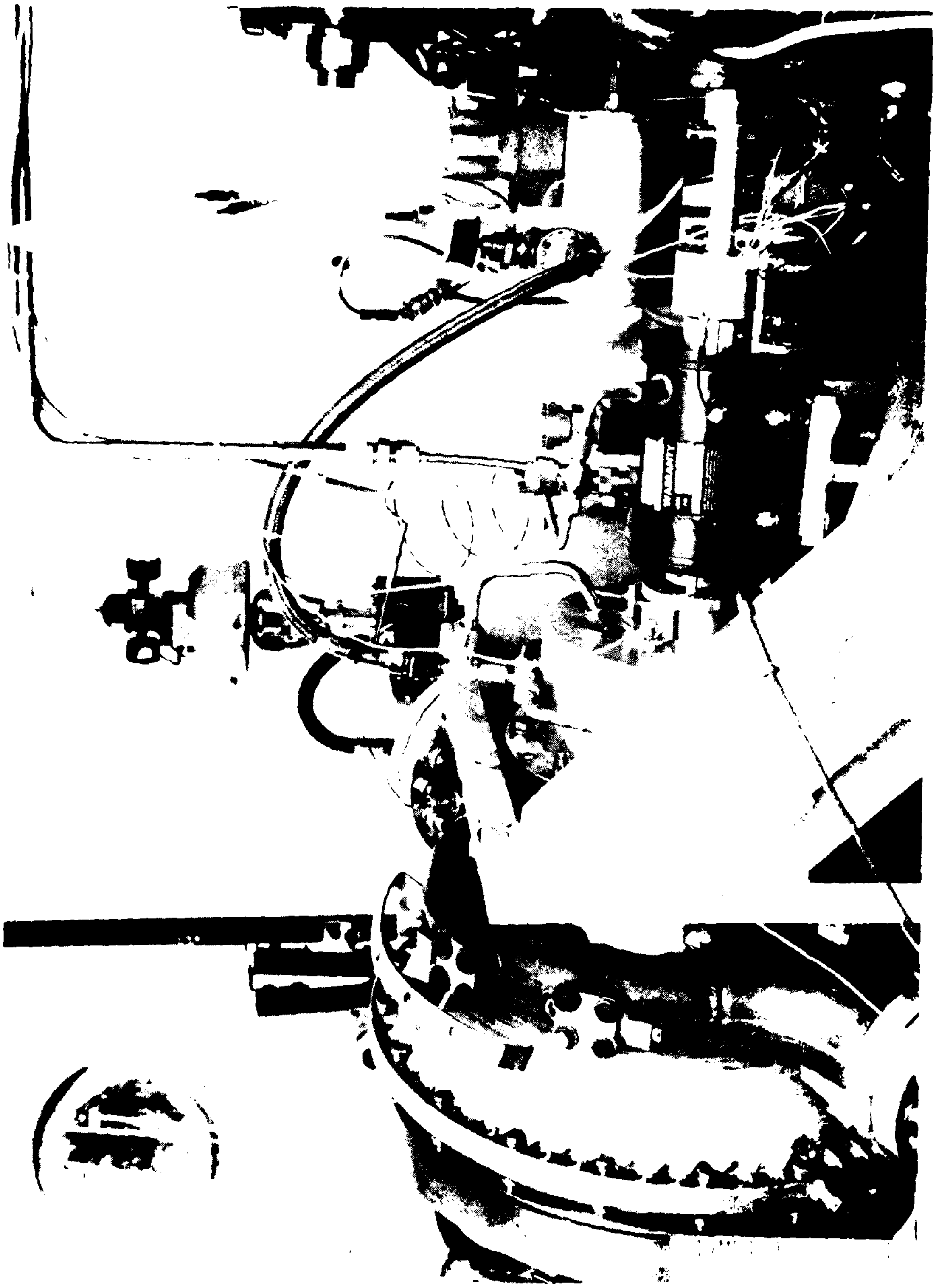


Figure 32. View of MK15E3-2 Windage Tester - Drive End

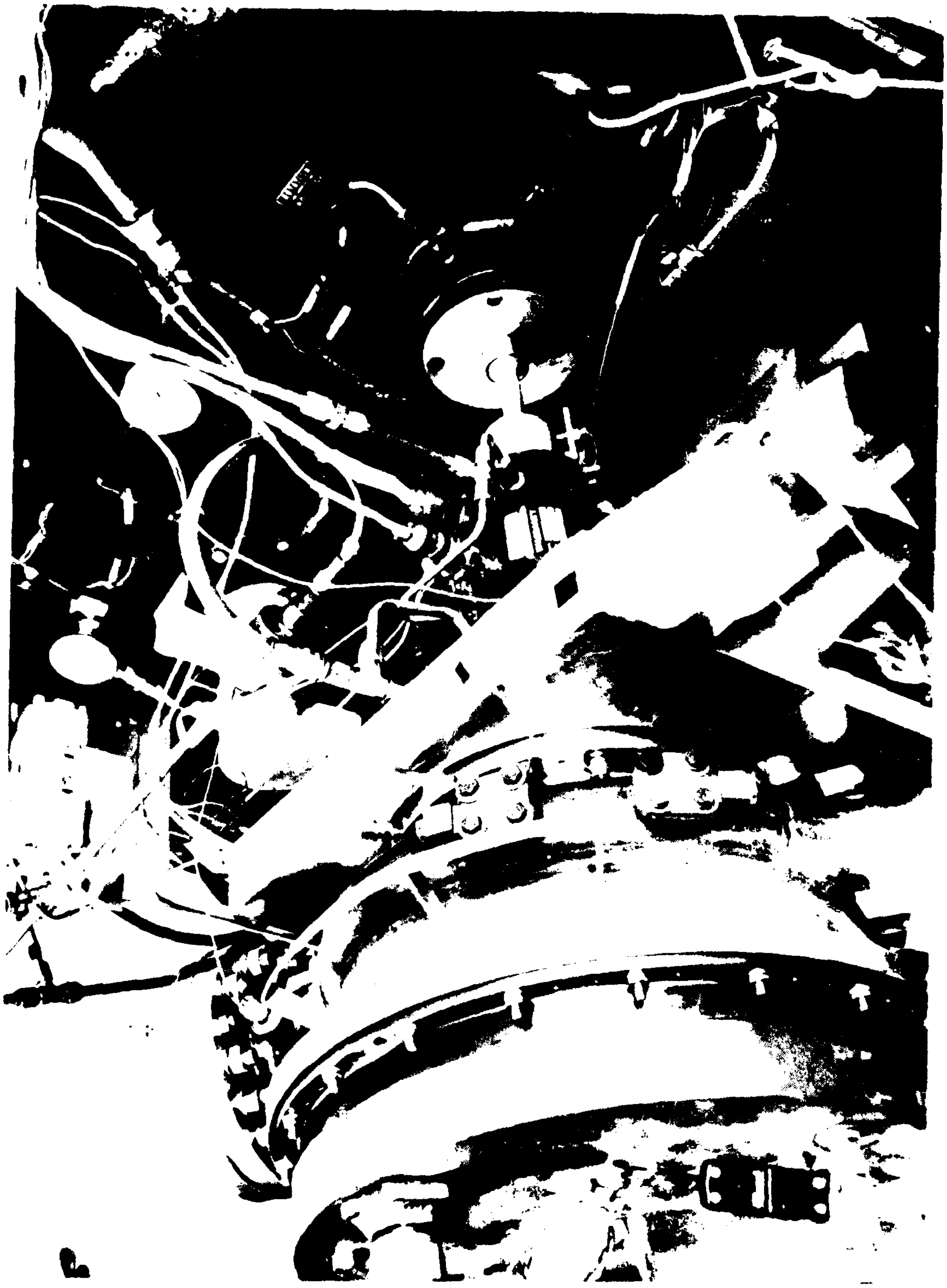


Figure 33. View of MK15E3-2 Windage Tester

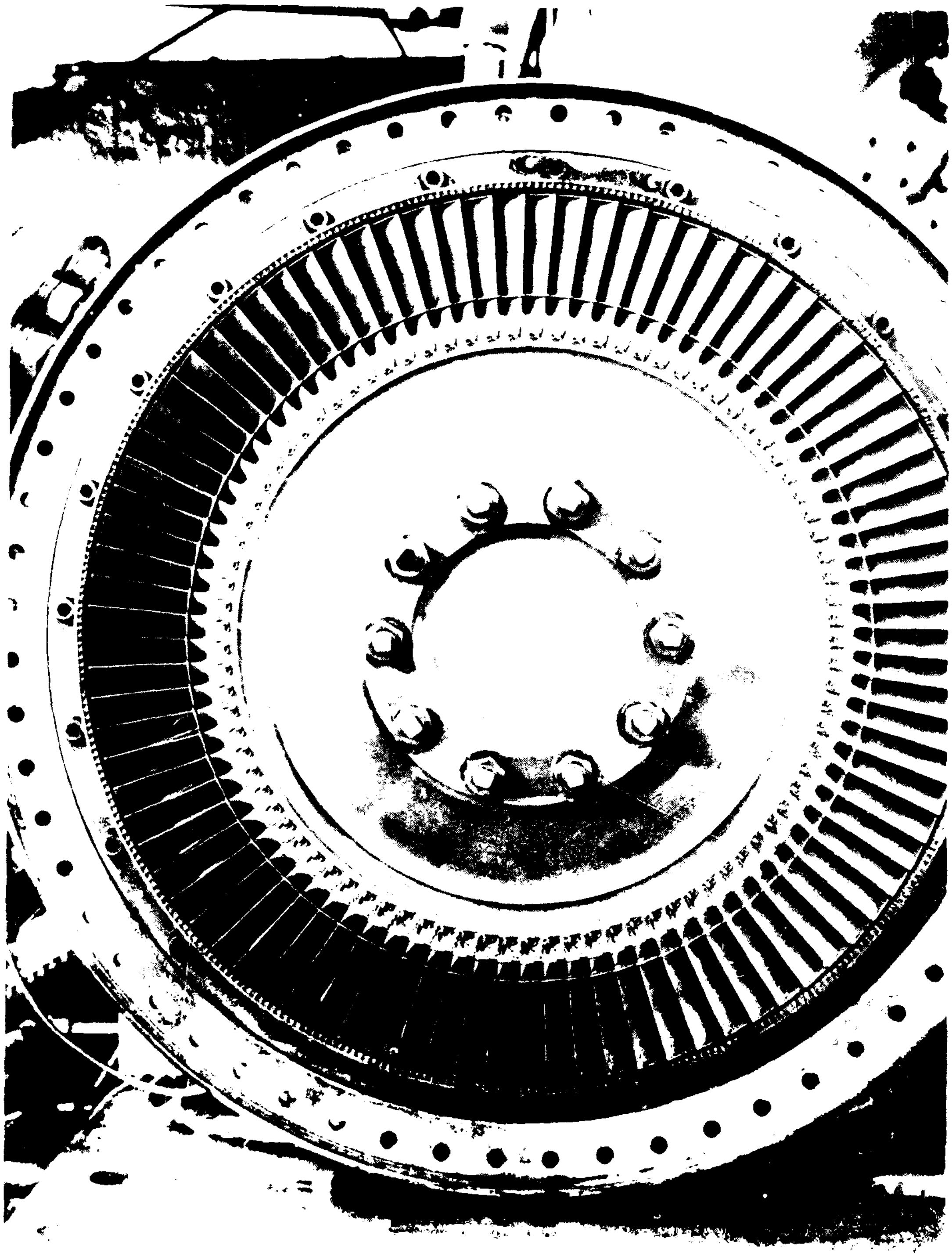


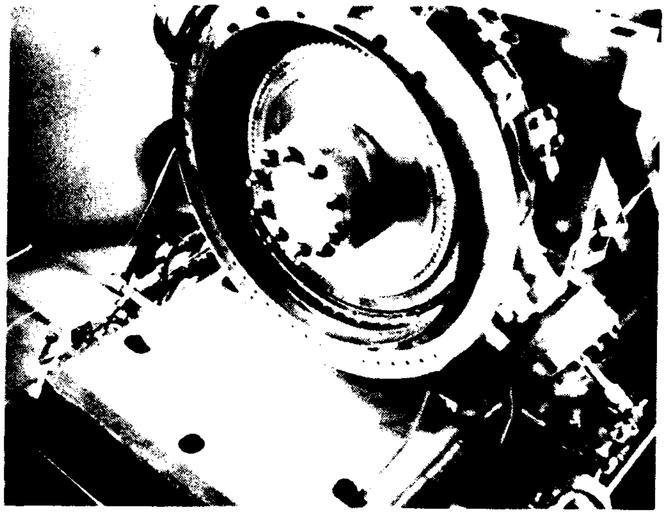
Figure 34. View of E3 Second Stage Wheel Test Series #1 - Cover Removed

[illegible]

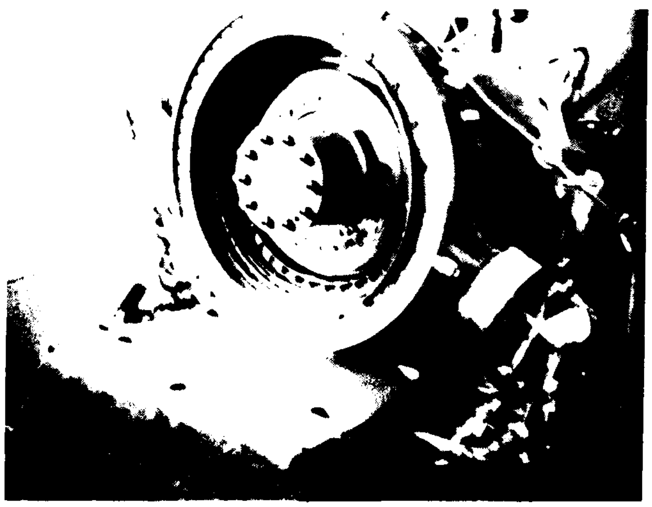
35a shows the small cylinder replacement second stage wheel installation (test series #2), while 35b shows the large cylinder replacement for the first and second stage wheels (test series #3). As a weight comparison, the E3 second stage wheel weighs about 27 pounds, the small cylinder weighs about 16 pounds. The first and second stage wheels in combination weigh about 50 pounds, while the large cylinder weighs about 28 pounds. The difference in masses had no effect on the steady state torque data. The use of the replacement discs was necessary only to secure the wheel studs which could not be removed without total turbine disassembly - a costly procedure. Figure 36 shows the E1 second stage unshrouded wheel which was installed for the fourth test series.

A test by test discussion is presented below, while a summary of the testing is shown in Table 10. Figures 37 through 40 present the observed power loss versus rotor speed and cavity pressure for the four test configurations of the MK15E3-2 turbine. Included in the power loss are vane pumping, disc friction and bearing and seal friction. A detailed analysis is presented in Task IV.

Test:	1-001
Test Date:	9-3-80
Duration:	385 seconds
Objective:	1. Checkout system to 5000 RPM. 2. Atmospheric pressure windage torque data with E3 1st and 2nd stage wheels. 3. Validate balance operation.
Results:	Obtained torque data at 1000, 2000, 3000, 4000 and 5000 RPM levels. Maximum torque at 5010 RPM was 39 in-lbs. All data acquisition systems functioned well. Maximum Bently displacement at the 5K RPM level was 0.0012 inch radial at the drive end quill shaft. The Hofmann balance analyzer shows comparable results.
Analysis:	Because of the apparent large unbalance corrections at the torquemeter, the next test will be conducted to verify the unbalance at 5000 RPM versus the balance speed of 2000 RPM. The Hofmann analyzer will be used as a red-line monitor for torquemeter displacements.



a) Small Cylinder - Test Series #2



b) Large Cylinder - Test Series #3

FIGURE 35. Test Series #2 and #3 Configurations - Exhaust Cover Removed

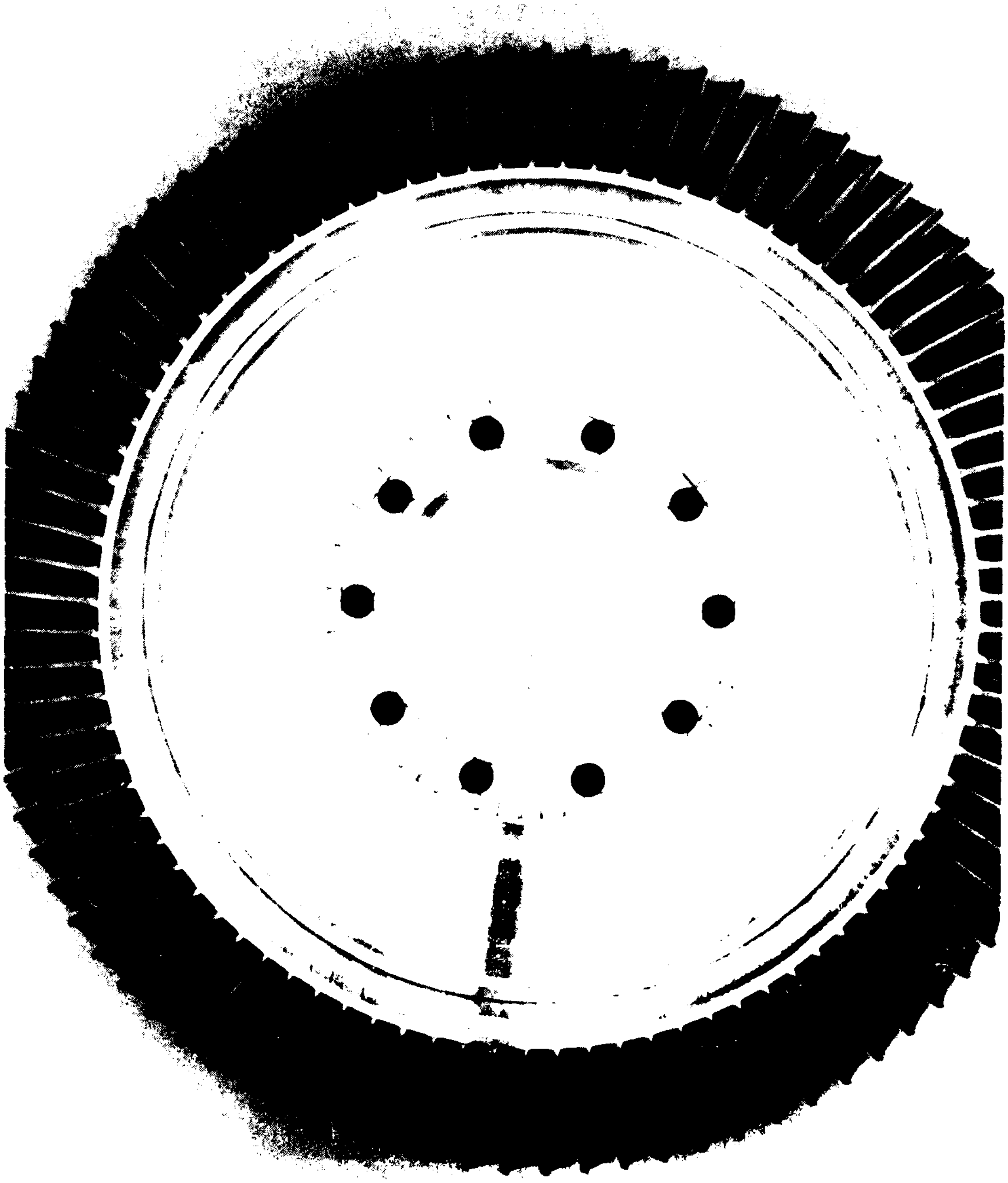


Figure 36. E1 Second Stage Unshrouded Wheel - Test Series #4

DATE OF TEST	TEST #	DURATION, SECONDS	ACCUMULATED DURATION, SECONDS	MAXIMUM SPEED, RPM
9/5/80	Balance #1	∿7200	7200	2000
9/8/80	1-001	385	7585	5010
9/9/80	1-002	953	8538	5000
9/10/80	1-003	256	8794	11900
9/11/80	Balance #2	∿3600	12394	9540
9/11/80	1-004	222	12616	9550
9/11/80	1-005	222	12838	9540
9/12/80	1-006	683	13521	30350
9/12/80	1-007	630	14151	30240
9/15/80	1-008	102	14253	9780
9/15/80	1-009	399	14652	30320
9/15/80	1-010	416	15068	29870
9/17/80	Balance #3	∿3600	18668	5000
9/18/80	2-011	604	19272	30140
9/18/80	2-012	290	19562	29770
9/19/80	2-013	563	20125	25570
9/22/80	Balance #4	∿3600	23725	5000
9/23/80	3-014	594	24319	27630
9/23/80	3-015	488	24807	27750
9/23/80	3-016	359	25166	25060
9/23/80	3-017H	254	25420	25080
9/23/80	3-018H	345	25745	25020
9/23/80	3-019H	335	26080	25020
9/25/80	Balance #5	∿3600	29680	5000
9/26/80	4-020	673	30353	29440
9/26/80	4-021	651	31004	27080
9/26/80	4-022	527	31531	26770
9/26/80	4-023H	468	31999	27020
9/26/80	4-024H	440	32439	27460
9/26/80	4-025H	371	32810	28000

NOTE: a) Total time = 9 hours, 6.83 minutes
b) X-XXXH = helium environment in cavity

TABLE 10. MK15E3-2 Windage Torque Test Summary

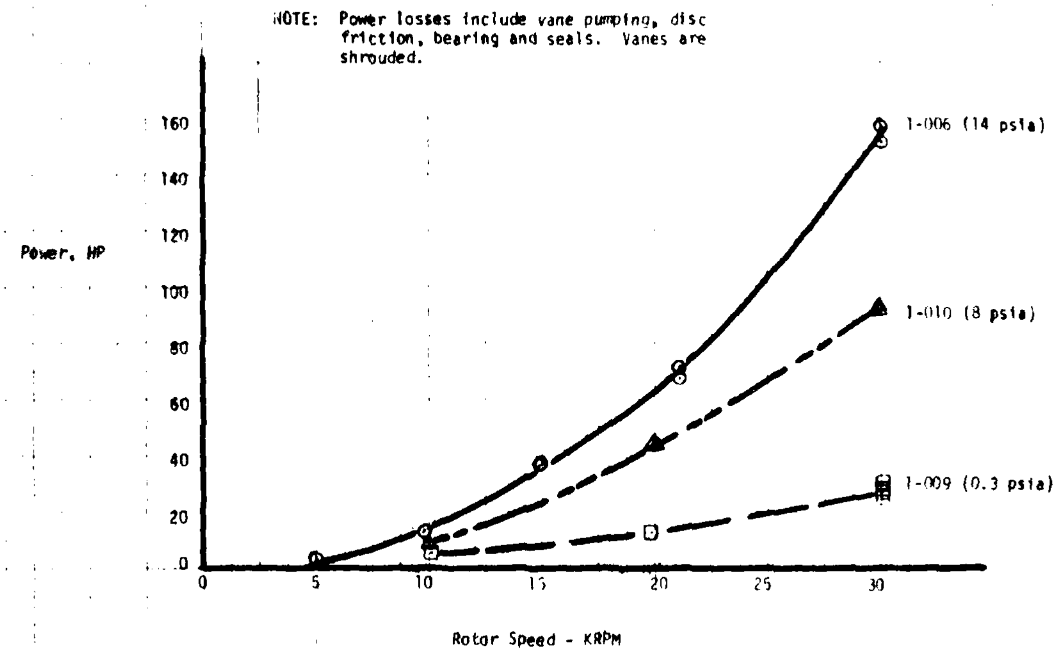


FIGURE 37. MK15E3-2 Power Losses - Test Series #1 (Two Wheel)

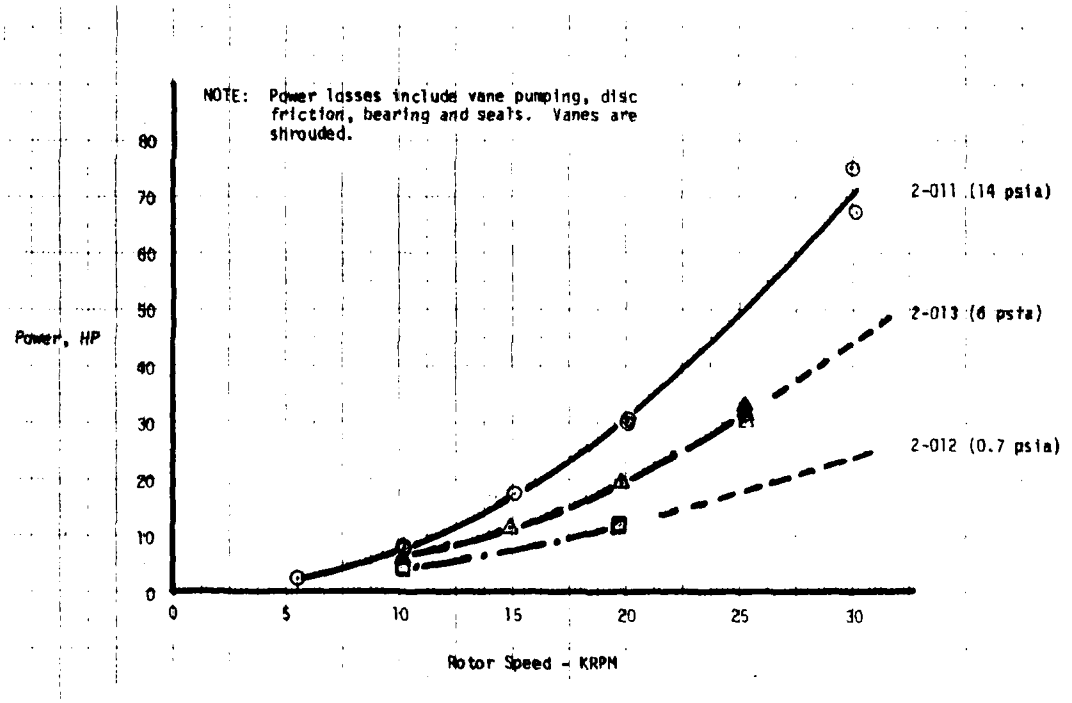


FIGURE 38. MK15E3-2 Power Losses - Test Series #2 (Single Wheel)

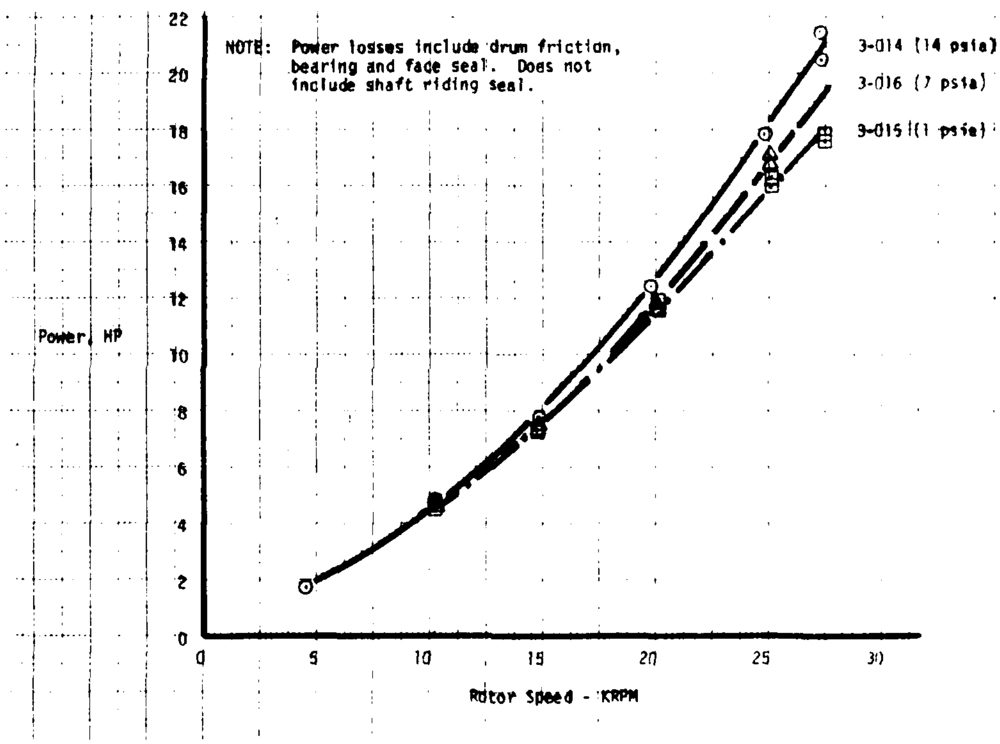


FIGURE 39. MK15E3-2 Power Losses - Test Series #3 (Bearing and Seal)

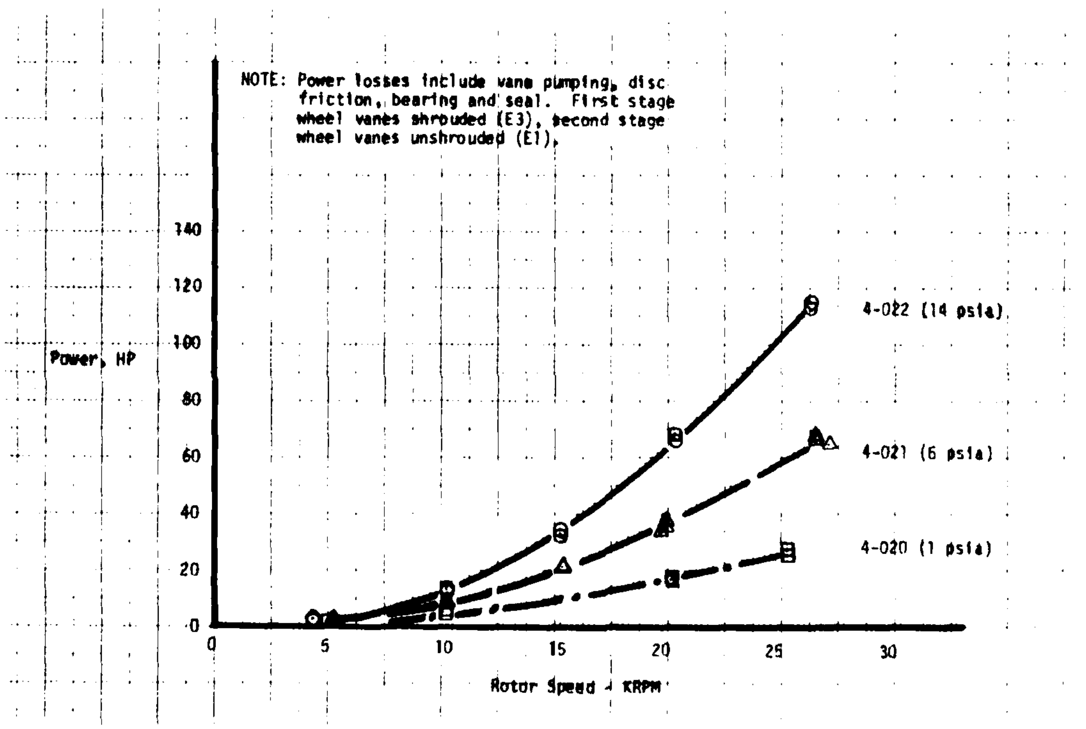


FIGURE 40. MK15E3-2 Power Losses - Test Series #4 (E3 and E1 Wheels)

Test: 1-002

Test Date: 9-9-80

Duration: 953 seconds

Objective:

1. Atmospheric pressure windage torque data with E3 1st and 2nd stage wheels to 5000 RPM.
2. Investigate capability of torquemeter quill shafts to indicated unbalance.

Results: Torque data consistent with previous test at 1K RPM increments from 1K to 5K RPM. Bently orbital deflections about the same as previous test.

Analysis: An attempt will be made to ramp to 30,000 RPM on the next test using the Hofmann analyzer as a red-line for the torquemeter displacement.

Test: 1-003

Test Date: 9-10-80

Duration: 256 seconds

Objective:

1. Atmospheric pressure windage torque data with E3 1st and 2nd stage wheels to 30,000 RPM.
2. Obtain comparative displacement data between Bently orbital plots and Hofmann analyzer.

Results: Test terminated by the Hofmann analyzer red-line observer when torquemeter housing displacement reached 30 micrometers. This is an unacceptable displacement when compared to industry standards for comparable rotating machinery systems. Figure 37 was used for the guide as the vibration severity indicator for this type of rotating machinery. Maximum acceleration of the turbine radial accelerometer was only 0.12 GRMS maximum - the red-line being set at 10 GRMS (refer to Figure 30). During the test, torque data was recorded at stabilized steady state speeds to 11,180 RPM. Testing was halted at this point since steady state speeds of 30,000 RPM seemed unlikely with the existing balance. The torquemeter/quill shaft

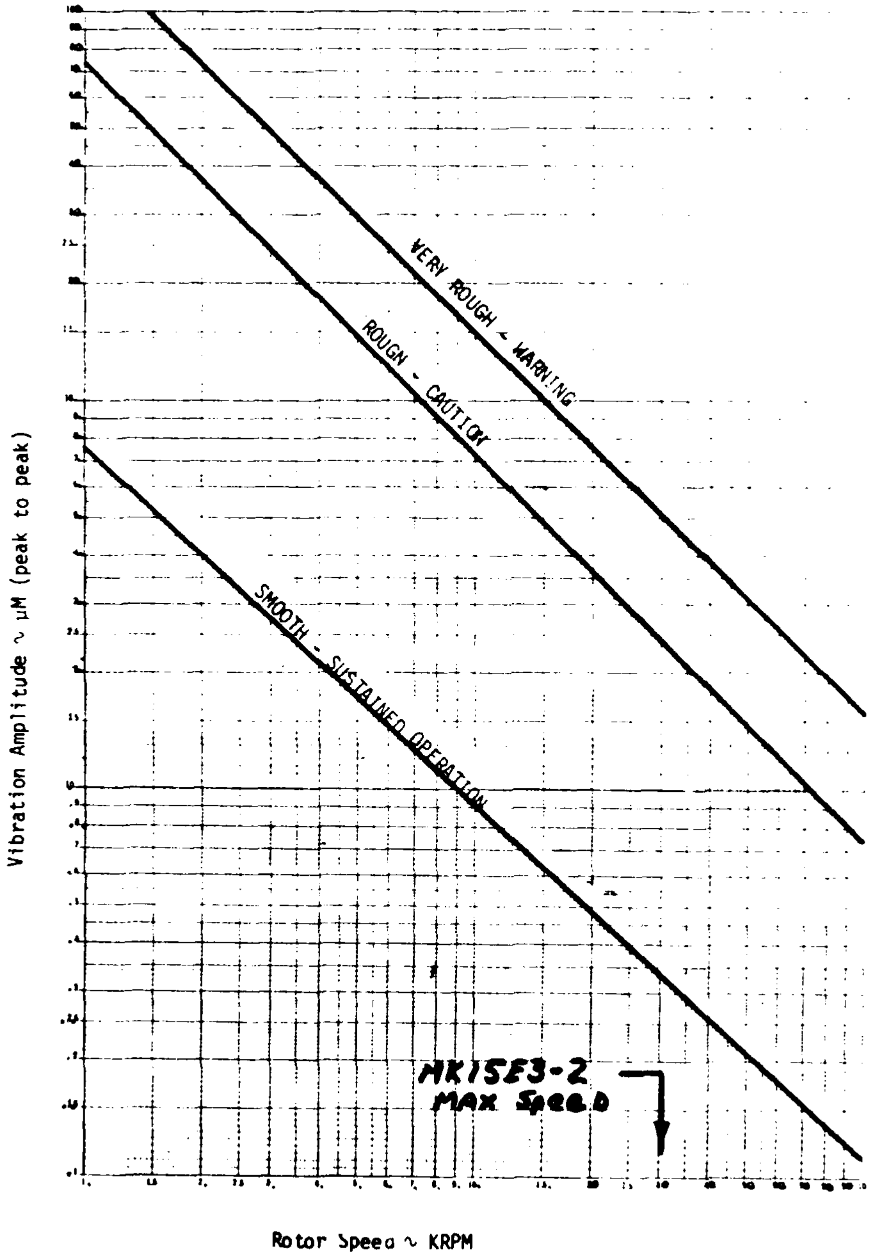


FIGURE 41. Rotating Machinery Vibration Severity Guide

system was then re-balanced at 9500 RPM to 0.13 gram-inch (turbine quill) and 0.38 gram-inch (drive quill).

Test: 1-004

Test Date: 9-11-80

Duration: 222 seconds

Objective:
1. Atmospheric pressure windage torque data with E3 1st and 2nd stage wheels to 30,000 RPM.
2. Torquemeter balance verification

Results: Hofmann analyzer red-line observer terminated test at approximately 12,000 RPM when the vibration amplitude of the torquemeter housing exceeded 10 micrometers. Bently orbital plots show maximum of only 0.002 inch deflection with no large excursions. Torque data successfully acquired up to cutoff.

Analysis: Lead shot bags were placed around the torquemeter pedestal in an effort to dampen the system. The turbine vibration was very low, about 0.1 to 0.2 GRMS. An additional test to 30,000 RPM will be attempted using only the Bently's and turbine accelerometer red-lines.

Test: 1-005

Test Date: 9-11-80

Duration: 222 seconds

Objective:
1. Atmospheric pressure windage torque data with E3 1st and 2nd stage wheels to 30,000 RPM.

Results: Test terminated at approximately 14,000 RPM (determined from Statos charts) when the Lebow speed sensor (red-line parameter) failed to indicate the proper speed. The speed count did not indicate greater than 12,000 RPM while the control panel rough indication was about 15,000 RPM. The Lebow Model 7540 signal conditioner is used to convert 60 pulses per revolution into RPM readout and provide the signal to the Doric analyzer for permanent speed recording. Torque data was recorded at 5000 and 9500 RPM.

Analysis: The speed sensor is a magnetic pickup and was set at 0.026 inch gap (pickup to rotor teeth gap). The gap was evidently too wide for this particular system, although the gap had been set per manufacturer's instructions. The gap was reset to 0.011 inch with no additional speed monitoring problems encountered throughout the remainder of the test program.

Test: 1-006

Test Date: 9-12-80

Duration: 683 seconds

Objective: 1. Atmospheric windage torque data with E3 1st and 2nd stage wheels to 30,000 RPM.

Results: Objective achieved. Torque at 30,350 RPM was 325 in-lbs. RPM was increased in increments to the 30,000 RPM level, then decreased in the same increments. Maximum turbine exhaust cavity temperature recorded was 937^{o}F (red-line was set at 1000^{o}F). The maximum rear bearing temperature was 138^{o}F, well below the 200^{o}F red-line. All systems performed satisfactorily.

Test: 1-007

Test Date: 9-12-80

Duration: 630 seconds

Objective: 1. Windage torque data at 7 psia cavity pressure with E3 1st and 2nd stage wheels to 30,000 RPM.

Results: Objective achieved. Cavity pressure varied between 4 and 9 psia. Maximum torque of 89 in-lbs at 30,240 RPM.

Test:	1-008
Test Date:	9-15-80
Duration:	102 seconds
Objective:	1. Windage torque data at one psia cavity pressure with E3 1st and 2nd stage wheels to 30,000 RPM.
Results:	Test terminated after recording torque at 9700 RPM due to Doric paper strip malfunction. Cavity pressure of about 0.3 psia was maintained.

Test:	1-009
Test Date:	9-15-80
Duration:	399 seconds
Objective:	1. Windage torque data at one psia cavity pressure with E3 1st and 2nd stage wheels to 30,000 RPM.
Results:	Objective achieved. Torque at 30,320 RPM was about 55 in-lbs. Cavity temperature maximum temperature was 355°F.

Test:	1-010
Test Date:	9-15-80
Duration:	416 seconds
Objective:	1. Repeat of test 1-007 to provide more stabilized pressure conditions within exhaust cavity. 2. Windage torque data at seven psia cavity pressure with E3 1st and 2nd stage wheels to 30,000 RPM.
Results:	Objectives achieved. Stabilized cavity pressure of about 7.5 psia maintained with a maximum torque of 197 in-lbs recorded at 29,870 RPM. This test completed the series number 1 configuration - E3 1st and 2nd stage wheels.

Test:	2-011
Test Date:	9-18-80
Duration:	604 seconds
Objective:	Windage torque data at atmospheric cavity pressure with

	E3 1st stage wheel and replacement cylinder for the E3 second stage wheel.
Results:	Objective achieved. Windage torque for this configuration (Series No. 2) was about one-half that of the two wheels in combination (159 versus 325 in-lbs, respectively). Maximum speed obtained was 30,140 RPM with a maximum cavity temperature of 492°F.
Test:	2-012
Test Date:	9-18-80
Duration:	290 seconds
Objective:	Windage torque data at one psia cavity pressure with the E3 1st stage wheel and replacement cylinder for the E3 second stage wheel.
Results:	Steady state torque data obtained for 10K and 20K RPM levels. During speed ramp from 21K to 30K RPM, the turbine vibration level indicated slightly more than 10 GRMS at a maximum speed of 29,770 RPM. The speed was immediately reduced to obtain steady state torque data on the downramp at the 20K and 10K RPM levels. No evidence of hardware failure or additional problems was noted.
Analysis:	A review of the orbital displays for the Bently transducers indicated no abnormal deflections during the test (no greater than about 0.010 inch). However, at about 23K-24K, an increase in the normal deflection (~0.006 inch) was noted which quickly subsided at about 25K. While ramping toward 30K RPM, another increase in Bently orbital deflection was noted starting at about 28K until the speed was backed off. Coupled with these observations, the turbine vibration level started to increase from approximately 1 GRMS at 28K RPM to the 10 GRMS red-line at the 29,770 RPM obtained. Several possibilities can explain the increase in "G" level at the 28K RPM level.

1. Too high a residual unbalance for this hardware configuration. (Actual residual unbalance was 0.77 gram-inch.)
2. Slight movement, or seating, of the replacement cylinder pilot press fit causing an increase and/or shift in the residual unbalance.
3. Bearing wear because of the accumulated run time (19,562 seconds).
4. Response of the turbine to the third critical (bending) speed of the (torquemeter) system.

A rigorous rotordynamic analysis of these possibilities was not performed, but the most probable reason for the noted increase in turbine vibration level at the 28K to 30K RPM is the coupling, or transmittal, of the torquemeter vibration at its bending mode critical speed (see Table 3). Calculated critical speed was between 27,079 and 34,371 RPM depending on the bearing support stiffness; the noted vibration occurred at 28K RPM which is in good agreement with the analytical estimates. It is also postulated that the second critical speed (torquemeter) of the system occurred between 23K and 24K as noted by the increase in Bently displacement. Again, referring to Table 3, the second critical speed was analytically projected to be between 24,045 to 28,274 RPM. For the second and third critical speeds to be between 24K to 28K, the apparent torquemeter bearing support stiffness should be about 200,000 lb/in. It thus appears that the analytical and empirical results are in good agreement.

Test:	2-013
Test Date:	9-19-80
Duration:	563 seconds
Objective:	Windage torque data at seven psia cavity pressure with

	E3 1st stage wheel and replacement cylinder for the E3 second stage wheel.
Results:	Objective achieved. Maximum steady state speed of 25,570 RPM resulted in a torque value of 33 in-lbs at a cavity temperature of 339^{0}F.

Test:	3-014
Test Date:	9-23-80
Duration:	594 seconds
Objective:	Windage torque data at atmospheric cavity pressure with a replacement cylinder for the 1st and 2nd stage wheels.
Results:	Objective achieved. Steady state torque data obtained up to 27,630 RPM.

Test:	3-015
Test Date:	9-23-80
Duration:	488 seconds
Objective:	Windage torque data at one psia cavity pressure with a replacement cylinder for the 1st and 2nd stage wheels.
Results:	Objective achieved. Cavity pressure of about 1.2 psia was maintained throughout speed excursions to 27,700 RPM. Maximum torque recorded was 40 in-lbs at a cavity temperature of 100^{0}F.

Test:	3-016
Test Date:	9-23-80
Duration:	359 seconds
Objective:	Windage torque data at seven psia cavity pressure with a replacement cylinder for the 1st and 2nd stage wheels.
Results:	Objective achieved. Cavity pressure of about 7.3 psia was maintained with a maximum torque of 43 in-lbs obtained at 25,000 RPM.

Test: 4-020

Test Date: 9-26-80

Duration: 673 seconds

Objective: Windage torque data at one psia cavity pressure with the shrouded E3 1st stage wheel and unshrouded E1 second stage wheel.

Results: Objective achieved. A maximum speed of 29,440 RPM was achieved for only a short time due to the high turbine vibration level increasing from about 1 GRMS at 28K to just over 10 GRMS at the maximum RPM. The speed was immediately reduced with stabilized torque data obtained at lower speed levels. (Refer to Test 2-012 test analysis.)

Test: 4-021

Test Date: 9-26-80

Duration: 651 seconds

Objective: Windage torque data at seven psia cavity pressure with shrouded E3 1st stage wheel and unshrouded E1 second stage wheel.

Results: Objective achieved. A stabilized cavity pressure of about 6.1 psia was maintained with a maximum torque of 159 in-lbs obtained at 26,880 RPM.

Test: 4-022

Test Date: 9-26-80

Duration: 527 seconds

Objective: Windage torque data at atmospheric cavity pressure with shrouded E3 1st stage wheel and unshrouded E1 second stage wheel.

Results: Objective achieved. A maximum torque of 272 in-lbs was recorded at 26,770 RPM with a cavity temperature of 367°F. This test completed the program test requirements.

Post-Test Disassembly/Storage

Following the test program, the E3 second stage wheel was re-installed, studs elongated 0.013 and lock tabs secured. Because of the extensive time accumulated on the bearings, Rocketdyne recommended that no further powered rotation of the turbine be attempted before disassembly, inspection of hardware, refurbishment if required, and re-assembly including balance at 5000 RPM.

The MK15E3-2 turbine tester assembly, P/N R0012809, was placed in a wooden storage container along with all other supportive hardware, including the Lebow Associates, Inc. Model 1604-100 and -500 torquemeters and Model 7540 signal conditioner.

Data Records and Appendices

Appendix B presents the raw data compilation as determined from the Doric analyzer and other supportive systems. Appendix C is the nomenclature and data reduction program written for this program. Appendix D is the reduced data as compiled by the computer program written for this project, while Appendix E is the revised torque and torque ratio printout.

TASK IV DATA ANALYSIS AND RESULTS

Data Reduction

Average rotor cavity conditions were calculated for each test point. Average cavity pressure was the average of the Stage 1 outlet static pressure (P2), turbine cavity pressure number 1 (TCP1), and turbine cavity pressure number 4 (TCP4). Average cavity temperature was the average of turbine inlet temperature (TT1) and turbine cavity temperature number 4 (TCT4). Turbine rotor cavity specific weight was calculated using the average pressure and temperature in the equation of state for air. The absolute viscosity of air was calculated as a function of the average cavity temperature.

The Reynolds number was calculated for each test point. Reynolds number is the product of the test speed, the effective diameter squared where the effective diameter is the turbine blading mean diameter with turbine rotors or the maximum drum diameter with no turbine rotors, and the cavity specific weight divided by the absolute viscosity.

Predicted torques were calculated for each test point. Predicted torques for the bearings, oil face seal, and turbine floating ring seal were functions of speed. The bearing torque characteristic is shown in Figure 42. The equations were supplied by the Mechanical Elements Specialist and are listed in Appendix C. The rotor disc friction torques were predicted using the empirically based method by Daily and Nece.[4] The blading windage torques were predicted using the test data correlation reported by Balje and Binsley.[5]

---

[4]Dailey, J. W., and Nece, R. E., "Chamber Dimension Effects on Induced Flow and Frictional Resistance of Enclosed Rotating Disks", Journal of Basic Engineering, Transactions of the ASME, Series D, Volume 82, Number 1, March 1960, pages 217-232.

[5]Balje, O. E., and Binsley, R. L., "Axial Turbine Performance Evaluation. Part A - Loss-Loss-Geometry Relationships", Journal of Engineering for Power, Transactions of the, October 1968, pages 341-348.

The shroud ring friction torque was predicted using an empirically developed method by Bilgen and Boulos.[6] Predicted torques for the drums used in place of the discs were the sum of cylindrical surface torques and the radial face torque. The equation for each predicted torque is given in Appendix C. Torque coefficients were calculated as functions of Reynolds number using the empirical correlations reported in the references.

---

[6] Bilgen, E., and Boulos, R., "Functional Dependence of Torque Coefficient of Coaxial Cylinders on Gap Width and Reynolds Number", Journal of Fluids Engineering, Transactions of the ASME, March 1973, pages 122-126.

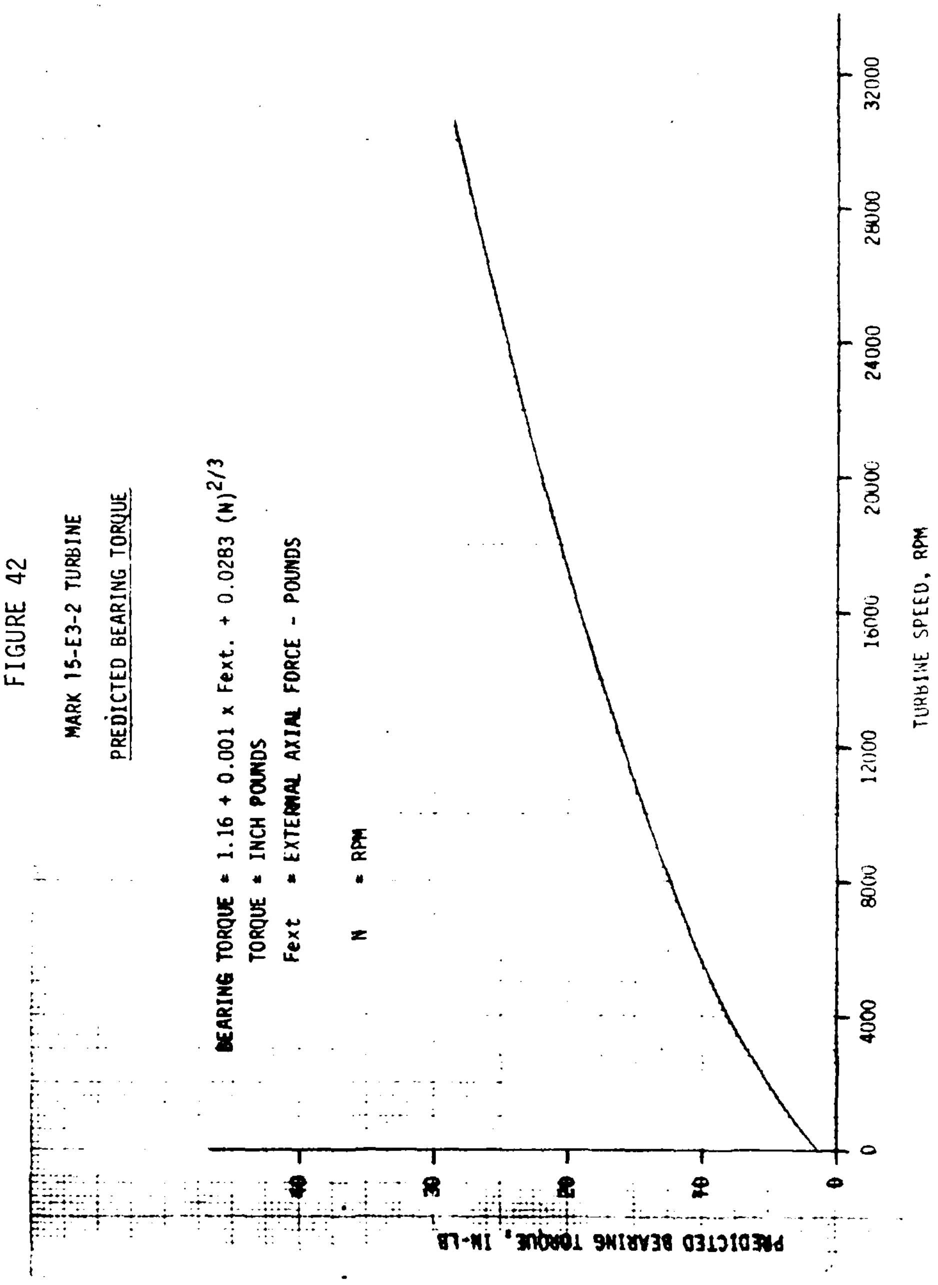


FIGURE 42 PREDICTED BEARING TORQUE

The turbine geometry dimensions are summarized in Table 11. Using these values, the predicted torque for each test point was the summation of the component torques for the configuration and test. The component torques for each configuration are listed in Table 12. A torque ratio (TR) was determined for each test point. The torque ratio is defined as the test torque divided by the total predicted torque. A torque ratio of 1.0 means the predicted torque equaled the test torque.

The reduced test data and parameters for each test point are tabulated in Appendix D. The predicted torques and torque ratios are tabulated in Appendix E.

Data Analysis

The torque ratios, TR (test torque divided by the predicted torque) for each point was plotted versus speed for each test. The test configuration and average cavity pressure were listed on each plot. The torque parameter plots were compared resulting in the following observations:

No Disc Tests. The no-disc tests had predicted torques for the bearings, oil face seal, and the drum cylinder and end face. The torque ratio versus speed for the original predicted torques is shown in Figure 43. At 5,000 RPM, the torque ratio was approximately 1.6 and at 30,000 RPM, the torque ratio was approximately 0.8. All of the no-disc tests had approximately the same torque ratio versus speed characteristic which did not vary with cavity pressure. This substantiates the prediction that drum friction torques were small compared with the predicted bearing and seal torque. A revised oil face seal torque characteristic was derived to reduce the data scatter based on the no-disc tests and the assumption that the predicted bearing torque was correct and neglecting the drum friction torque. The original and revised predicted oil face seal torque characteristics are shown in Figure 44. The torque ratio was recalculated using the revised oil seal torque characteristic for the no-disc tests and is shown in Figure 45. Figure 45 indicated an acceptable prediction of the torque and a significant reduction in the 2-sigma scatter as shown in the following:

DESCRIPTION	PROGRAM SYMBOL	DIMENSION, INCH
Turbine Mean Diameter	DM	12.3
Drum Cylinder Dia. No. 1	DDM1	5.5
Drum Cylinder Dia. No. 2	DDM2	6.0
First Rotor Blade Height	H1R	0.69
Second Rotor Blade Height	H2R	1.67
Axial Space - First Disc Upstream	S1DKUS	0.3
Axial Space - First Disc Downstream	S1DKDS	0.2
Axial Space - First Disc Downstream - Single Rotor	S1DK1R	4.0
Axial Space - Second Disc Upstream	S2DKUS	0.2
Axial Space - Second Disc Downstream	S2DKDS	2.0
Axial Space - Drum Downstream	SDM	1.25
Radial Space - First Rotor Shroud	T1R	0.06
Radial Space - Second Rotor Shroud	T2R	0.06
Radial Space - Drum	TDM	4.6
Drum Cylinder Length @ 5.5 Dia., Single Rotor	LDM2R1	1.5
Drum Cylinder Length @ 6.0 Dia., Single Rotor	LDM2R2	0.86
Drum Cylinder Length @ 5.5 Dia., No Rotors	LDM1R1	3.491
Drum Cylinder Length @ 6.0 Dia., No Rotors	LDM1R2	1.125
First Rotor Shroud Length	L1RSH	0.6
Second Rotor Shroud Length	L2RSH	0.6

TABLE 11. Turbine Geometry Summary

TEST SERIES		1-XXX	2-XXX	3-XXX	4-XXX
Configuration:					
First Rotor		E3	E3	None	E3
Second Rotor		E3	None	None	E1
PREDICTED TORQUES					
ELEMENT	PROGRAM SYMBOL				
Bearings	TBG	X	X	X	X
Oil Face Seal	TOFS	X	X	X	X
Turbine Seal	TFRS	X	X		X
First Disc Upstream	T1DKUS	X	X		X
First Disc Downstream	T1DKDS	X	X		X
First Rotor Blading	T1BD	X	X		X
First Rotor Shroud	T1SH	X	X		X
Second Disc Upstream	T2DKUS	X			X
Second Disc Downstream	T2DKDS	X			X
Second Rotor Blading	T2BD	X			X
Second Rotor Shroud	T2SH	X			
Drum End Face	TDMFS		X	X	
Drum Cylinder 1 Rotor	TDM1OD		X		
Drum Cylinder No Rotors	TDM2OD			X	

TABLE 12. Predicted Torques for each Configuration

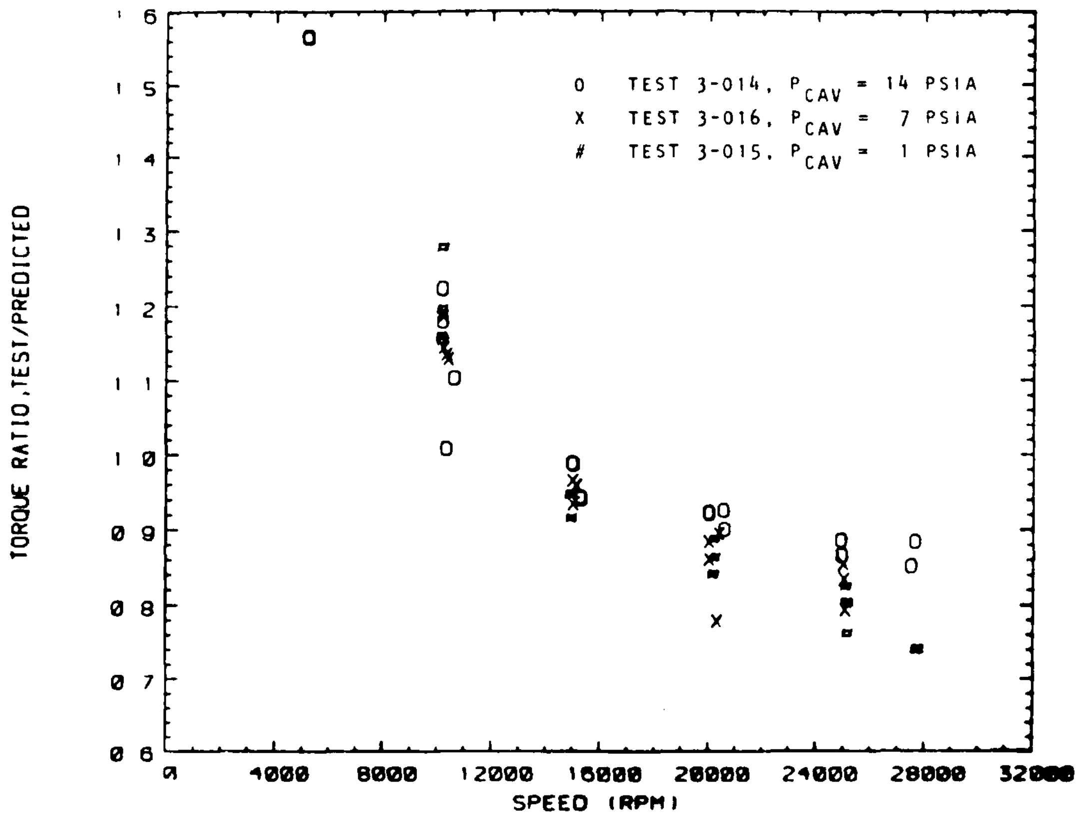


FIGURE 43. No Disc Tests - Original Torque Ratio versus Speed

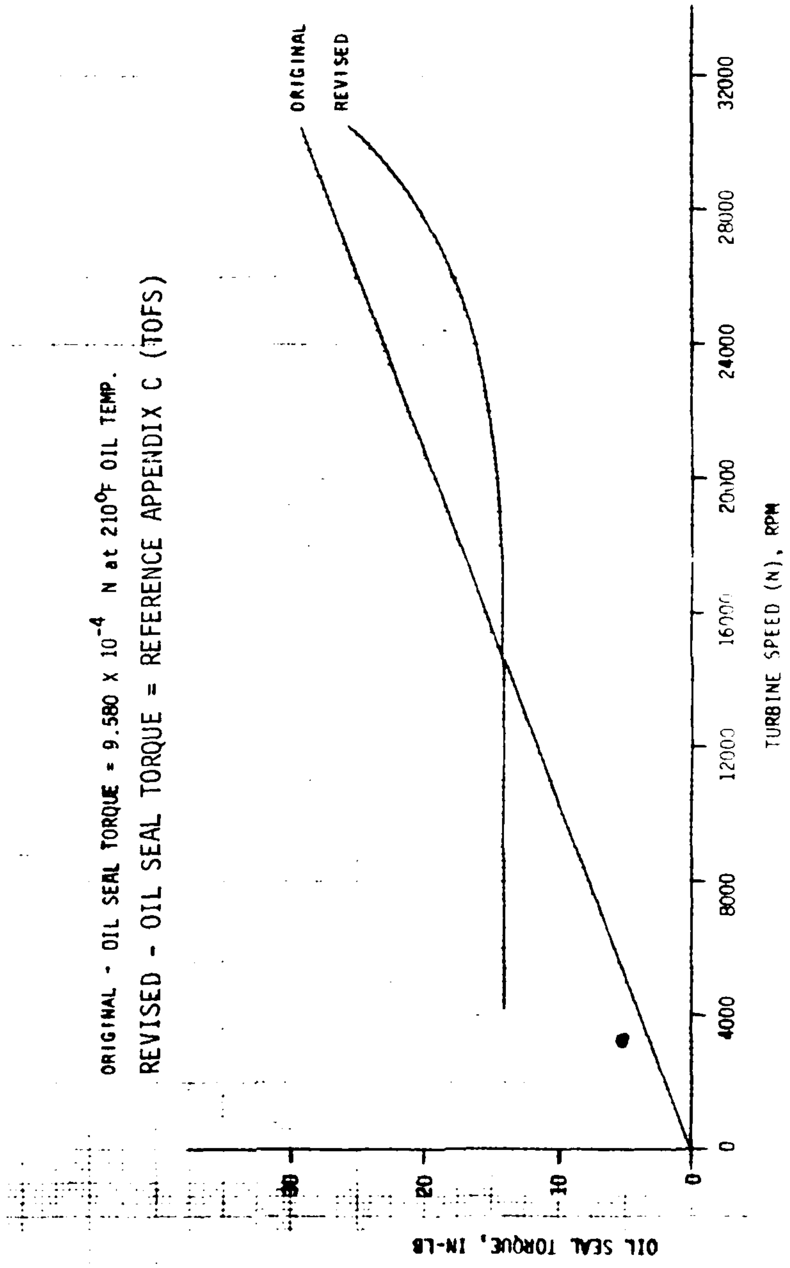


FIGURE 44. Predicted Oil Face Seal Torque

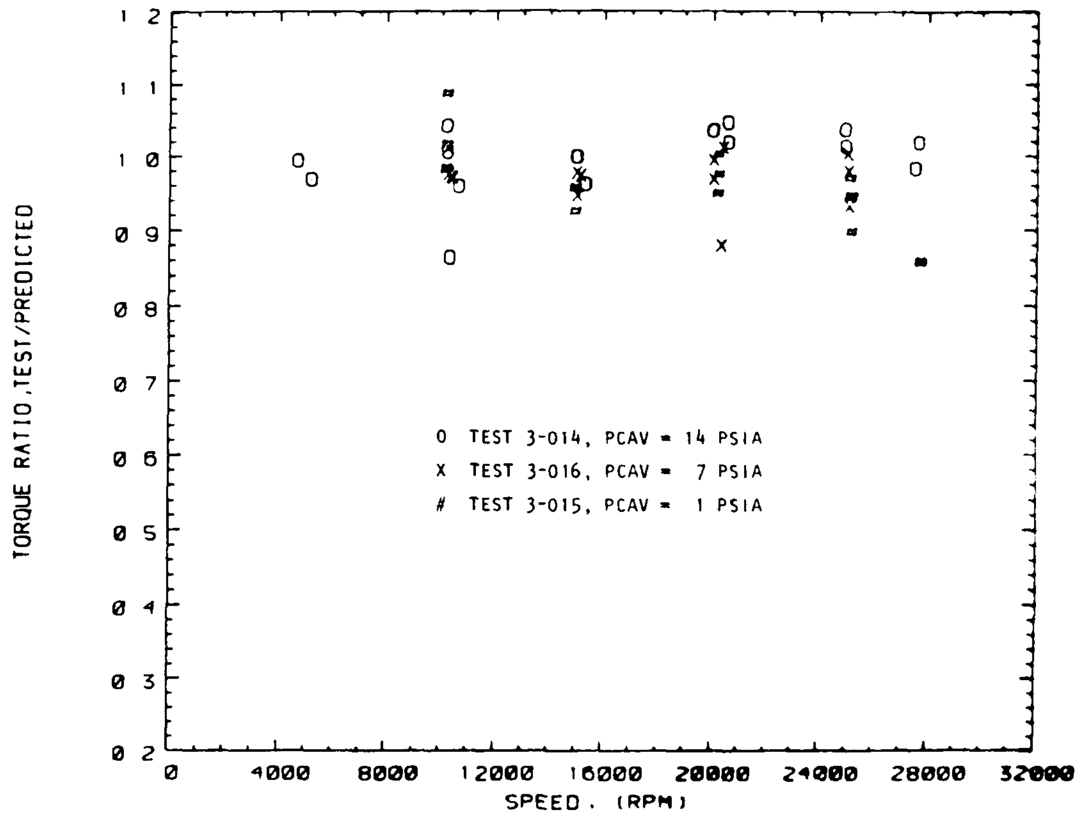


FIGURE 45. No disc Tests - Revised Torque Ratio versus Speed

Test Numbers	3-014, 3-015, 3-016	
Range of Cavity Pressure, psia	0.3 to 14	
Oil Seal Torque Prediction	Original	Revised
Number of Test Points	52	52
Average Torque Ratio	0.9911	0.9752
2-Sigma Scatter, Percent	41.58	9.61

Low Cavity Pressure Tests (1.3 psia max.). The low cavity pressure tests, with either a single rotor or two rotors, had similar torque ratio characteristics as the no-disc tests with the original predicted torques for all components. At low cavity pressures, the predicted rotor friction and windage torques were a small percentage of the total predicted torque. The turbine floating ring seal was the additional mechanical torque for the tests with either single or two rotors. Torque ratio using the original prediction equations was considerably less than 1.0 (0.4 minimum) for most test points. A revised predicted turbine floating ring seal torque characteristic was derived based on the test torque, the revised oil face seal torque characteristic, and neglecting the rotor friction and windage torques at the low cavity pressures. The original and revised turbine seal torque characteristics are shown in Figure 46 and a substantial decrease in predicted turbine seal torque is shown. The torque ratio was recalculated using the revised oil seal and turbine seal characteristics and is shown in Figure 47. The revised characteristics resulted in predicted torques closer to test torques and a significant reduction in data scatter as shown below:

Test Numbers	1-009, 2-012, 4-020	
Configurations	2 rotors, E3; 1 rotor, E3; rotor 1 - E3; rotor 2 - E1	
Range of Cavity Pressure, psia	0.3 to 1.3	
Seal Torque Predictions	Original	Revised
Number of Test Points	43	43
Average Torque Ratio	0.6793	0.9565
2-Sigma Scatter, Percent	48.49	21.57

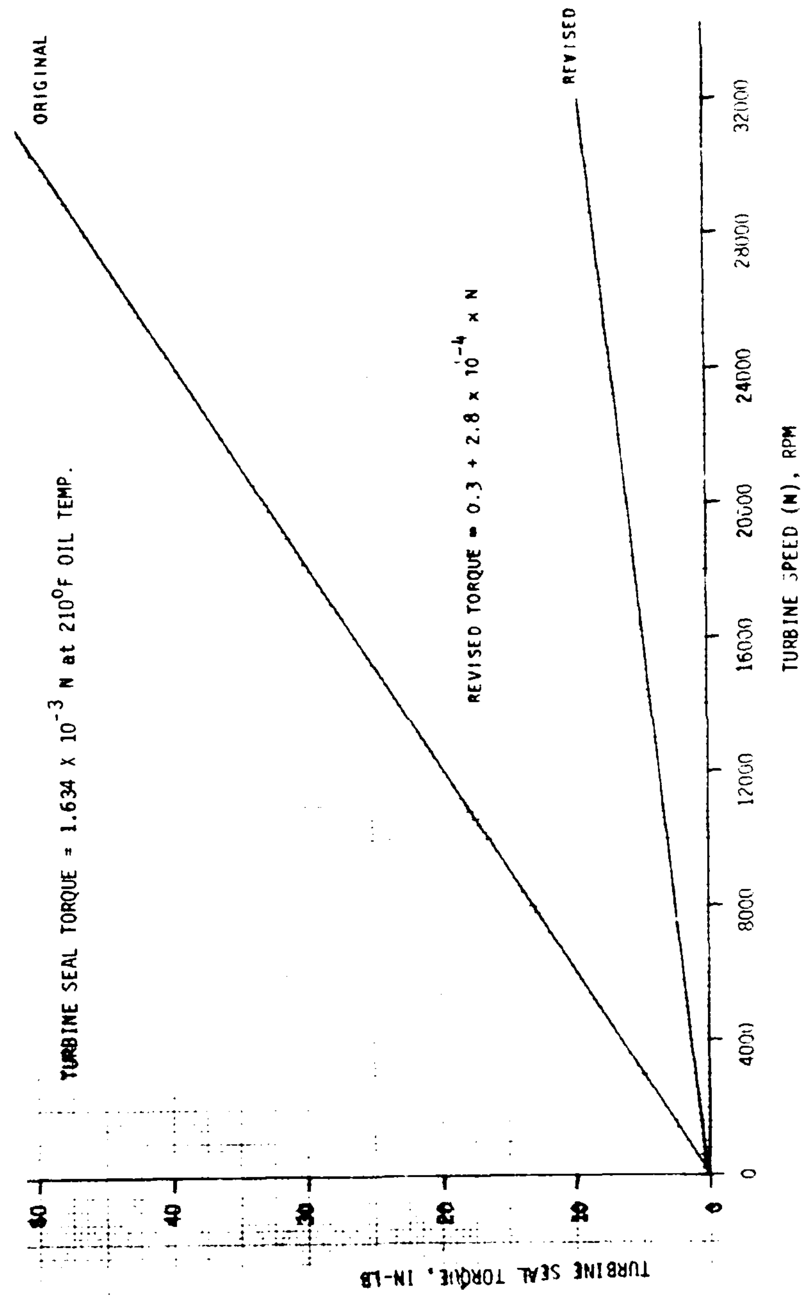
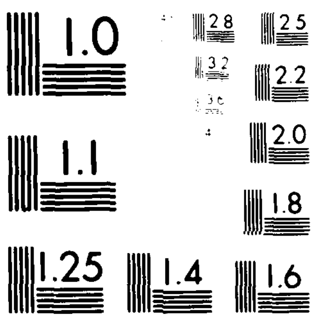


FIGURE 46. Predicted Turbine Floating Ring Seal Torque

AD-A098 310 ROCKWELL INTERNATIONAL CANOGA PARK CA ROCKETDYNE DIV F/G 21/5
TURBINE WINDAGE TORQUE TESTS.(U)
JAN 81 R F SUTTON F33615-79-C-2073
UNCLASSIFIED RI/RD-80-220 AFWAL-TR-80-2123 NL

2 of 2

END
DATE FILMED
5-81
DTIC



MICROCOPY RESOLUTION [illegible] CHART
NATIONAL [illegible]

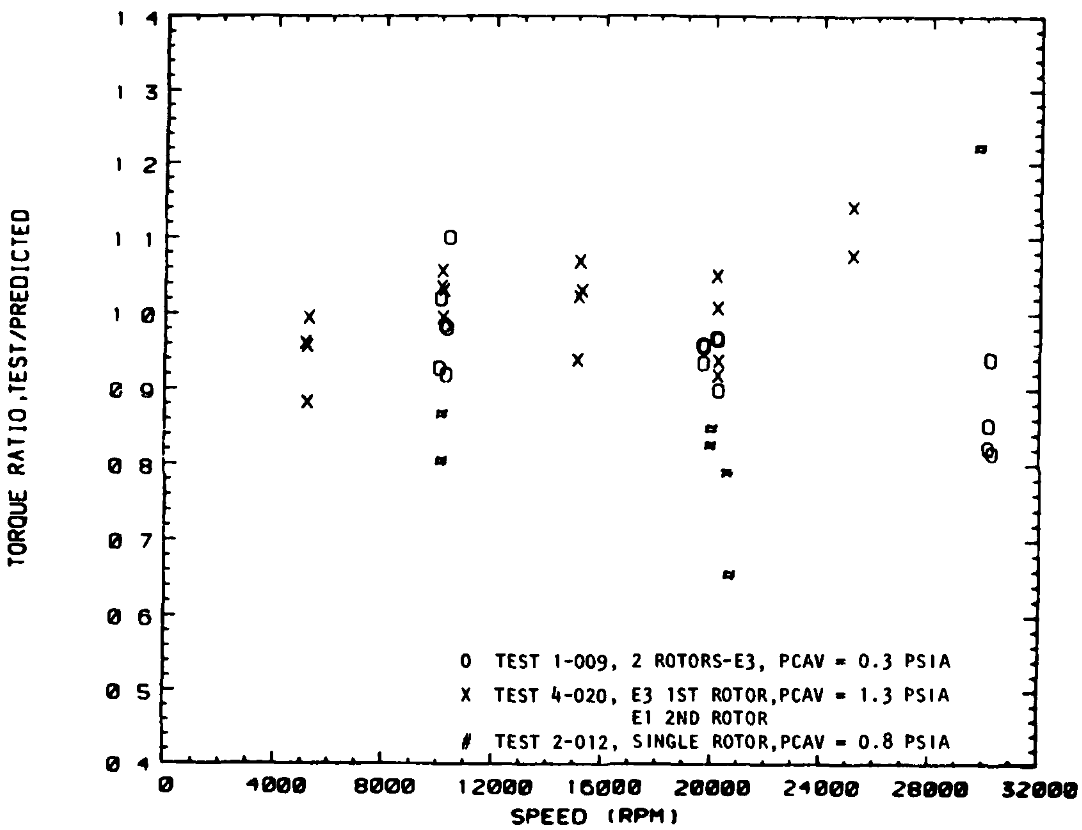


FIGURE 47. Low Cavity Pressure Tests - Torque Ratio versus Speed

Single Rotor Tests. The torque ratio was calculated using the revised oil face seal and turbine floating ring seal torque characteristics for the single rotor tests. Torque ratio versus speed is shown in Figure 48 and indicates an increasing torque ratio with speed from 5,000 to 20,000 RPM and approximately constant torque ratio from 20,000 to 30,000 RPM. The torque ratio also increases with cavity pressure. The average torque ratios from 20,000 to 30,000 RPM are listed below as a function of cavity pressure.

Target Cavity Pressure, psia	14	7
Number of Test Points	8	8
Average Torque Ratio	1.3324	1.1126
2-Sigma Scatter, Percent	7.74	8.51

Two Rotor Tests. The torque ratio was calculated using the revised oil and turbine seal characteristics for the two rotor tests. Torque ratio versus speed is shown in Figure 49. A large increase in torque ratio is shown for speeds from 5,000 to 20,000 RPM for both cavity pressures. The torque ratio values from 20,000 to 30,000 RPM are much higher than for the single rotor tests. Torque ratio increases with cavity pressure. Test points taken during the ascending speed steps had higher torque ratio values than data from descending speed steps. No observable difference is shown in the data between tests with the E3 second rotor with shrouded and fir-treed blading and the E1 second rotor with unshrouded integral blading. The blade profiles from hub to tip are the same for both second rotors.

Average torque ratio values between 20,000 and 30,000 RPM are listed below:

Target Cavity Pressure, psia	14		7	
Second Rotor	E3	E1	E3	R1
Number of Points	6	6	8	8
Average TR	1.9215	2.0383	1.7090	1.6086
2-Sigma Scatter, Percent	15.42	15.71	12.55	13.37

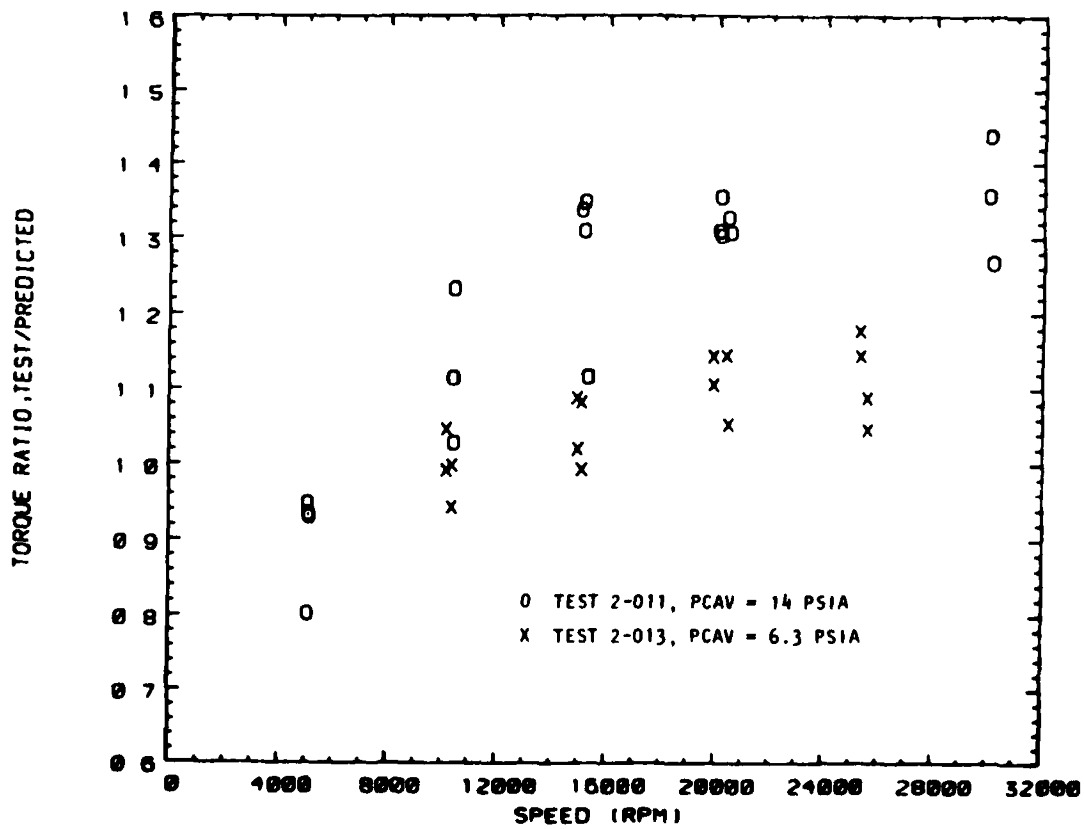


FIGURE 48. Single Rotor Tests - Torque Ratio versus Speed

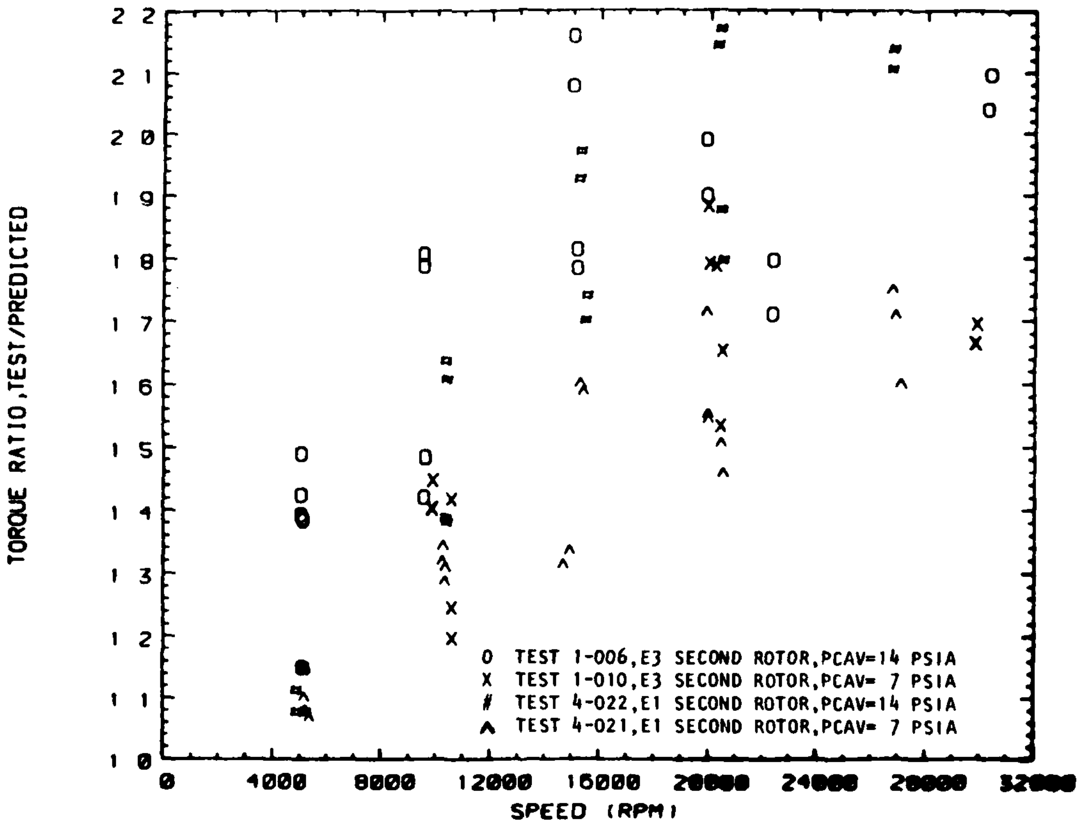


FIGURE 49. Two Rotor Tests - Torque Ratio versus Speed

Results

Predicted torque for the bearings and oil seal differed from the test torques for the no-disc tests. The predicted oil seal torque characteristic was revised to better agree with the test torque.

Predicted torque for the turbine floating ring seal differed from a test derived value. A revised turbine seal torque characteristic was developed to better agree with the test data.

For the single rotor tests, the test torque averaged 33 percent higher than the revised predicted torque at 14 psia cavity pressure from 20,000 to 30,000 RPM. At 7 psia cavity pressure, the test torque averaged 11 percent higher than the revised predicted torque.

For the two rotor tests, the test torque averaged 98 percent higher than the revised predicted torque at 14 psia cavity pressure from 20,000 to 30,000 RPM. At 7 psia cavity pressure, the test torque averaged 66 percent higher than the revised predicted torque.

No observable difference was shown between the shrouded E3 second rotor and the unshrouded E1 second rotor.

Conclusions

The original predictions of mechanical element torques (bearings and seals) were not representative for the test setup. Mechanical element torques should be verified or derived as part of the testing.

The experimentally based correlations from the references did not adequately predict the disc friction, blade windage, and shroud ring friction torques. Torque ratios varied with both speed and cavity pressure for both single and two rotor tests.

Predicted torque deviated the most from the test torque for the configuration with two rotors. The nonsymmetrical, reaction type blading of the second rotor apparently cause greater windage torque than predicted using torque coefficients from tests of symmetrical blading. The effect of the type of blading should be studied in more detail.

Recommendations

Modify the no-disc drums so the no-disc, tare tests could be run with the turbine floating ring seal installed.

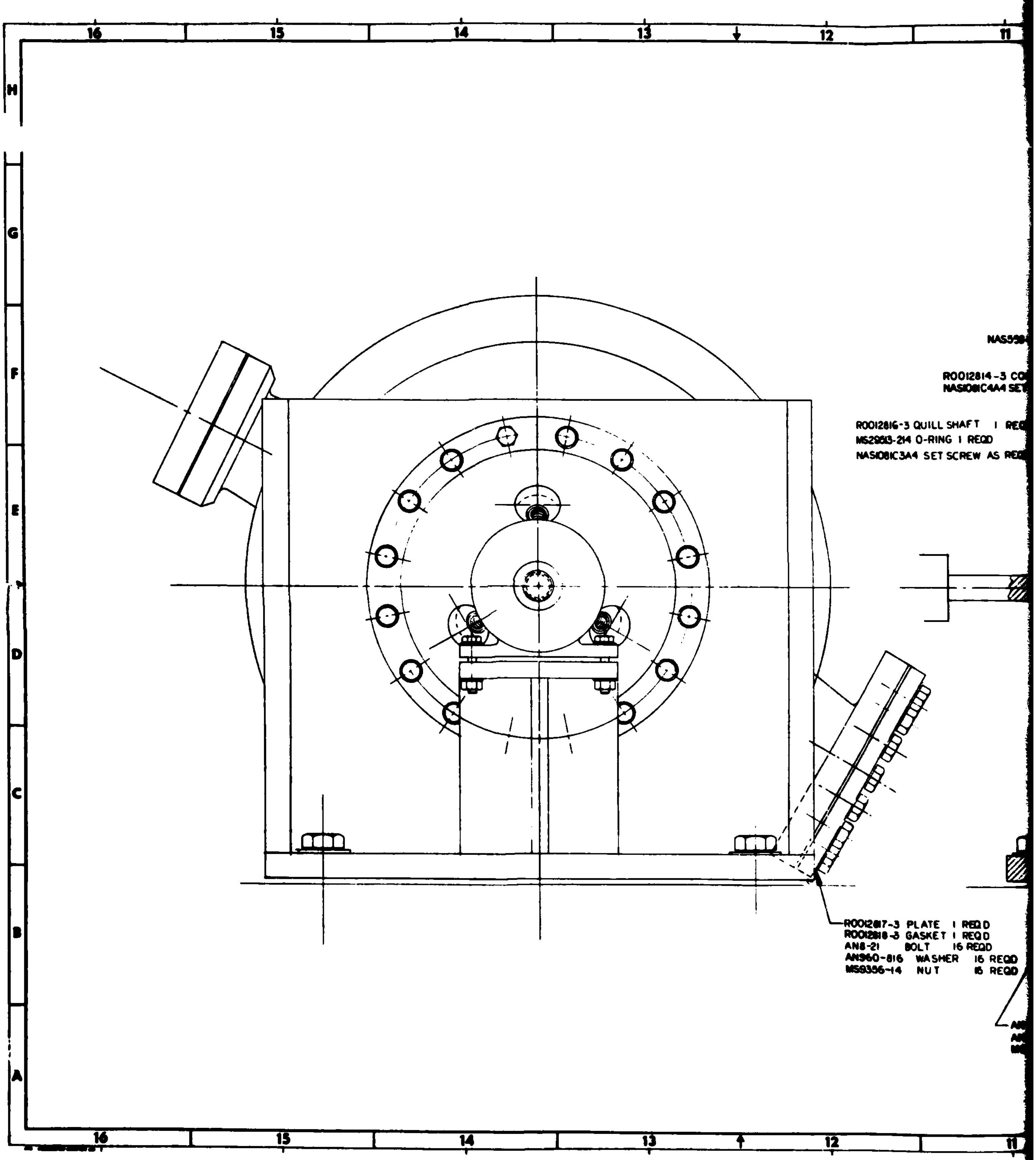
Install additional temperature and pressure measurements to determine conditions upstream and downstream of each disc and blade row.

Run the single rotor configuration with the blades removed and the fir tree slots filled to determine the blading torque for the nearly symmetrical impulse first rotor blades.

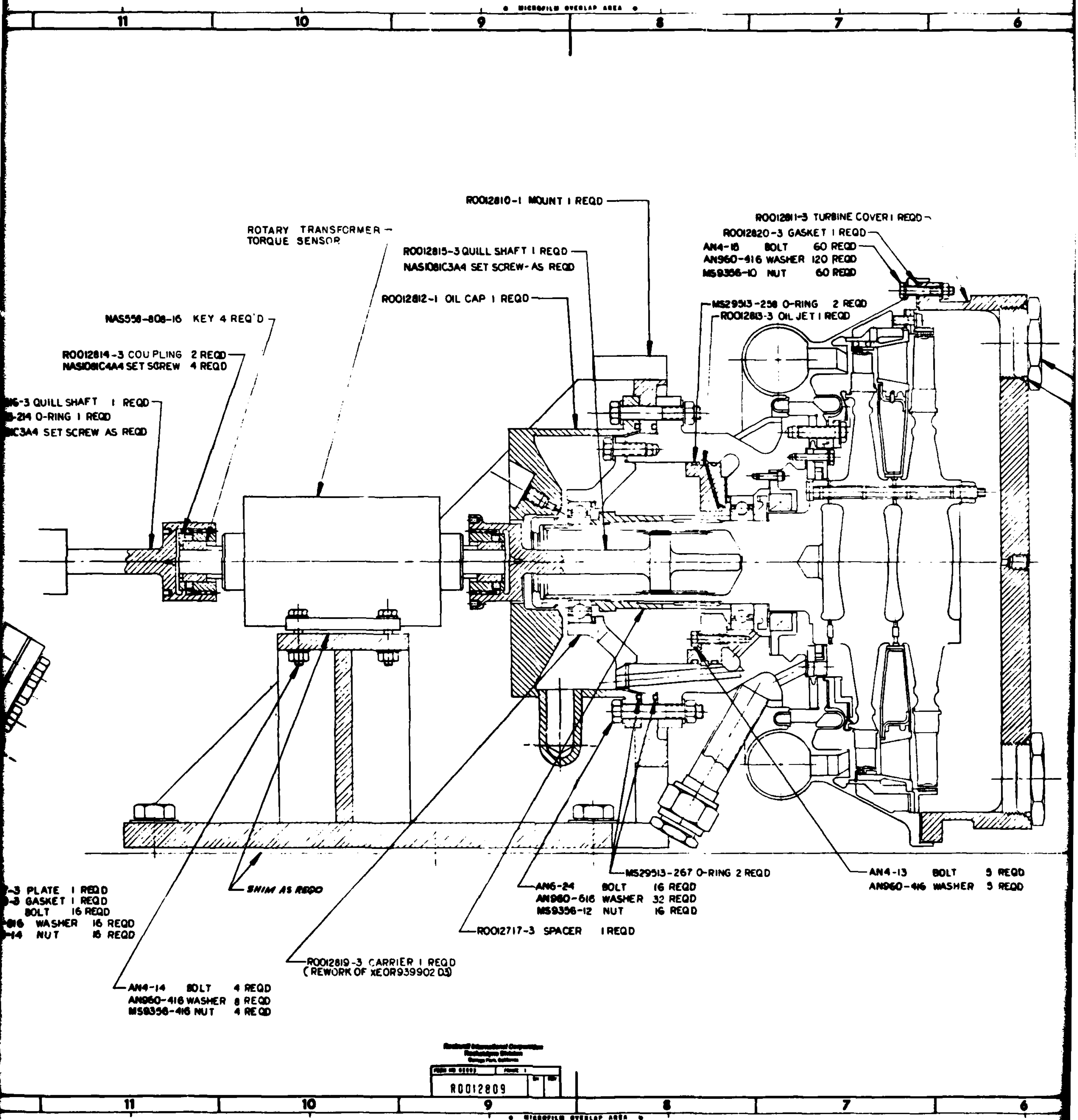
Run the second rotor alone, with and without blades, to determine the blading torque for the nonsymmetrical reaction type second rotor blading.

APPENDIX A

Windage Tester
Assembly Drawing
P/N R0012809



R0012816-3 QUILL SHAFT 1 REQ
MS29513-214 O-RING 1 REQD
NAS1081C3A4 SET SCREW AS REQ
R0012817-3 PLATE 1 REQD
R0012818-3 GASKET 1 REQD
AN8-21 BOLT 16 REQD
AN960-816 WASHER 16 REQD
MS9356-14 NUT 16 REQD



R0012810-1 MOUNT 1 REQD
R0012811-3 TURBINE COVER 1 REQD
ROTARY TRANSFORMER - TORQUE SENSOR
R0012820-3 GASKET 1 REQD
AN4-18 BOLT 60 REQD
AN960-416 WASHER 120 REQD
MS9356-10 NUT 60 REQD
R0012815-3 QUILL SHAFT 1 REQD
NAS1081C3A4 SET SCREW - AS REQD
R0012812-1 OIL CAP 1 REQD
MS29513-258 O-RING 2 REQD
R0012813-3 OIL JET 1 REQD
NAS558-808-16 KEY 4 REQ'D
R0012814-3 COUPLING 2 REQD
NAS1081C4A4 SET SCREW 4 REQD
16-3 QUILL SHAFT 1 REQD
-214 O-RING 1 REQD
C3A4 SET SCREW AS REQD
-3 PLATE 1 REQD
-3 GASKET 1 REQD
BOLT 16 REQD
-616 WASHER 16 REQD
-14 NUT 16 REQD
SHIM AS REQD
MS29513-267 O-RING 2 REQD
AN6-24 BOLT 16 REQD
AN960-616 WASHER 32 REQD
MS9356-12 NUT 16 REQD
AN4-13 BOLT 5 REQD
AN960-416 WASHER 5 REQD
R0012717-3 SPACER 1 REQD
R0012819-3 CARRIER 1 REQD (REWORK OF XEOR939902 D3)
AN4-14 BOLT 4 REQD
AN960-416 WASHER 8 REQD
MS9356-416 NUT 4 REQD
R0012809

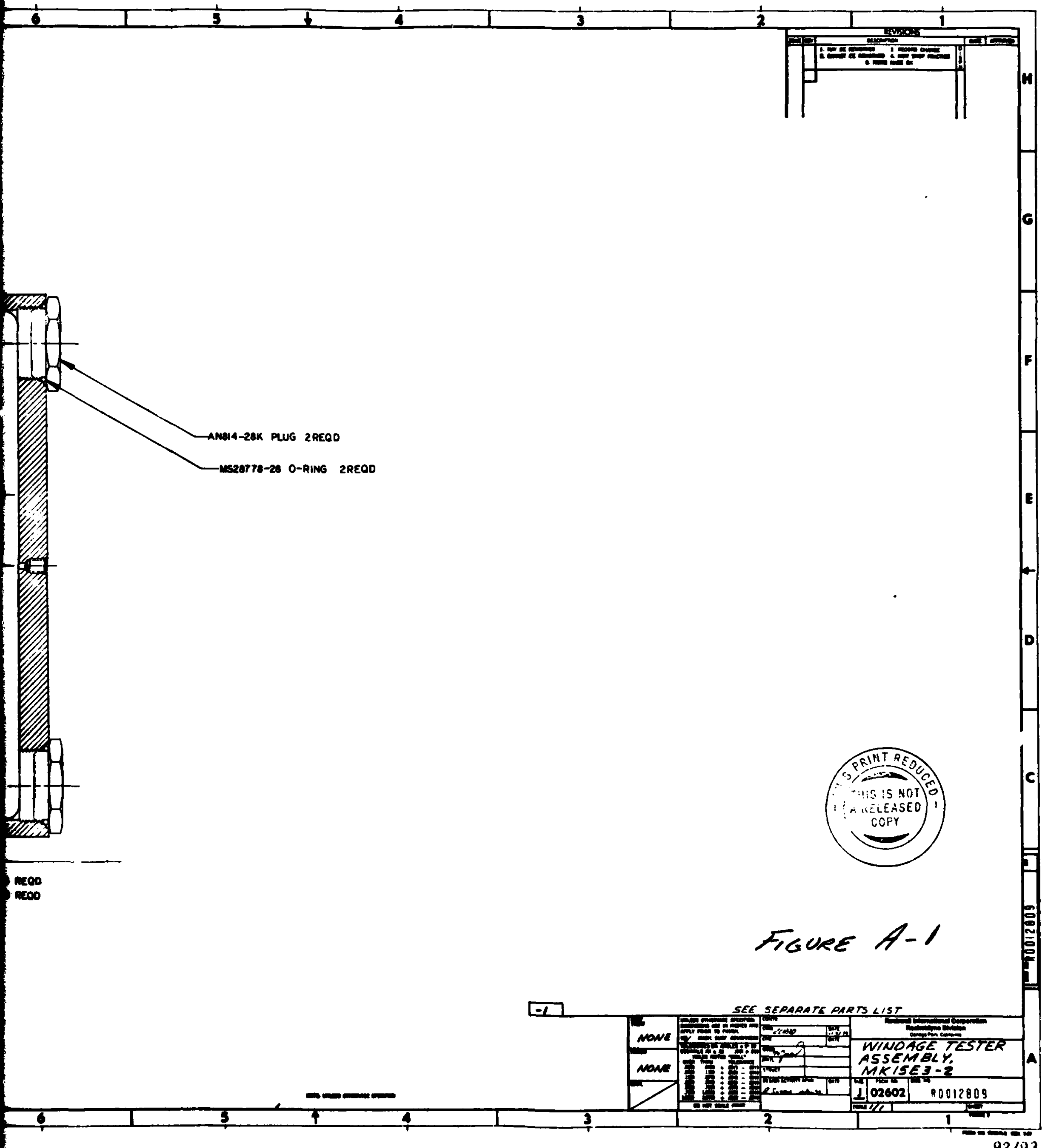

AN814-28K PLUG 2REQD
MS28778-28 O-RING 2REQD
REQD
REQD
REVISIONS
PRINT REDUCED
THIS IS NOT A RELEASED COPY
-1
SEE SEPARATE PARTS LIST
NONE
NONE
WINDAGE TESTER ASSEMBLY, MK15E3-2
02602
R0012809

FIGURE A-1

. 3

APPENDIX B

Turbine Windage Tests

- Data Compilation

MK15E3-2 TEST No. 1-001A DATE: 9/8/80 NOTE: BAROMETRIC P_a = 29.09 in Hg = 738.886 mm Hg x 0.0193* = 14.260 psia

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18–20
	Time	TCP1 CH 1	TCP4 CH 2	P_2 CH 3	(TURBINE) Q1 CH 4	(OUTBD) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR	AIR/OIL MIST PR.		REMARKS
	1 Sec	psia	psia	psia	GPM	GPM		in-lb	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
1	4:39	14.258	14.270	14.258	.698	.623	850	32	73	73	73	75	75	100	90	10		START TRANSIENT
2	7:22	14.253	14.272	14.256	.637	.593	1020.	18	73	73	73	75	75					STEADY STATE (SS)
3	8:22	14.218	14.276	14.250	.640	.594	2030	22	75	73	73	75	76					SS
4	9:05	14.157	14.288	14.238	.642	.595	3050	27	78	74	73	76	77					SS
5	9:30	14.088	14.302	14.224	.644	.596	4020	31	82	74	73	77	78					SS
6	10:04	13.978	14.321	14.204	.646	.597	5010	39	88	75	74	79	78					END TEST - SS
7	10:13	13.979	14.305	14.202	.646	.597	4810	6	89	76	74	79	78	100	90	10		SHUTDOWN
8	11:04																	STOP
9																		
10																		
11																		
12			TEST TIME =				6 MIN	25 SEC										
13																		
14																		
15																		
16																		
17																		
18																		
19																		
20																		
21																		
22																		
23																		
24																		
25																		
26																		
27																		
28																		
29																		
30																		
31																		
32																		
33																		
34																		
35																		

* Hg at 39F on Standard.

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.

CALCULATED BY
CHECKED BY [signature]
DATE 9/8/80

TABLE B-1: Raw Data

MK15E3-2 TEST No 1-002 DATE: 9/9/80 NOTE: BAROMETRIC P_A = 29.08 in Hg = 738.632 mm Hg x 0.0193* = 14.256 psia

	1 Time 15hr	2 TCP1 CH 1 psia	3 TCP4 CH 2 psia	4 P_2 CH 3 psia	5 (THROUGH) Q1 CH 4 GPM	6 (OUTA'S) Q2 CH 5 GPM	7 RPM CH 6	8 TORQUE CH 7 in-lb	9 TCT4 CH 11 °F	10 TCT2 CH 12 °F	11 TT1 CH 13 °F	12 TM-1 CH 14 °F	13 TM-2 CH 15 °F	14 LUBE TANK PR. PSIG	15 LUBE JET PR PSIG	16 Airfoil MIST PR. PSIG	17	18 REMARKS	19	20
1	29:44	14.256	14.256	14.256	.693	.614	0	25	73	73	74	75	75	110	100	10		TEST	START	
2	32:18	14.246	14.258	14.254	.650	.604	1050	16	74	73	74	75	76					Steady		STATE
3	35:09	14.214	14.262	14.248	.640	.596	2010	20	76	73	74	76	77						"	
4	37:51	14.155	14.264	14.238	.628	.586	3020	27	80	74	74	78	78						"	
5	41:23	14.072	14.276	14.222	.623	.579	4060	31	89	76	75	80	80						"	
6	43:56	13.981	14.298	14.203	.626	.578	5000	40	100	78	76	83	83						"	
7	45:20	14.246	14.262	14.254	.625	.578	1080	17	90	76	78	83	83					SS-	downramp.	
8	45:37																	STOP		
9																				
10																				
11			TEST		DURATION		=	15MIN	53SEC											
12																				
13																				
14																				
15																				
16																				
17																				
18																				
19																				
20																				
21																				
22																				
23																				
24																				
25																				
26																				
27																				
28																				
29																				
30																				
31																				
32																				
33																				
34																				
35																				

* Hg at 39F or standard.

PROJECT MK 15E3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.

CALCULATED BY / CHECKED BY: [illegible signature]
DATE: 9/9/80

TABLE B-2: Raw Data

MK15E3-2 TEST No. 1-003 DATE: 9/10/80 NOTE: BAROMETRIC P_a = 29.13 in Hg = 739.902 mm Hg x 0.0193 = 14.280 psia

	Time (1)	TCP1 CH 1 (2)	TCP4 CH 2 (3)	P_a CH 3 (4)	Q1 (TURBINE) CH 4 (5)	Q2 (OUTB'D) CH 5 (6)	RPM CH 6 (7)	TORQUE CH 7 (8)	TCT4 CH 11 (9)	TBT2 CH 12 (10)	TT1 CH 13 (11)	TM-1 CH 14 (12)	TM-2 CH 15 (13)	LUBE TANK PR. (14)	LUBE JET PR. (15)	AIR/OIL MIST PR. (16)	(17)	REMARKS (18–20)
	14 HR	PSIA	PSIA	PSIA	GPM	GPM		IN-LB	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
1	57:15	14.280	14.282	14.280	1.086	.904	0	30	73	74	74	76	76	220	180	10		TEST START
2	58:06	14.234	14.286	14.272	1.152	.964	2030	22	75	74	74	76	77	↓	↓	↓		Steady State
3	58:49	14.099	14.304	14.246	1.102	.928	3980	32	82	74	74	78	78	↓	↓	↓		Steady State
4	59:49	13.996	14.323	14.224	1.160	.972	5030	40	91	75	74	78	79	↓	↓	↓		Steady State
5	59:57	13.986	14.325	14.222	1.161	.973	5300	76	93	75	75	78	79	↓	↓	↓		UP RAMP
6	15 HR																	
7	00:06	13.831	14.349	14.189	1.162	.973	6720	124	100	76	75	79	79	↓	↓	↓		UP RAMP
8	00:14	13.553	14.494	14.123	1.164	.974	10030	154	135	78	75	80	81	↓	↓	↓		UP RAMP
9	00:23	12.870	14.674	13.994	1.165	.973	11180	108	158	81	76	82	83	↓	↓	↓		UP RAMP - C/O
10	00:31	13.037	14.537	14.042	1.166	.973	10280	24	154	82	77	83	83	↓	↓	↓		DOWN RAMP
11	01:14	14.242	14.294	14.272	1.167	.973	1940	23	104	77	78	81	81	↓	↓	↓		DOWN RAMP
12	01:31	14.280	14.286	14.280	1.154	.965	0	—	100	77	78	81	81	↓	↓	↓		TEST STOP

TOTAL DURATION = 4 min 16 SEC

* Hg at 32°F on standard.

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.

PROJECT MK15E3-2 SHEET 1 OF

CALCULATED BY
CHECKED BY R. [illegible]
DATE

TABLE B-3: Raw Data

MK15E3-2 TEST No. BALANCE DATE: 9/11/80 NOTE: BAROMETRIC P_A = 29.08 in Hg = 738.632 mm Hg × 0.0193* = 14.256 psia

	Time	TCP1 CH 1	TCP4 CH 2	P_2 CH 3	(TURBINE) Q1 CH 4	(OUTBD) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR.	AIRFOIL MIST PR.		REMARKS
	13	PSIA	PSIA	PSIA	GPM	GPM		IN-LB	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
1	04:28	14.252	14.256	14.252	1.302	1.038	0	43	75	74	75	76	76	200	180	10		START #1
2	05:20	14.151	14.268	14.232	1.218	.997	3010	25	79	75	75	77	78					55
3	07:11	13.964	14.301	14.196	1.232	1.009	5060	43	93	76	76	79	79					55
4	08:45	13.276	14.448	14.061	1.247	1.015	9540	86	160	83	82	87	86					
7	16:10	14.252	14.256	14.252	1.281	1.030	0	10	97	77	86	82	82					START #2
8	17:09	14.153	14.274	14.234	1.222	.996	3020	25	108	76	86	83	83					55
9	18:09	13.982	14.307	14.200	1.226	1.001	5020	41	116	77	85	84	84					55
10	18:43	13.312	14.436	14.063	1.234	1.006	9500	100	155	81	86	87	86					55
13	25:10	14.252	14.256	14.252	1.280	1.027	0	0	102	77	90	83	83					START #3
14	26:39	14.153	14.274	14.234	1.230	0.998	3040	23	111	77	89	84	84					55
16	27:56	13.290	14.307	14.168	1.225	0.998	5050	40	118	77	89	85	85					55
17	28:47	13.290	14.444	14.063	1.235	1.002	9540	82	167	82	91	89	88					55
20	42:05	13.345	14.438	14.075	1.245	1.007	9530	80	200	85	107	92	91					55 #4
23	57:09	14.250	14.254	14.252	1.321	1.036	0	0	138	80	111	86	86					START #5
24	58:26	13.365	14.436	14.077	1.251	1.006	9510	85	203	85	112	91	90					55
26	14:																	
27	02:48	14.250	14.254	14.252	0	0	0	0	145	81	119	88	88	↓	↓	↓		START #6
28	04:04	13.381	14.434	14.081	1.256	1.010	9470	84	207	85	117	93	91					55
29	04:30	13.379	14.434	14.079	1.252	1.007	9510	84	212	86	118	93	92					55

* Hg at 39F on standard

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

CALCULATED BY R Sutton
CHECKED BY
DATE

TABLE B-4: Raw Data

MK15E3-2 TEST No 1-004 DATE: 9/11/80 NOTE: BAROMETRIC P_a = 29.08 in Hg = 738.632 mm Hg x 0.0193* = 14.256 psia

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18–20
	Time	TCP1 CH 1	TCP4 CH 2	P_a CH 3	(TURBINE) Q1 CH 4	(OUTBD) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR.	AIRFOIL MIST PR.		REMARKS
	15hr	PSIA	PSIA	PSIA	GPM	GPM		in-lb	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
1	11:42	14.248	14.252	14.252	1.430	1.077	0	2	98	82	97	81	81	200	180	10		START
2	12:25	14.147	14.268	14.232	1.365	1.055	3080	25	103	81	97	82	82	↓	↓	↓		SS
3	13:33	13.972	14.297	14.198	1.371	1.064	5090	45	113	83	97	84	83					SS
4	14:16	13.288	14.446	14.061	1.382	1.070	9550	82	164	86	98	88	86					SS
5	14:23	13.304	14.444	14.063	1.384	1.071	9550	94	168	87	99	88	87					SS
6	15:15:24																	STOP
7																		
8																		
9				TEST		DURATION		=		3MIN	42 SEC							

* Hg at 39F as standard.

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.

PROJECT MK15E3-2 SHEET 1 OF

CALCULATED BY R. SUTTON CHECKED BY DATE

TABLE B-5: Raw Data

MK15E3-2 TEST No. L-005 DATE: 9/11/80 NOTE: BAROMETRIC Pr. = 29.08 in Hg = 738.632 mm Hg x 0.0193 = 14.256 psia

	Time	TCP1 CH 1	TCP4 CH 2	P_2 CH 3	Q1 (turbine) CH 4	Q2 (nutec) CH 5	RPM CH 6	Torque CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	Lube Tank Pr.	Lube Jet Pr.	Ampl. Mist Pr.		Remarks	
	15 hr	psia	psia	psia	GPM	GPM		in-lb	°F	°F	°F	°F	°F	psig	psig	psig			
1	24:45	14.246	14.254	14.252	1.432	1.082	920	86	116	82	102	85	85	200	180	10		START	
2	25:36	13.926	14.307	14.198	1.370	1.057	5100	44	129	83	102	87	86					55	
3	26:19	13.312	14.440	14.067	1.376	1.062	9530	83	174	86	103	90	89					55	
4	26:27	13.326	14.438	14.067	1.377	1.063	9540	91	178	87	103	91	89					55	
5																			
6	27:44	12.417	14.653	13.903	1.395	1.070		140	292	95	116	96	93					55 - 40	
7	28:27	14.244	14.258	14.252	—	—												STOP	
8																			
9																			
10																			
11				TEST		DURATION			3 MIN	42 SEC									

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

CALCULATED BY [signature]
CHECKED BY
DATE

* Hg at 32°F on standard

TABLE B-6: Raw Data

MK15E3-2 TEST No. 1-006 DATE: 9/12/80 NOTE: BAROMETRIC P_a = 29.03 in Hg = 737.362 mm Hg x 0.0193* = 14.231 psia

PROJECT MK15E3-2 | SHEET __ OF __

ROCKETDYNE A DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION

1 Time	2 TCP1 CH 1	3 TCP4 CH 2	4 P_2 CH 3	5 (TURBINE) Q1 CH 4	6 (OUTBD) Q2 CH 5	7 RPM CH 6	8 TORQUE CH 7	9 TCT4 CH 11	10 TBT2 CH 12	11 TT1 CH 13	12 TM-1 CH 14	13 TM-2 CH 15	14 LUBE TANK PR	15 LUBE JET PR	16 AMPL MIST PR	17	18–20 REMARKS
MIN	PSIA	PSIA	PSIA	GPM	GPM		IN LB	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
14:37	14.229	14.233	14.231	1.307	1.027	0	2	76	76	77	77	78	200	180	10		START
15:54	13.999	14.282	14.125	1.235	.990	5010	46	91	77	77	79	79					SS
16:03	13.945	14.282	14.175	1.235	.991	5010	43	93	77	77	79	79					SS
16:11	13.945	14.282	14.175	1.236	.991	5010	44	93	77	77	79	79					SS
17:03	13.266	14.426	14.049	1.244	.995	9520	88	145	82	80	84	82					SS
17:11	13.274	14.426	14.049	1.245	.996	9520	87	148	82	81	84	83					SS
18:19	12.210	14.676	13.837	1.265	1.002	14970	153	286	91	94	90	87					SS
18:28	12.216	14.672	13.839	1.267	1.003	15000	159	292	92	97	90	88					SS
19:43	11.340	14.881	13.694	1.293	1.012	22320	201	490	108	141	101	97					SS
19:53	11.442	14.875	13.698	1.295	1.013	22320	191	497	108	146	102	97					SS
20:36	9.435	15.508	13.391	1.317	1.020	30260	316	917	135	172	117	108					SS
20:45	9.534	15.460	13.377	1.321	1.022	30350	325	931	138	179	117	109					SS
21:36	11.762	14.781	13.801	1.330	1.026	19840	179	694	120	226	111	110					SS
21:44	11.726	14.777	13.799	1.330	1.027	19870	171	694	118	230	110	111					SS
22:36	12.701	14.550	13.970	1.327	1.029	15140	122	592	100	263	112	110					SS
22:44	12.729	14.550	13.968	1.327	1.029	15140	120	591	100	268	112	110					SS
23:35	13.620	14.357	14.126	1.323	1.031	9540	63	507	97	291	112	109					SS
23:44	13.649	14.353	14.124	1.322	1.031	9580	66	502	97	294	112	109					SS
25:09	14.045	14.259	14.201	1.317	1.033	5070	41	449	94	308	110	108					SS
25:17	14.042	14.259	14.199	1.316	1.033	5080	34	447	94	307	110	108					SS
25:36	14.042	14.259	14.199	1.316	1.033	5100	41	445	94	307	110	108					SS
26:00	14.221	14.225	14.231	0	0	0	3	427	91	297	109	107	↓	↓	↓		STOP

DURATION = 11 min 23 sec

* Hg at 32°F as standard.

TABLE B-7: Raw Data

MK15E3-2 TEST No 1-007 DATE: 9/12/80 NOTE BAROMETRIC P_a = 29.03 in Hg = 737.362 mm Hg x 0.0193 = 14.231 psia

Time 16 hr	TCP1 CH 1 psia	TCP4 CH 2 psia	P_a CH 3 psia	Q1 (turbine) CH 4 GPM	Q2 (outa'd) CH 5 GPM	RPM CH 6	Torque CH 7 in-lb	TCT4 CH 11 °F	TBT2 CH 12 °F	TT1 CH 13 °F	TM-1 CH 14 °F	TM-2 CH 15 °F	Lube Tank Pr psig	Lube Jet Pr psig	Air/Oil Mist Pr psig		Remarks	
25:35	3.981	3.82	4.000	1.497	1.089	0	2	119	93	109	84	84	200	180	10		START	
26:43	3.961	3.88	4.020	1.391	1.063	5010	28	144	92	108	85	85	↓	↓	↓		55	
26:52	3.961	3.88	4.039	1.391	1.063	5000	28	144	92	108	86	85					55	
27:00	3.961	3.88	4.020	1.391	1.064	5000	30	144	92	108	86	85					55	
27:35	3.801	3.923	4.000	1.395	1.069	9920	48	179	92	108	90	87					55	
27:43	3.801	3.923	4.000	1.396	1.070	9920	57	182	92	108	90	87					55	
28:43	3.542	3.913	3.960	1.408	1.076	14830	69	263	97	108	95	90					55	
28:52	3.542	3.913	3.960	1.411	1.078	14820	68	268	98	109	95	91					55	
29:00	3.542	3.913	3.960	1.412	1.078	14800	68	273	98	109	95	91					55	
29:51	3.242	4.066	3.900	1.426	1.085	19930	95	407	112	111	103	96					55	
30:00	3.242	4.066	3.900	1.431	1.086	19800	94	416	112	112	105	97					55	
30:08	3.242	4.066	3.900	1.435	1.087	19800	87	430	114	112	106	98					55	
30:42	2.463	3.821	3.380	1.447	1.092	29950	131	694	139	115	117	105					55	*
30:51	5.560	9.209	8.376	1.445	1.092	30240	89	784	143	123	119	107					55	*
31:50	1.564	1.759	1.841	1.462	1.095	20240	59	590	127	136	114	107					55	
31:59	1.724	1.993	2.021	1.462	1.095	20220	67	586	125	136	113	107					55	
32:08	1.943	2.249	2.361	1.461	1.095	20250	68	588	124	141	113	108					55	
32:59	3.282	3.474	3.480	1.453	1.095	15110	54	515	105	164	113	107					55	
33:07	2.623	2.760	2.840	1.452	1.094	15030	46	506	104	165	113	107					55	
33:15	2.323	2.493	2.521	1.451	1.094	15130	57	501	104	164	113	107					55	
33:58	3.522	3.739	4.000	1.435	1.085	10390	43	449	102	160	112	106					55	
34:06	5.300	5.515	5.598	1.426	1.079	10390	54	451	102	162	112	106					55	
34:15	5.200	5.332	5.338	1.415	1.073	10410	48	447	101	164	112	106					55	
35:14	2.703	2.535	2.721	1.351	1.031	5190	35	389	100	156	110	105					55	
35:23	2.223	2.270	2.241	1.337	1.022	5140	32	382	99	151	109	105	↓	↓	↓		55	
36:05	14.191	14.190	14.191	-	-	-	-	347	96	179	107	104					STOP	

DURATION = 10 min 30 sec

* NON STABILIZED PRESSURES.

* Hg at 39F or Standard.

TABLE B-8: Raw Data

MK15E3-2 TEST No. 1-008 DATE: 9/15/80 NOTE: BAROMETRIC P = 29.13 in Hg = 739.902 mm Hg x 0.0193* = 14.280 psia

Time (hr)	TCP1 CH 1 (PSIA)	TCP4 CH 2 (PSIA)	P_2 CH 3 (PSIA)	(TURBINE) Q1 CH 4 (GPM)	(OUTA'S) Q2 CH 5 (GPM)	RPM CH 6	TORQUE CH 7 (IN-LB)	TCT4 CH 11 (°F)	TBT2 CH 12 (°F)	TT1 CH 13 (°F)	TM-1 CH 14 (°F)	TM-2 CH 15 (°F)	LUBE TANK PR. (PSIG)	LUBE JET PR (PSIG)	AIRFOIL MIST PR. (PSIG)		REMARKS
24:17	0.416	0.216	0.455	1.193	.956	0	1	73	73	73	74	74	200	180	10		start
25:17	0.416	0.216	0.435	1.113	.920	9780	34	90	79	73	78	77	↓	↓	↓		SS
25:25	0.416	0.216	0.435	1.116	.922	9780	30	90	79	73	79	77	↓	↓	↓		SS
25:34	0.416	0.216	0.435	1.118	.923	9770	29	91	80	73	79	77	↓	↓	↓		SS
25:59	0.376	0.236	0.416	TRANSIENT		DATA	1	153	90	73	85	81					FAC C/O NO [illegible]

TEST DURATION ≅ 1 min 42 SEC

* Hg at 32°F as standard.

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.

CALCULATED BY R. Smith
CHECKED BY
DATE

TABLE B-9: Raw Data

MK15E3-2 TEST No. 1-009 DATE: 9/15/80 NOTE BAROMETRIC Pr = 29.13 in Hg = 739.902 mm Hg x 0.0193 = 14.280 psia

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE

Time (hr)	TCP1 CH 1 (psia)	TCP4 CH 2 (psia)	P_3 CH 3 (psia)	Q1 (inboard) CH 4 (GPM)	Q2 (outboard) CH 5 (GPM)	RPM CH 6	Torque CH 7 (N·m)	TCT4 CH 11 (°F)	TBT2 CH 12 (°F)	TT1 CH 13 (°F)	Tm1 CH 14	TA2 CH 15 (°F)	Lube Tank Pr (psig)	Lube Jet Pr (psig)	Air/Oil Mist Pr (psig)	Remarks
31:21	0.416	0.216	0.435	1.166	.941	0	2	75	79	73	[illegible]	80	2.0	180	10	START
32:21	0.416	0.216	0.435	1.113	.913	10050	33	98	83	73	[illegible]	82				55
32:29	0.416	0.216	0.435	1.113	.914	10060	33	99	83	73	86	82				55
32:38	0.416	0.216	0.435	1.114	.914	10030	30	99	83	73	86	83				55
33:37	0.376	0.236	0.416	1.136	.921	19640	42	174	98	73	93	89				55
33:46	0.376	0.236	0.416	1.138	.922	19650	43	176	100	73	93	89				55
33:54	0.376	0.236	0.416	1.142	.923	19600	43	177	101	73	94	90				55
34:37	0.316	0.256	0.416	1.166	.929	30040	51	333	130	73	112	99				55
34:45	0.316	0.256	0.416	1.169	.930	30160	57	339	132	73	113	100				55
34:54	0.316	0.256	0.416	1.176	.932	30320	55	343	137	73	116	102				55
35:02	0.316	0.256	0.416	1.179	.933	30230	63	352	139	73	118	103				55
35:11	0.316	0.256	0.416	1.182	.934	30170	55	355	140	73	119	104				55
35:53	0.376	0.236	0.416	1.187	.936	20100	44	244	118	73	116	103				55
36:02	0.376	0.236	0.416	1.184	.936	20150	44	242	116	73	110	103				55
36:10	0.376	0.236	0.416	1.184	.937	20200	41	241	115	73	110	104				55
36:53	0.416	0.216	0.416	1.175	.936	10200	32	169	101	74	107	102				55
37:01	0.416	0.216	0.416	1.174	.937	10260	30	166	100	74	107	102				55
37:10	0.416	0.216	0.416	1.172	.937	10290	32	164	99	74	107	102				55
37:18	0.416	0.216	0.416	1.171	.937	10350	36	162	97	74	107	102				55
38:01	0.416	0.216	0.435	0	0	0	6	115	93	74	104	101				STOP

TEST DURATION = 6 min 39 sec

TABLE B-10: Raw Data

MK1SE3-2 TEST No 1-010 DATE: 9/15/80 NOTE: BAROMETRIC Pa = 29.13 in Hg = 739.902 mm Hg x 0.0193* = 14.280 psia

Time	TCP1 CH 1	TCP4 CH 2	P_2 CH 3	Q1 (TURBINE) CH 4	Q2 (OUTBD) CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR	LUBE JET PR	AIR/OIL MIST PR.	17	REMARKS
11 hr	psia	psia	psia	GPM	GPM		in-lb	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
45:11	8.429	8.411	8.587	1.222	.966	0	4	94	89	81	96	95	200	180	10		START
46:19	7.040	7.501	7.397	1.139	.921	9870.	61	176	88	81	98	96					SS
46:28	7.040	7.501	7.397	1.137	.920	9870.	59	179	88	82	98	96					SS
46:36	7.040	7.501	7.397	1.135	.919	9850	59	181	88	82	98	96					SS
47:44	6.108	7.913	7.259	1.155	.926	19930.	142	453	103	91	105	101					SS
47:53	6.128	7.913	7.259	1.157	.927	19960.	135	464	104	93	105	101					SS
48:01	6.108	7.913	7.259	1.159	.927	20200.	136	477	105	96	105	102					SS
48:52	5.354	8.088	7.140	1.181	.934	29870	197	873	133	116	118	108					SS
49:01	5.374	8.068	7.140	1.185	.935	29820	192	896	137	119	119	109					SS
49:09	5.414	8.047	7.140	1.188	.935	29790	191	915	139	124	119	109					SS
50:00	6.287	7.643	7.259	1.194	.939	20380.	111	723	120	168	114	108					SS
50:08	6.326	7.643	7.259	1.194	.939	20440	120	724	118	172	113	108					SS
50:59	7.120	7.400	7.378	1.185	.940	10570.	59	565	102	181	111	106					SS
51:08	7.140	7.400	7.378	1.184	.940	10590	52	559	99	181	111	106					SS
51:16	7.120	7.420	7.378	1.183	.941	10590	50	554	98	183	110	106					SS
52:07	7.437	7.299	7.397	1.179	.942	0	2	444	95	190	108	105					STOP

TEST DURATION = 6 min 56 SEC

* Hg at 39F on Standard.

PROJECT MK1SE3-2 SHEET OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

CALCULATED BY
CHECKED BY R. Sutton
DATE

TABLE B-11: Raw Data

MK15E3-2 TEST No 2-011 DATE: 9/18/80 NOTE BAROMETRIC PR: 29.08 in Hg • 738.632 mm Hg × 0.0193 • 14.256 PSIA

Time	TCP1 CH 1	TCP4 CH 2	P_2 CH 3	Q1 (TURBINE) CH 4	Q2 (OUTA'S) CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR	LUBE JET PR	A/O/L MIST PR	REMARKS
15hr	PSIA	PSIA	PSIA	GPM	GPM		IN-16	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG	
20:27	14.256	14.256	14.256	1.494	1.074	0	0	82	82	84	83	83	200	180	10	START
21:27	14.156	14.232	14.236	1.450	1.072	5110	26	89	83	84	85	85	↓	↓	↓	55
21:35	14.156	14.236	14.236	1.442	1.066	5090	26	90	83	84	85	85				55
21:44	14.156	14.236	14.212	1.434	1.061	5080	26	90	83	84	85	85				55
22:35	13.658	14.297	14.316	1.413	1.046	10430	51	118	90	87	91	87				55
22:43	13.638	14.297	14.316	1.450	1.070	10400	46	120	91	88	91	87				55
22:52	13.658	14.297	14.316	1.473	1.086	10410	46	121	91	88	92	87				55
23:35	12.940	14.358	14.376	1.514	1.111	15170	72	172	99	96	95	91				55
23:47	12.940	14.358	14.376	1.505	1.105	15160	74	176	100	98	96	92				55
23:52	12.940	14.358	14.376	1.497	1.098	15080	73	180	100	99	96	92				55
24:43	12.143	14.439	14.435	1.460	1.066	20140	92	260	112	118	103	97				55
24:52	12.143	14.419	14.435	1.462	1.066	20080	92	266	113	120	104	99				55
25:00	12.163	14.419	14.415	1.465	1.067	20100	95	277	115	125	105	100				55
25:43	10.249	14.602	14.535	1.476	1.074	30140	142	445	140	150	117	108				55
25:51	10.508	14.602	14.515	1.489	1.077	30020	159	474	146	161	120	110				55
26:08	10.628	14.581	14.495	1.496	1.080	30000	149	492	149	175	121	112				55
26:42	12.342	14.398	14.396	1.503	1.085	20410	91	408	131	197	115	113				55
26:51	12.362	14.398	14.396	1.503	1.086	20490	90	407	129	198	115	114				55
27:50	13.140	14.337	14.336	1.500	1.087	15330	59	354	109	210	114	113				55
27:57	13.140	14.337	14.336	1.490	1.081	15340	58	352	109	209	114	113				55
28:53	13.738	14.276	14.296	1.428	1.041	10420	42	309	104	203	114	113				55
28:58	13.738	14.276	14.296	1.421	1.035	10430	41	308	103	203	114	111				55
29:49	14.136	14.256	14.236	1.371	1.004	5070	22	282	101	188	112	110				55
29:58	14.136	14.256	14.256	1.364	1.000	5070	26	280	101	187	112	110	↓	↓	↓	55
30:31	14.256	14.256	14.216	—	—	0	0	253	97	190	110	109				STOP

TEST DURATION = 10 min 4 SEC

* Hg at 39F on Standard.

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE

CALCULATED BY R. Sutton

CHECKED BY

DATE

TABLE B-12: Raw Data

MK15E3-2 TEST No. 2-012 DATE: 9/18/80 NOTE: BAROMETRIC P_a = 29.08 in Hg = 738.632 mm Hg x 0.0193* = 14.256 psia

Time	TCP1 CH 1	TCP4 CH 2	P_3 CH 3	(TURBINE) Q1 CH 4	(OUTA'S) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR.	AIR/OIL MIST PR.		REMARKS
15	PSIA	PSIA	PSIA	GPM	GPM		in-lb	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
53:25	0.860	0.609	0.841	1.595	1.124	0	0	208	95	128	95	95	200	180	10		START
54:42	0.895	0.629	0.841	1.531	1.105	10130	28	223	97	127	99	97					SS
54:51	0.895	0.629	0.841	1.523	1.102	10130	26	223	97	127	99	97					SS
55:59	0.781	0.629	0.861	1.525	1.100	19940	38	259	116	126	108	104					SS
56:07	0.781	0.629	0.861	1.529	1.102	19930	37	260	117	126	108	105					SS
56:33	0.661	0.649	0.881	1.544	1.147	29770	79	313	138	125	119	110					TRANSIENT ?
57:07	0.741	0.629	0.841	1.556	1.117	20640	30	277	130	125	114	108					SS
57:15	0.741	0.629	0.861	1.561	1.120	20530	36	276	127	125	113	109					SS
58:15	0.821	0.629	0.841	0	0	0	2	219	110	125	109	107					STOP

TEST DURATION = 4 min 50 s

* Hg at 39F as standard.

PROJECT MK15E3-2 SHEET OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.

CALCULATED BY
CHECKED BY R. Sutton
DATE

TABLE B-13: Raw Data

MK15E3-2 TEST No 2-013 DATE: 9/19/80 NOTE BAROMETRIC P = 29.198 in Hg. 741.629 mm Hg x 0.0193 = 14.313 psia

1 Time	2 TCP1 CH 1	3 TCP4 CH 2	4 P_s CH 3	5 (TURBINE) Q1 CH 4	6 (OUTBD) Q2 CH 5	7 RPM CH 6	8 TORQUE CH 7	9 TCT4 CH 11	10 TBT2 CH 12	11 TT1 CH 13	12 TM-1 CH 14	13 TM-2 CH 15	14 LUBE TANK PR	15 LUBE JET PR	16 AIR/OIL MIST PR.	17	18	19 REMARKS	20
10 hr	PSIA	PSIA	PSIA	GPM	GPM		IN-16	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG				
23:12	6.227	6.055	6.194	1.256	1.047	0	0	78	78	77	79	79	200	150	10			START	
25:03	6.247	6.360	6.512	1.227	.950	10160	38	107	85	78	85	83	↓	↓	↓			55	
25:12	6.247	6.360	6.512	1.233	.953	10160	36	108	86	78	86	83						55	
26:20	5.988	6.401	6.552	1.260	.965	14930	50	157	94	80	91	87						55	
26:29	5.988	6.401	6.552	1.266	.969	14960	47	160	95	81	91	87						55	
27:[illegible]	5.671	6.462	6.612	1.326	1.004	19890	63	232	107	89	99	93						55	
27:37	5.671	6.462	6.612	1.330	1.006	19870	65	237	108	91	100	93						55	
28:20	5.313	6.503	6.651	1.347	1.012	25330	82	324	125	101	108	100						55	
28:28	5.313	6.482	6.631	1.349	1.012	25310	81	332	127	104	109	101						55	
28:37	5.313	6.482	6.631	1.350	1.012	25260	83	339	128	108	111	102						55	
29:28	5.353	6.482	6.631	1.357	1.012	25550	77	392	132	121	114	105					[illegible]	55	
29:36	5.353	6.482	6.631	1.358	1.012	25570	74	402	134	125	114	106						55	
30:19	5.750	6.442	6.572	1.356	1.011	20350	65	365	122	131	112	106						55	
30:28	5.750	6.442	6.572	1.354	1.010	20440	60	366	120	133	111	106						55	
31:02	6.068	6.401	6.552	1.349	1.009	15100	49	330	106	133	110	106						55	
31:10	6.068	6.401	6.552	1.347	1.009	15110	45	328	104	133	110	105						55	
31:52	6.306	6.360	6.512	1.339	1.006	10370	36	295	100	129	109	104						55	
32:01	6.306	6.360	6.512	1.338	1.006	10360	34	292	100	128	109	104	↓	↓	↓			55	
32:35	6.305	6.320	6.472	.295	.019	0	2	231	97	131	107	103						STOP	

TEST DURATION = 9 min 23 s

* Hg at 39° on [illegible].

ROCKETDYNE

PROJECT MK15E3-2 SHEET 1 OF

TABLE B-14: Raw Data

MK1SE3-2 TEST No 3-014 DATE: 9/23/80 NOTE BAROMETRIC P_a = 29.05 in Hg = 737.87 mm Hg x 0.0193* = 14.241 psia

PROJECT MK1SE3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

Time	TCP1 CH 1	TCP4 CH 2	P_2 CH 3	(TURBINE) Q1 CH 4	(OUTB'D) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR	LUBE JET PR	AIR/OIL MIST PR	17	REMARKS
10	PSIA	PSIA	PSIA	GPM	GPM		IN-16	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG		
37:14	14.241	14.241	14.241	—	—	—	—	74	74	74	76	76	220	180	10		START
38:56	14.181	14.241	14.241	1.136	.901	4660	23	74	85	74	79	79					55
40:03	13.883	14.241	14.241	1.151	.909	10200	29	76	81	74	83	81					53
40:13	13.883	14.241	14.241	1.153	.909	10180	30	76	82	74	84	81					55
40:56	13.426	14.241	14.241	1.158	.906	14990	33	80	89	74	88	83					55
41:04	13.426	14.241	14.241	1.160	.907	14960	33	80	90	74	89	84					55
41:38	12.811	14.241	14.241	1.207	.935	19940	39	86	102	74	93	88					55
41:47	12.830	14.241	14.241	1.213	.937	19970	39	87	104	74	95	89					55
42:29	12.075	14.241	14.241	1.238	.947	24920	44	96	123	74	105	97					55
42:38	12.115	14.241	14.241	1.240	.947	24900	45	97	124	74	106	98					55
43:12	11.579	14.241	14.241	1.252	.950	27630	49	106	135	75	116	107					55
43:20	11.638	14.241	14.241	1.254	.950	27490	47	107	136	75	117	108					55
44:11	12.751	14.241	14.241	1.256	.952	20530	40	99	122	76	112	110					55
44:19	12.791	14.241	14.241	1.256	.952	20560	39	99	122	76	111	111					55
45:02	13.426	14.241	14.241	1.251	.951	15270	32	95	104	76	109	109					55
45:10	13.407	14.241	14.241	1.250	.951	15300	32	95	102	76	109	109					55
45:27	13.824	14.241	14.241	1.248	.951	10620	22	92	100	76	109	108					55
45:36	13.883	14.241	14.241	1.246	.950	10320	25	92	100	76	108	108					55
46:35	14.162	14.241	14.241	1.237	.949	5170	23	89	97	77	107	105					55
46:43	14.162	14.241	14.241	1.235	.949	5180	23	89	96	77	106	105					55
47:08	14.241	14.241	14.241	—	—	—	—	87	93	77	106	104					STOP

TEST DURATION = 9m 54s

CALCULATED BY R. Sutton

CHECKED BY

DATE

* Hg at 39F as standard.

TABLE B-15: Raw Data

MK15E3-2 TEST No 3-015 DATE 9/23/80 NOTE BAROMETRIC P_a = 29.05 in Hg = 737.87 mm Hg x 0.0193* = 14.241 psia

Time	TCP1 CH 1	TCP4 CH 2	P_a CH 3	(turbine) Q1 CH 4	(outa's) Q2 CH 5	RPM CH 6	TORQUE CH 7	T:T4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR.	AIR/OIL MIST PR.	17	18	REMARKS
"	psia	psia	psia	GPM	GPM		in-lb	°F	°F	°F	°F	°F	psig	psig	psig			
02:45	1.387	1.167	1.387	1.176	.906	0	0	85	86	76	93	92	220	180	10			START
03:36	1.347	1.167	1.387	1.156	.899	10190	28	88	87	76	96	93						55
03:44	1.347	1.167	1.387	1.186	.920	10180	29	88	88	76	96	93						55
04:18	1.307	1.167	1.387	1.254	.967	14910	31	90	92	76	99	95						55
04:26	1.307	1.167	1.387	1.265	.973	14930	31	90	93	76	99	96						55
05:00	1.267	1.167	1.387	1.276	.977	20190	36	92	104	77	104	99						55
05:09	1.267	1.167	1.387	1.278	.977	20190	37	93	106	77	104	100						55
05:59	1.208	1.167	1.387	1.242	.944	25080	41	96	124	77	114	107						55
06:08	1.208	1.167	1.387	1.238	.939	25090	40	97	126	77	114	108						55
06:41	1.168	1.167	1.387	1.228	.922	27750	40	99	136	77	120	111						55
06:50	1.168	1.167	1.387	1.219	.921	27700	40	100	136	77	120	112						55
07:49	1.208	1.167	1.387	1.230	.925	25150	40	99	136	77	121	113						55
07:57	1.208	1.167	1.367	1.231	.926	25140	38	98	135	77	121	113						55
08:47	1.267	1.167	1.367	1.234	.930	20140	35	95	125	77	119	113						55
08:56	1.267	1.167	1.367	1.234	.930	20150	35	95	124	77	118	113						55
09:21	1.307	1.167	1.367	1.232	.930	14940	30	93	106	77	117	112						55
09:29	1.307	1.167	1.367	1.231	.931	14930	31	93	105	77	116	112						55
10:11	1.347	1.167	1.767	1.226	.932	10130	28	91	102	77	115	110						55
10:20	1.347	1.167	1.367	1.226	.932	10140	28	91	102	77	114	110						55
10:53	1.367	1.167	1.367	—	—	—	—	89	98	77	113	109						STOP

TEST DURATION = 8m 8s

* Hg at 32F or standard

PROJECT MK15E3-2

ROCKETDYNE

CALCULATED BY R. Sutton

TABLE B-16: Raw Data

MK15E3-2 TEST No. 3-016 DATE: 9/23/80 NOTE: BAROMETRIC P_a = 29.05 in Hg = 737.87 mm Hg x 0.0193* = 14.241 psia

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Time	TCP1 CH 1	TCP4 CH 2	P_3 CH 3	(turbine) Q1 CH 4	(outer's) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR.	Air/oil MIST PR.		REMARKS		
	11th	psia	psia	psia	GPM	GPM		in-lb	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG				
1	16:36	6.393	6.255	6.373	0	0	0	0	88	97	82	104	103	220	180	10			START	
2	17:09	7.228	7.288	7.407	1.221	.933	10400	28	94	92	82	106	104						55	
3	17:18	7.228	7.309	7.407	1.217	.931	10330	28	94	92	82	106	104						55	
4	18:00	7.029	7.309	7.407	1.201	.920	15010	31	97	94	82	109	105						55	
5	18:08	7.029	7.309	7.407	1.211	.927	14990	32	98	95	82	109	105						55	
6	18:50	6.711	7.309	7.426	1.269	.964	20000	37	103	109	82	113	108						55	
7	18:58	5.209	7.309	7.426	1.275	.967	20000	36	103	112	82	113	109						55	
8	19:32	6.413	7.369	7.466	1.290	.975	25060	40	110	123	82	120	113						55	
9	19:40	6.413	7.369	7.486	1.293	.975	25000	43	111	126	83	121	114						55	
10	19:48	6.433	7.369	7.486	1.294	.976	25020	42	111	127	83	121	114						55	
11	20:30	6.751	7.369	7.486	1.298	.977	20360	38	107	122	83	118	113						55	
12	20:39	6.791	7.369	7.486	1.298	.977	20300	33	107	121	83	118	113						55	
13	21:20	7.069	7.369	7.486	1.293	.977	15120	32	103	102	83	116	111						55	
14	21:29	7.069	7.369	7.486	1.292	.977	15130	32	103	101	83	116	111						55	
15	22:02	7.307	7.369	7.486	1.286	.976	[illegible]210	29	101	100	83	115	110						55	
16	22:10	7.307	7.369	7.486	1.285	.975	10230	28	100	99	83	115	110						55	
17	22:35	7.486	7.369	7.486	0	0	0	0	97	97	83	113	109						STOP	
23					TEST DURATION:			5m	59s											

* Hg at 39F as standard.

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

PROJECT MK15E3-2

SHEET OF

CALCULATED BY

CHECKED BY R. Sutton

DATE

TABLE B-17: Raw Data

MK15E3-2 TEST No 4-020 DATE: 9/26/80 NOTE: BAROMETRIC Pr. = 29.01 in Hg = 736.854 mm Hg x 0.0193* = 14.221 psia

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Time	TCP1 CH 1	TCP4 CH 2	P3 CH 3	(TURBINE) Q1 CH 4	(OUTB'D) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR	AIR/OIL MIST PR.		REMARKS		
	13 hr	psia	psia	psia	GPM	GPM		in-lb	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG				
1	45:04	1.424	1.224	1.424	0	0	0	0	79	77	78	78	78	220	180	10			START	
2	45:55	1.324	1.143	1.344	1.250	.949	5090	25	85	78	78	79	79						SS	
3	46:03	1.324	1.143	1.344	1.251	.950	5160	25	85	78	78	79	79						SS	
4	47:02	1.264	1.163	1.324	1.267	.961	10150.	34	115	84	78	82	82						SS	
5	47:11	1.264	1.163	1.324	1.274	.964	10110	36	117	85	78	83	83						SS	
6	48:02	1.184	1.184	1.324	1.292	.970	15110	45	175	94	78	89	87						SS	
7	48:10	1.184	1.184	1.304	1.297	.972	15100	43	183	95	78	89	87						SS	
8	49:01	1.085	1.184	1.284	1.313	.978	20140	51	269	107	78	96	92						SS	
9	49:09	1.085	1.184	1.284	1.314	.979	20110	53	280	108	78	97	93						SS	
10	49:59	1.005	1.204	1.284	1.333	.983	25140	69	399	125	79	108	100						SS	
11	50:08	1.005	1.204	1.284	1.335	.984	25110	65	406	128	79	109	101						SS	
12	50:41	.925	1.224	1.244	1.342	.986	29440	136	499	133	79	114	104						TRANSIENT ?	
13	52:05	1.105	1.163	1.284	1.351	.990	20190	47	404	125	79	113	109						SS	
14	52:14	1.105	1.163	1.284	1.351	.991	20170	46	399	123	79	112	110						SS	
15	53:29	1.184	1.143	1.304	1.345	.991	15220	43	329	103	80	110	110						SS	
16	53:38	1.184	1.143	1.304	1.344	.991	15080	39	327	102	80	110	110						SS	
17	54:28	1.244	1.123	1.304	1.339	.991	10100	35	273	101	81	110	108						SS	
18	54:36	1.264	1.123	1.304	1.338	.991	10180	35	271	101	81	110	108						SS	
19	55:35	1.284	1.102	1.304	1.331	.991	5210	26	231	97	82	108	106						SS	
20	55:43	1.284	1.102	1.304	1.330	.991	5180	23	230	97	82	108	106						SS	
21	56:17	1.304	1.102	1.304	0	0	0	0	193	94	83	107	106						STOP	

TEST DURATION: 11m 13s

* Hg at 39F or standard.

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

CALCULATED BY R. [illegible]
CHECKED BY
DATE

TABLE B-18: Raw Data

MK15E3-2 TEST No 4-021 DATE: 9/26/80 NOTE: BAROMETRIC Pa = 29.01 in Hg = 736.854 mm Hg x 0.0193* = 14.221 psia

	Time	TCP1 CH 1	TCP4 CH 2	P2 CH 3	(TURBINE) Q1 CH 4	(OUTBD) Q2 CH 5	RPM CH 6	TORQUE CH 7	TCT4 CH 11	TBT2 CH 12	TT1 CH 13	TM-1 CH 14	TM-2 CH 15	LUBE TANK PR.	LUBE JET PR	AIR/OIL MIST PR.	17	18	REMARKS	20
	19th	PSIA	PSIA	PSIA	GPM	GPM		IN-16	°F	°F	°F	°F	°F	PSIG	PSIG	PSIG				
1	00:00	6.068	6.045	6.148	1.325	.986	—	—	218	90	83	102	101	220	180	10			START	
2	01:23	6.108	6.085	6.168	1.292	.967	5170	31	214	90	NR	NR	NR						SS	
3	01:30	6.108	6.085	6.168	1.289	.966	5180	30	214	90	NR	NR	NR						SS	
4	01:37	6.108	6.085	6.168	1.288	.965	5170	30	213	90	NR	NR	NR						SS	
5	01:56	6.108	6.085	6.168	1.287	.967	5170	31	213	90	107	102	101						SS	
6	02:54	5.869	6.146	6.148	1.292	.970	10360	54	254	91	108	103	101						SS	
7	03:03	5.889	6.146	6.148	1.294	.970	10340	53	257	91	108	103	101						SS	
8	03:45	5.470	6.248	6.108	1.302	.973	15410	88	347	95	109	106	103						SS	
9	03:53	5.470	6.228	6.108	1.303	.973	15300	88	354	97	110	106	103						SS	
10	04:31	5.271	6.329	6.068	1.315	.977	19930	107	485	106	115	110	106						SS	
11	04:43	5.291	6.309	6.048	1.317	.977	19870	118	495	108	116	110	106						SS	
12	04:52	5.291	6.309	6.048	1.319	.977	19920	107	505	109	118	111	106						SS	
13	05:37	4.832	6.533	6.028	1.332	.981	27080	151	742	127	132	119	111						SS	
14	05:42	4.852	6.533	6.008	1.335	.982	26880	159	761	130	135	120	111						SS	
15	05:59	4.872	6.472	6.008	1.337	.983	26740	161	776	132	137	121	111						SS	
16	06:57	5.371	6.289	6.068	1.344	.986	20400	103	684	121	149	117	111						SS	
17	07:05	5.371	6.289	6.068	1.344	.986	20470	100	686	120	151	117	111						SS	
18	07:30	5.729	6.146	6.108	1.343	.986	14670	67	609	109	159	115	111						SS	
19	07:39	5.729	6.167	6.108	1.342	.987	14890	69	604	107	161	115	111						SS	
20	08:37	5.988	6.085	6.128	1.337	.987	10240	52	541	102	170	115	110						SS	
21	08:46	5.988	6.106	6.148	1.336	.986	10250	53	536	102	174	115	109						SS	
22	09:36	6.148	6.048	6.148	1.332	.987	5200	30	492	98	175	113	108						SS	
23	09:44	6.148	6.048	6.148	1.331	.987	5350	30	488	98	172	113	108						SS	
24	10:51	6.188	6.004	6.148	0	0	0	0	432	95	168	110	107						STOP	

Test Duration = 10m 51s

NR = Recording channel not turned on.

* Hg at 32°F on standard.

PROJECT MK15E3-2 SHEET 1 OF

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

CALCULATED BY
CHECKED BY [signature]
DATE

TABLE B-19: Raw Data

MK15E3-2 TEST No. 4-022 DATE: 9/26/80 NOTE: BAROMETRIC P_a = 29.01 in Hg = 736.854 mm Hg × 0.0193* = 14.221 psia

	1 Time	2 TCP1 CH 1	3 TCP4 CH 2	4 P_2 CH 3	5 (turbine) Q1 CH 4	6 (outa's) Q2 CH 5	7 RPM CH 6	8 Torque CH 7	9 TCT4 CH 11	10 TBT2 CH 12	11 TT1 CH 13	12 TM-1 CH 14	13 TM-2 CH 15	14 Lube Tank Pr.	15 Lube Jet Pr.	16 Airfoil Mist Pr.	17	18–20 Remarks
	15hr	psia	psia	psia	GPM	GPM		in-lb	°F	°F	°F	°F	°F	psig	psig	psig		
1	15:09	14.241	14.221	14.221	1.468	1.017	0	0	210	97	152	84	84	220	180	10		START
2	15:52	14.081	14.241	14.181	1.386	.990	4870	33	219	97	147	85	85					SS
3	16:00	14.081	14.241	14.181	1.396	.998	4880	32	218	97	147	86	85					SS
4	16:43	13.464	14.363	14.081	1.434	1.030	10420	81	261	97	146	89	86					SS
5	16:52	13.464	14.363	14.081	1.432	1.032	10360	82	264	97	146	89	87					SS
6	17:34	12.646	14.546	13.942	1.443	1.036	15290	142	364	101	152	93	89					SS
7	17:43	12.686	14.546	13.942	1.444	1.037	15240	138	370	101	154	94	89					SS
8	18:17	11.769	14.290	13.802	1.451	1.040	20370	211	502	108	164	98	92					SS
9	18:25	11.809	14.770	13.822	1.454	1.040	20250.	206	516	111	167	99	93					SS
10	19:50	11.032	15.035	13.683	1.482	1.049	26770	272	867	141	218	115	102					SS
11	19:59	11.071	15.014	13.703	1.484	1.050	26710	266	879	142	225	116	103					SS
12	20:33	12.228	14.648	13.902	1.481	1.052	20410	171	736	132	245	113	103					SS
13	20:41	12.208	14.648	13.882	1.488	1.052	20460	164	735	128	250	113	104					SS
14	20:50	12.208	14.648	13.882	1.488	1.052	20350	95	732	128	254	114	104					TRANSIENT
15	21 24	12.945	14.465	14.002	1.485	1.053	15480	115	637	113	259	113	105					SS
16	21:32	12.945	14.465	14.002	1.484	1.053	15510	118	632	111	260	113	105					SS
17	22:23	13.643	14.323	14.121	1.481	1.053	10360	65	555	108	280	113	105					SS
18	22:32	13.643	14.323	14.121	1.480	1.052	10410	65	545	106	284	113	105					SS
19	23.14	14.101	14.221	14.201	1.478	1.052	5140	34	505	105	306	112	106					SS
20	23:22	14.081	14.221	14.201	1.477	1.052	5200	34	494	104	314	111	106					SS
21	23:31	14.081	14.221	14.201	1.476	1.052	5210	32	496	104	316	111	106					SS
22	23:56	14.221	14.221	14.221	0	0	0	0	474	101	313	110	105					SS

TEST DURATION = 8m 47s

* Hg at 32F on standard.

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION INC

PROJECT MK15E3-2

SHEET OF

CALCULATED BY

CHECKED BY R. Sutton

DATE

TABLE B-20: Raw Data

APPENDIX C

Data Reduction

Program

MARK 15E3-2 WINDAGE TORQUE TESTS

APPENDIX C, DATA REDUCTION PROGRAM

NOMENCLATURE

P CAV	-	Average Cavity Pressure	-	psia
T CAV	-	Average Cavity Temperature	-	°R
RO	-	Average Cavity Specific Weight	-	LB/FT^3
N	-	Speed	-	RPM
T	-	Torque	-	IN-LB
VIS	-	Absolute Viscosity	-	LB/FT-HR
OD	-	Drum Cylinder Diameter	-	inch
D	-	Diameter	-	inch
H	-	Height	-	inch
S	-	Axial Space	-	inch
T	-	Radial Space	-	inch
L	-	Cylinder Length	-	inch
NR	-	Reynolds Number		
CM	-	Torque Coefficient		
FS	-	Drum End Face		
R	-	Rotor		
1	-	First		
2	-	Second		
M	-	Mean		
DK	-	Disk		
DM	-	Drum		
US	-	Upstream		
DS	-	Downstream		
SH	-	Shroud		

TABLE C-1: Data Reduction Nomenclature

TEST DATA

N	,	RPM	Speed
P2	,	psia	Pressure at Nozzle Outlet
TCP1	,	psia	Downstream Cavity Centerline Pressure
TCP4	,	psia	Downstream Cavity Tip Pressure
TT1	,	^oR	Manifold Temperature
TCT4	,	^oR	Downstream Cavity Tip Temperature

GAS PROPERTIES FOR AIR

Gas Constant - R = $53.36\ FT\ LB_f/LB_m\ ^oR$

Absolute Viscosity - VIS = $0.012210 + 6.0101 \times 10^{-5} \times TCAV\ AVG$, $\frac{LB}{FT\ HR}$

CALCULATION EQUATIONS

$$P\ CAV = \frac{P2 + TCP1 + TCP4}{3}, \quad psia$$

$$T\ CAV = \frac{TT1 + TCT4}{2}, \quad ^oR$$

$$RO\ CAV = \frac{P\ CAV \times 144}{R \times T\ CAV}, \quad \frac{LB}{FT^3}$$

$$NR = \frac{N \times (DM)^2 \times RO}{VIS} \times 0.6545$$

PREDICTED TORQUE EQUATIONS

$$TBG = 1.16 + 0.0283 \times (N)^{2/3}$$

Original Seal Equations

$$TOFS = 9.58 \times 10^{-4} \times N$$

$$TFRS = 1.634 \times 10^{-3} \times N$$

TABLE C-2: Data Reduction Formula

Revised Seal Equations

TOFS = 14.0 for N = 4,000 to 16,000 RPM

$$TOFS = 80.980461 - 0.013358118 \times N + 0.99124152 \times 10^{-6} \times (N)^2 - 0.3275304 \times 10^{-10} \times (N)^3 + 0.41408091 \times 10^{-15} \times (N)^4$$

for N greater than 16,000 RPM

$$N\ RIDK = \frac{N \times (DM-H1R)^2 \times RO}{VIS} \times 0.6545$$

$$CM1US = \frac{0.102 \times (2 \times S1DKUS/(DM-H1R))^{0.1}}{(NR1DK)^{0.2}}$$

$$T1DKUS = CM1US \times RO \times (N)^2 \times (DM-H1R)^5 \times 1.2842 \times 10^{-10}$$

$$CM1DS = \frac{0.102\ (2 \times S1DKDS/(DM-H1R))^{0.1}}{(NR1DK)^{0.2}}$$

$$T1DKDS = CM1DS \times RO \times (N)^2 \times (DM-H1R)^5 \times 1.2842 \times 10^{-10}$$

$$NR1BD = \frac{N \times (DM + H1R)^2 \times RO}{VIS} \times 0.6545$$

$$CM1BD = \frac{0.574\ (H1R/(DM + H1R))^{0.6}}{(NR1BD)^{0.1429}}$$

$$T1BD = CM1BD \times RO \times (N)^2 \times (DM)^5 \times 2.5684 \times 10^{-10}$$

$$NR1SH = \frac{N\ (DM + H1R) \times T1R \times RO}{VIS} \times 1.3090$$

$$CM1SH = \frac{0.065\ (2 \times T1R/(DM + H1R))^{0.3}}{(NR1SH)^{0.2}}$$

$$T1SH = CM1SH \times RO \times (N)^2 \times (DM + H1R)^4 \times L1RSH \times 1.6125 \times 10^{-9}$$

TABLE C-2: Data Reduction Formula

$$NR2DK = \frac{N \times (DM - H2R)^2 \times RO}{VIS} \times 0.6545$$

$$CM2US = \frac{0.102\ (2 \times S2DKUS/(DM - H2R))^{0.1}}{(NR2DK)^{0.2}}$$

$$T2DKUS = CM2US \times RO \times (N)^2 \times (DM - H2R)^5 \times 1.2842 \times 10^{-10}$$

$$CM2DS = \frac{0.102\ (2 \times S2DKDS/(DM - H2R))^{0.1}}{(NR2DK)^{0.2}}$$

$$NR2BD = \frac{N \times (DM + H2R)^2 \times RO}{VIS} \times 0.6545$$

$$CM2BD = \frac{0.574\ (H2R/(DM + H2R))^{0.6}}{(NR2BD)^{0.1429}}$$

$$T2BD = CM2BD \times RO \times (N)^2\ (DM)^5 \times 2.5684 \times 10^{-10}$$

$$NR2SH = \frac{N \times (DM + H2R) \times T2R \times RO}{VIS} \times 1.3090$$

$$CM2SH = \frac{0.065\ (2 \times T2R/(DM + H2R))^{0.3}}{(NR2SH)^{0.2}}$$

$$T2SH = CM2SH \times RO \times (N)^2 \times (DM + H2R)^4 \times L2RSH \times 1.6125 \times 10^{-9}$$

$$DDMAV = \frac{DDM1 + DDM2}{2}$$

$$NRDMOD = \frac{RO \times N \times DDMAV \times TDM \times 1.3090}{VIS}$$

$$CMDMOD = \frac{0.065\ (2 \times TDM/DDMAV)^{0.3}}{(NRDMOD)^{0.2}}$$

$$NRDMFS = \frac{RO \times N \times (DDM2)^2}{VIS} \times 0.6545$$

$$CMDMFS = \frac{0.102 \times (2 \times SDM/DDM2)^{0.1}}{(NRDMFS)^{0.2}}$$

$$TDMFS = CMDMFS \times RO \times (N)^2 \times (DDM2)^5 \times 1.2842 \times 10^{-10}$$

TABLE C-2: Data Reduction Formula

$$TDM2OD = CMDMOD \times RO \times (N)^2 \times \left|(DDM1)^4 \times LDM2R1 + (DDM2)^4 \times LDM2R2\right| \times 1.6125 \times 10^{-9}$$

$$TDM1OD = CMDMOD \times RO \times (N)^2 \left|(DDM1)^4 \times LDM1R1 + (DDM2)^4 \times LDM1R2\right| \times 1.6125 \times 10^{-9}$$

$$TDM2 = TDMFS + TDM2OD$$

$$TDM1 = TDMFS + TDM1OD$$

TABLE C-2: Data Reduction Formula

APPENDIX D

Reduced Test Data

and Parameters

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
1006	15-58	5010.	46.0	14.135	544.	.0701	.04490	.77467E+06
1006	16-03	5010.	43.0	14.134	545.	.0700	.04497	.77214E+06
1006	16-11	5010.	44.0	14.135	545.	.0700	.04497	.77222E+06
1006	17-03	9520.	88.0	13.912	573.	.0656	.04662	.13261E+07
1006	17-11	9520.	87.0	13.915	575.	.0654	.04674	.13183E+07
1006	18-19	14970.	153.0	13.574	650.	.0564	.05128	.16292E+07
1006	18-28	15000.	159.0	13.576	655.	.0560	.05155	.16129E+07
1006	19-45	22320.	201.0	13.305	776.	.0463	.05882	.17397E+07
1006	19-53	22320.	191.0	13.338	782.	.0461	.05918	.17201E+07
1006	20-36	30260.	316.0	12.761	1005.	.0343	.07258	.14153E+07
1006	20-45	30350.	325.0	12.790	1018.	.0339	.07339	.13884E+07
1006	21-36	19840.	179.0	13.448	920.	.0394	.06750	.11480E+07
1006	21-44	19870.	171.0	13.434	922.	.0393	.06762	.11440E+07
1006	22-36	15140.	122.0	13.740	888.	.0418	.06555	.95554E+06
1006	22-44	15140.	120.0	13.749	889.	.0417	.06567	.95225E+06
1006	23-35	9540.	63.0	14.032	859.	.0441	.06384	.65235E+06
1006	23-44	9580.	66.0	14.030	858.	.0441	.06378	.65637E+06
1006	25-09	5070.	41.0	14.168	839.	.0456	.06260	.36566E+06
1006	25-17	5080.	34.0	14.167	837.	.0457	.06251	.36753E+06
1006	25-26	5100.	41.0	14.167	836.	.0457	.06245	.36977E+06

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
1009	32-21	10050.	33.0	.356	546.	.0018	.04500	.38915E+05
1009	32-29	10060.	33.0	.356	546.	.0018	.04503	.38892E+05
1009	32-38	10030.	30.0	.356	546.	.0018	.04503	.38776E+05
1009	32-37	19640.	42.0	.343	584.	.0016	.04728	.65189E+05
1009	33-46	19650.	43.0	.343	585.	.0016	.04734	.65027E+05
1009	33-54	19600.	43.0	.343	586.	.0016	.04743	.64573E+05
1009	34-48	30160.	57.0	.329	666.	.0013	.05224	.76292E+05
1009	34-54	30320.	55.0	.329	668.	.0013	.05236	.76292E+05
1009	35-02	30230.	63.0	.329	673.	.0013	.05263	.75168E+05
1009	35-11	30170.	55.0	.329	674.	.0013	.05272	.74724E+05
1009	35-53	20100.	44.0	.343	619.	.0015	.04930	.60259E+05
1009	36-02	20150.	44.0	.343	618.	.0015	.04932	.60380E+05
1009	36-10	20200.	41.0	.343	617.	.0015	.04929	.60817E+05
1009	36-53	10200.	32.0	.349	582.	.0016	.04716	.34721E+05
1009	37-01	10200.	30.0	.349	580.	.0016	.04707	.35151E+05
1009	37-10	10290.	32.0	.349	579.	.0016	.04701	.35291E+05
1009	37-18	10350.	36.0	.349	578.	.0016	.04695	.35604E+05

TABLE D-1: Reduced Data - Tests 1006 and 1009

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
1010	46-19	9870.	61.0	7.313	589.	.0335	.04750	.68880E+06
1010	46-28	9870.	59.0	7.313	591.	.0334	.04770	.68474E+06
1010	46-36	9850.	59.0	7.313	592.	.0334	.04776	.68134E+06
1010	47-44	19930.	142.0	7.093	732.	.0262	.05620	.91822E+06
1010	47-53	19960.	135.0	7.100	739.	.0259	.05659	.90607E+06
1010	48-01	20200.	136.0	7.093	747.	.0256	.05708	.89865E+06
1010	48-52	29870.	197.0	6.861	955.	.0198	.06958	.82458E+06
1010	49-01	29820.	192.0	6.861	968.	.0191	.07036	.80312E+06
1010	49-09	29790.	191.0	6.867	980.	.0189	.07108	.78516E+06
1010	50-00	20380.	111.0	7.063	906.	.0210	.06663	.63752E+06
1010	50-08	20440.	120.0	7.076	908.	.0210	.06678	.63737E+06
1010	50-59	10570.	59.0	7.299	833.	.0236	.06227	.39748E+06
1010	51-08	10590.	52.0	7.306	830.	.0238	.06209	.40116E+06
1010	51-16	10590.	50.0	7.306	829.	.0238	.06200	.40287E+06

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
2011	21-27	5110.	26.0	14.223	547.	.0702	.04506	.78874E+06
2011	21-38	5090.	26.0	14.223	547.	.0702	.04509	.78441E+06
2011	21-48	5080.	26.0	14.223	547.	.0702	.04509	.78287E+06
2011	22-35	10430.	51.0	14.084	563.	.0676	.04602	.15164E+07
2011	22-43	10400.	46.0	14.084	564.	.0674	.04611	.15051E+07
2011	22-52	10410.	46.0	14.084	565.	.0673	.04614	.15082E+07
2011	23-35	15170.	72.0	13.891	594.	.0631	.04791	.19787E+07
2011	23-43	15160.	74.0	13.891	597.	.0628	.04809	.19601E+07
2011	23-52	15080.	73.0	13.891	600.	.0625	.04824	.19356E+07
2011	24-43	20140.	92.0	13.672	649.	.0569	.05122	.22137E+07
2011	24-52	20080.	92.0	13.666	653.	.0565	.05146	.21823E+07
2011	25-00	20100.	95.0	13.666	661.	.0558	.05194	.21380E+07
2011	25-43	30140.	142.0	13.129	758.	.0468	.05774	.24177E+07
2011	25-51	30020.	159.0	13.208	778.	.0458	.05894	.23122E+07
2011	26-08	30000.	149.0	13.238	794.	.0450	.05990	.22322E+07
2011	26-42	20410.	91.0	13.712	763.	.0485	.05804	.16899E+07
2011	26-51	20490.	90.0	13.719	763.	.0486	.05804	.16974E+07
2011	27-50	15330.	59.0	13.938	742.	.0507	.05680	.13586E+07
2011	28-58	10430.	41.0	14.103	716.	.0532	.05521	.99501E+06
2011	29-49	5070.	22.0	14.216	695.	.0552	.05398	.51337E+06
2011	29-58	5070.	26.0	14.216	694.	.0553	.05389	.51534E+06

TABLE D-2: Reduced Data - Tests 1010 and 2011

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
2012	54-42	10130.	28.0	.708	635.	.0034	.05037	.66712E+05
2012	54-51	10130.	26.0	.708	635.	.0034	.05037	.66712E+05
2012	55-59	19940.	38.0	.757	653.	.0031	.05143	.12021E+06
2012	56-07	19930.	37.0	.757	653.	.0031	.05146	.11998E+06
2012	56-33	29770.	79.0	.730	679.	.0029	.05302	.16139E+06
2012	57-07	20640.	30.0	.737	661.	.0030	.05194	.11840E+06
2012	57-19	20530.	36.0	.744	661.	.0030	.05191	.11900E+06

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
2013	25-03	10160.	38.0	6.373	553.	.0311	.04542	.68955E+06
2013	25-12	10160.	36.0	6.373	553.	.0311	.04545	.68847E+06
2013	26-20	14930.	50.0	6.314	579.	.0295	.04698	.92684E+06
2013	26-29	14960.	47.0	6.314	581.	.0294	.04710	.92318E+06
2013	27-29	19890.	63.0	6.248	621.	.0272	.04950	.10812E+07
2013	27-37	19870.	65.0	6.248	624.	.0270	.04971	.10695E+07
2013	28-28	25310.	81.0	6.142	678.	.0244	.05296	.11569E+07
2013	28-37	25240.	83.0	6.142	684.	.0243	.05329	.11382E+07
2013	29-28	25550.	77.0	6.155	717.	.0232	.05527	.10612E+07
2013	29-36	25570.	74.0	6.155	724.	.0230	.05569	.10438E+07
2013	30-19	20350.	65.0	6.255	708.	.0238	.05476	.87726E+06
2013	30-28	20440.	60.0	6.255	710.	.0238	.05485	.87783E+06
2013	31-02	15100.	49.0	6.340	692.	.0247	.05377	.68806E+06
2013	31-10	15110.	45.0	6.340	691.	.0248	.05371	.69028E+06
2013	31-52	10370.	36.0	6.393	672.	.0257	.05260	.50118E+06
2013	32-01	10360.	34.0	6.393	670.	.0257	.05248	.50334E+06

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
3014	38-56	4660.	23.0	14.221	534.	.0719	.04430	.14966E+06
3014	40-05	10200.	29.0	14.122	535.	.0712	.04436	.32425E+06
3014	40-13	10180.	30.0	14.122	535.	.0712	.04436	.32362E+06
3014	40-56	14990.	33.0	13.969	537.	.0702	.04448	.46036E+06
3014	41-04	14960.	33.0	13.969	537.	.0702	.04448	.46742E+06
3014	41-30	19990.	39.0	13.764	540.	.0688	.04466	.60953E+06
3014	41-47	19970.	39.0	13.771	541.	.0688	.04469	.60822E+06
3014	42-29	24920.	44.0	13.519	545.	.0669	.04497	.73452E+06
3014	42-38	24900.	45.0	13.532	546.	.0669	.04500	.73349E+06
3014	43-12	27630.	49.0	13.354	551.	.0655	.04530	.79059E+06
3014	43-20	27490.	47.0	13.373	551.	.0655	.04533	.78650E+06
3014	44-11	20530.	40.0	13.744	548.	.0677	.04512	.61036E+06
3014	44-19	20560.	39.0	13.750	548.	.0678	.04512	.61185E+06
3014	45-02	15270.	32.0	13.969	546.	.0691	.04500	.46434E+06
3014	45-10	15300.	32.0	13.963	546.	.0691	.04500	.46508E+06
3014	45-27	10620.	28.0	14.102	544.	.0700	.04490	.32756E+06
3014	45-36	10320.	25.0	14.122	544.	.0701	.04490	.31875E+06
3014	46-38	5170.	23.0	14.215	543.	.0706	.04484	.16125E+06
3014	46-43	5180.	23.0	14.215	543.	.0706	.04484	.16156E+06

TABLE D-3: Reduced Data - Tests 2012, 2013 and 3014

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
3015	03-36	10190.	28.0	1.300	542.	.0065	.04478	.29166E+05
3015	03-44	10180.	29.0	1.300	542.	.0065	.04478	.29138E+05
3015	04-18	14910.	31.0	1.287	543.	.0064	.04484	.42104E+05
3015	04-26	10190.	31.0	1.287	543.	.0064	.04484	.28775E+05
3015	05-00	20190.	36.0	1.278	545.	.0063	.04493	.56155E+05
3015	05-09	20190.	37.0	1.278	545.	.0063	.04497	.56066E+05
3015	05-59	25080.	41.0	1.254	547.	.0062	.04506	.68205E+05
3015	06-08	25090.	40.0	1.254	547.	.0062	.04509	.68164E+05
3015	06-41	27750.	40.0	1.241	548.	.0061	.04515	.74354E+05
3015	06-50	27700.	40.0	1.241	549.	.0061	.04518	.74103E+05
3015	07-49	25150.	40.0	1.254	548.	.0062	.04515	.68112E+05
3015	07-57	25140.	38.0	1.287	548.	.0061	.04512	.67830E+05
3015	08-47	20140.	35.0	1.267	546.	.0063	.04503	.55459E+05
3015	08-56	20150.	35.0	1.267	546.	.0063	.04503	.55486E+05
3015	09-21	14940.	30.0	1.280	545.	.0063	.04497	.41705E+05
3015	09-29	14930.	31.0	1.280	545.	.0063	.04497	.41677E+05
3015	10-11	10130.	28.0	1.294	544.	.0064	.04490	.28663E+05
3015	10-20	10140.	28.0	1.294	544.	.0064	.04490	.28691E+05

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
3016	17-09	10400.	28.0	7.308	548.	.0360	.04515	.16413E+06
3016	17-18	10330.	28.0	7.315	548.	.0360	.04515	.16319E+06
3016	18-00	15010.	31.0	7.248	550.	.0356	.04528	.23386E+06
3016	18-08	14990.	32.0	7.248	550.	.0356	.04527	.23318E+06
3016	18-50	20000.	37.0	7.149	553.	.0349	.04542	.30444E+06
3016	18-58	20000.	36.0	6.848	553.	.0325	.04542	.28312E+06
3016	19-32	25060.	40.0	7.249	556.	.0352	.04563	.38262E+06
3016	19-40	25000.	43.0	7.089	557.	.0343	.04569	.37212E+06
3016	19-48	25020.	42.0	7.096	557.	.0344	.04569	.37277E+06
3016	20-30	20360.	38.0	7.202	555.	.0350	.04557	.30900E+06
3016	20-39	20300.	33.0	7.215	555.	.0351	.04557	.30966E+06
3016	21-20	15120.	32.0	7.308	553.	.0357	.04545	.23492E+06
3016	21-29	15130.	32.0	7.308	553.	.0357	.04545	.23507E+06
3016	22-02	10210.	29.0	7.307	552.	.0361	.04536	.16111E+06
3016	22-10	10230.	28.0	7.307	552.	.0361	.04536	.16142E+06

TABLE D-4: Reduced Data - Tests 3015 and 3016

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
4020	45-55	5090.	25.0	1.270	542.	.0063	.04475	.71496E+05
4020	46-03	5160.	25.0	1.270	542.	.0063	.04475	.72276E+05
4020	47-02	10150.	34.0	1.250	557.	.0061	.04566	.13347E+06
4020	47-11	10100.	36.0	1.250	558.	.0061	.04572	.13240E+06
4020	48-02	15110.	45.0	1.231	587.	.0057	.04786	.17852E+06
4020	48-10	15100.	43.0	1.224	591.	.0056	.04770	.17534E+06
4020	49-01	20140.	51.0	1.184	634.	.0050	.05028	.20009E+06
4020	49-09	20110.	53.0	1.184	639.	.0050	.05061	.19678E+06
4020	49-59	25140.	69.0	1.164	699.	.0045	.05422	.20638E+06
4020	50-08	25110.	65.0	1.164	703.	.0045	.05443	.20431E+06
4020	52-05	20190.	47.0	1.184	702.	.0046	.05437	.16748E+06
4020	52-14	20170.	46.0	1.184	699.	.0046	.05422	.16830E+06
4020	53-29	15220.	43.0	1.210	665.	.0049	.05215	.14206E+06
4020	53-38	15080.	39.0	1.210	664.	.0049	.05209	.14112E+06
4020	54-28	10100.	35.0	1.224	637.	.0052	.05049	.10268E+06
4020	54-36	10180.	35.0	1.230	636.	.0052	.05043	.10434E+06
4020	55-35	5210.	26.0	1.230	617.	.0054	.04926	.56385E+05
4020	55-43	5180.	23.0	1.230	616.	.0054	.04923	.56140E+05

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
4021	01-56	5170.	31.0	6.120	620.	.0266	.04997	.27546E+06
4021	02-54	10360.	54.0	6.058	641.	.0255	.05073	.51538E+06
4021	03-03	10340.	53.0	6.061	643.	.0255	.05082	.51284E+06
4021	03-45	15410.	88.0	5.942	688.	.0233	.05356	[illegible]
4021	03-53	15300.	88.0	5.935	692.	.0231	.05380	.65180E+06
4021	04-35	19930.	107.0	5.889	760.	.0209	.05789	.71293E+06
4021	04-43	19870.	118.0	5.883	766.	.0207	.05822	.70088E+06
4021	04-52	19920.	107.0	5.883	772.	.0206	.05858	.69238E+06
4021	05-33	27080.	151.0	5.798	897.	.0174	.06612	.70736E+06
4021	05-42	26880.	159.0	5.798	908.	.0172	.06678	.68676E+06
4021	05-50	26740.	161.0	5.784	917.	.0170	.06729	.67013E+06
4021	06-57	20400.	103.0	5.909	877.	.0182	.06489	.56639E+06
4021	07-05	20470.	100.0	5.909	879.	.0182	.06501	.56599E+06
4021	07-30	14670.	67.0	5.994	844.	.0192	.06298	.44239E+06
4021	07-39	14890.	69.0	6.001	843.	.0192	.06285	.45099E+06
4021	08-37	10240.	52.0	6.067	816.	.0201	.06122	.33251E+06
4021	08-46	10250.	53.0	6.081	815.	.0201	.06119	.33395E+06
4021	09-36	5200.	30.0	6.115	794.	.0208	.05998	.17876E+06
4021	09-44	5350.	30.0	6.115	790.	.0209	.05969	.18538E+06

TABLE D-5: Reduced Data - Tests 4020 and 4021

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX D REVISED TEST DATA AND PARAMETERS

TEST NO	TIME	SPEED RPM	TORQUE IN-LB	PCAV PSIA	TCAV R	ROCAV LB/FT**3	VISCOSITY LB/FTHR	RE
4022	15-58	4070.	33.0	14.160	643.	.0595	.05085	.56303E+06
4022	16-00	4080.	32.0	14.160	643.	.0595	.05082	.56576E+06
4022	16-43	10420.	81.0	13.969	664.	.0568	.05209	.11255E+07
4022	16-52	10360.	82.0	13.969	665.	.0567	.05218	.11146E+07
4022	17-34	15290.	142.0	13.711	718.	.0515	.05536	.14093E+07
4022	17-43	15240.	130.0	13.725	722.	.0513	.05560	.13923E+07
4022	18-17	20370.	211.0	13.454	793.	.0458	.05987	.15425E+07
4022	18-25	20250.	206.0	13.467	802.	.0453	.06038	.15058E+07
4022	19-50	26770.	272.0	13.250	1003.	.0357	.07246	.13048E+07
4022	19-59	26710.	266.0	13.263	1012.	.0354	.07303	.12808E+07
4022	20-33	20410.	171.0	13.593	951.	.0386	.06934	.11249E+07
4022	20-41	20460.	164.0	13.579	953.	.0385	.06946	.11222E+07
4022	21-24	15480.	115.0	13.804	908.	.0410	.06670	.94167E+06
4022	21-32	15510.	110.0	13.804	906.	.0411	.06666	.94728E+06
4022	22-23	10360.	65.0	14.029	878.	.0431	.06495	.64105E+06
4022	22-32	10410.	65.0	14.029	875.	.0433	.06477	.64900E+06
4022	23-16	5100.	34.0	14.174	866.	.0442	.06423	.35022E+06
4022	23-22	5200.	34.0	14.160	867.	.0441	.06429	.35341E+06
4022	23-31	5210.	32.0	14.160	866.	.0441	.06426	.35446E+06

TABLE D-6: Reduced Data, Test 4022

APPENDIX E

Revised Predicted Torque and Torque Ratio

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST DATA							PREDICTED TORQUES, IN-LB													TORQUE
TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBG	TOFS	TFRS	T1DKU	T1DKD	T1BD	T1BH	T2DKU	T2DKD	T2BD	T2BH	TDH	TOTAL	RATIO TEST/PRED
1006	15-54	AIR	5010.	14.135	544.	46.0	9.4	14.0	1.7	.2	.2	1.8	.1	.2	.2	2.8	.2	0.0	30.9	1.489
1006	16-03	AIR	5010.	14.134	545.	43.0	9.4	14.0	1.7	.2	.2	1.8	.1	.2	.2	2.8	.2	0.0	30.9	1.392
1006	16-11	AIR	5010.	14.135	545.	44.0	9.4	14.0	1.7	.2	.2	1.8	.1	.2	.2	2.8	.2	0.0	30.9	1.424
1006	17-03	AIR	9520.	13.912	573.	88.0	13.9	14.0	3.0	.7	.7	5.6	.4	.5	.6	8.9	.5	0.0	48.7	1.806
1006	17-11	AIR	9520.	13.915	575.	87.0	13.9	14.0	3.0	.7	.7	5.6	.4	.5	.6	8.8	.5	0.0	48.7	1.787
1006	18-19	AIR	14970.	13.574	650.	153.0	18.4	14.0	4.5	1.5	1.5	11.5	.8	1.0	1.2	18.3	1.0	0.0	73.6	2.077
1006	18-28	AIR	15000.	13.576	655.	159.0	18.4	14.0	4.5	1.5	1.5	11.5	.8	1.0	1.2	18.3	1.0	0.0	73.6	2.159
1006	19-45	AIR	22320.	13.305	776.	201.0	23.6	15.2	6.5	2.7	2.6	20.8	1.4	1.8	2.2	33.1	1.8	0.0	111.9	1.796
1006	19-53	AIR	22320.	13.338	782.	191.0	23.6	15.2	6.5	2.7	2.6	20.7	1.4	1.8	2.2	33.0	1.8	0.0	111.7	1.710
1006	20-36	AIR	30260.	12.761	1005.	316.0	28.7	24.1	8.8	3.9	3.7	29.1	2.0	2.5	3.2	46.4	2.6	0.0	155.0	2.039
1006	20-45	AIR	30350.	12.790	1018.	325.0	28.7	24.3	8.8	3.9	3.7	29.1	2.0	2.5	3.2	46.3	2.6	0.0	155.1	2.096
1006	21-36	AIR	19840.	13.448	920.	179.0	21.9	14.5	5.9	2.0	1.9	14.8	1.0	1.3	1.6	23.7	1.3	0.0	90.0	1.989
1006	21-44	AIR	19870.	13.434	922.	171.0	21.9	14.5	5.9	2.0	1.9	14.9	1.0	1.3	1.6	23.7	1.3	0.0	90.1	1.899
1006	22-36	AIR	15140.	13.740	888.	122.0	18.5	14.0	4.5	1.3	1.2	9.4	.7	.8	1.0	15.0	.9	0.0	67.3	1.812
1006	22-44	AIR	15140.	13.749	889.	120.0	18.5	14.0	4.5	1.3	1.2	9.4	.7	.8	1.0	15.0	.9	0.0	67.3	1.783
1006	23-35	AIR	9540.	14.032	859.	63.0	13.9	14.0	3.0	.6	.6	4.2	.3	.4	.5	6.6	.4	0.0	44.3	1.421
1006	23-44	AIR	9580.	14.030	858.	66.0	13.9	14.0	3.0	.6	.6	4.2	.3	.4	.5	6.7	.4	0.0	44.5	1.483
1006	25-09	AIR	5070.	14.168	839.	41.0	9.5	14.0	1.7	.2	.2	1.3	.1	.1	.2	2.1	.1	0.0	29.5	1.388
1006	25-17	AIR	5080.	14.167	837.	34.0	9.5	14.0	1.7	.2	.2	1.3	.1	.1	.2	2.1	.1	0.0	29.6	1.150
1006	25-26	AIR	5100.	14.167	836.	41.0	9.5	14.0	1.7	.2	.2	1.3	.1	.1	.2	2.1	.1	0.0	29.6	1.384

TABLE E-1: Revised Predicted Torques - Test 1006

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBB	TDFS	TFRS	T1DKU	T1DKD	T1BD	T1SH	T2DKU	T2DKD	T2BD	T2SH	TDM	TOTAL	TORQUE RATIO TEST/PRED
			- - - TEST DATA - - -				-- -- --			--PREDICTED TORQUES, IN-LB--							-- -- --			
1009	32-21	AIR	10050.	.356	540.	33.0	14.3	14.0	3.1	.0	.0	.3	.0	.0	.0	.4	.0	0.0	32.4	1.019
1009	32-29	AIR	10060.	.356	540.	33.0	14.4	14.0	3.1	.0	.0	.3	.0	.0	.0	.4	.0	0.0	32.4	1.019
1009	32-30	AIR	10030.	.356	540.	30.0	14.3	14.0	3.1	.0	.0	.3	.0	.0	.0	.4	.0	0.0	32.4	.927
1009	32-37	AIR	19640.	.343	584.	42.0	21.0	14.5	5.8	.1	.1	.9	.1	.1	.1	1.4	.1	0.0	45.0	.934
1009	33-46	AIR	19650.	.343	585.	43.0	21.8	14.5	5.8	.1	.1	.9	.1	.1	.1	1.4	.1	0.0	45.0	.956
1009	33-54	AIR	19600.	.343	586.	43.0	21.7	14.5	5.8	.1	.1	.9	.1	.1	.1	1.4	.1	0.0	44.9	.958
1009	34-45	AIR	30160.	.329	666.	57.0	28.6	23.8	8.7	.3	.3	1.7	.1	.2	.2	2.7	.2	0.0	66.8	.853
1009	34-54	AIR	30320.	.329	668.	55.0	28.7	24.2	8.8	.3	.3	1.7	.1	.2	.2	2.7	.2	0.0	67.4	.816
1009	35-02	AIR	30230.	.329	673.	63.0	28.6	24.0	8.8	.3	.3	1.7	.1	.2	.2	2.7	.2	0.0	67.1	.940
1009	35-11	AIR	30170.	.329	674.	55.0	28.6	23.8	8.7	.3	.3	1.7	.1	.2	.2	2.7	.2	0.0	66.8	.823
1009	35-53	AIR	20100.	.343	619.	44.0	22.1	14.6	5.9	.1	.1	.9	.1	.1	.1	1.4	.1	0.0	45.5	.967
1009	36-02	AIR	20150.	.343	618.	44.0	22.1	14.6	5.9	.1	.1	.9	.1	.1	.1	1.4	.1	0.0	45.6	.965
1009	36-10	AIR	20200.	.343	617.	41.0	22.2	14.6	6.0	.1	.1	.9	.1	.1	.1	1.4	.1	0.0	45.7	.898
1009	36-53	AIR	10200.	.349	582.	32.0	14.5	14.0	3.2	.0	.0	.3	.0	.0	.0	.4	.0	0.0	32.5	.984
1009	37-01	AIR	10280.	.349	580.	30.0	14.5	14.0	3.2	.0	.0	.3	.0	.0	.0	.4	.0	0.0	32.6	.919
1009	37-10	AIR	10290.	.349	579.	32.0	14.6	14.0	3.2	.0	.0	.3	.0	.0	.0	.4	.0	0.0	32.6	.980
1009	37-18	AIR	10350.	.349	578.	36.0	14.6	14.0	3.2	.0	.0	.3	.0	.0	.0	.4	.0	0.0	32.7	1.100

TABLE E-[illegible]: Revised Predicted Torques - Test 1009

MARK 15-23-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

- - - - TEST	DATA - - - - TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBS	TDFS	TFRS	T1DKU	T1DKD	T1BD	T1SH	T2DKU	T2DKD	T2BD	T2SH	TDM	TOTAL	TORQUE RATIO TEST/PRED
							-- -- PREDICTED TORQUES, IN-LB -- --													
1010	46-19	AIR	9870.	7.313	589.	61.0	14.2	14.0	3.1	.5	.4	3.4	.2	.3	.4	5.4	.3	0.0	42.1	1.448
1010	46-28	AIR	9870.	7.313	591.	59.0	14.2	14.0	3.1	.5	.4	3.4	.2	.3	.4	5.3	.3	0.0	42.1	1.402
1010	46-36	AIR	9850.	7.313	592.	59.0	14.2	14.0	3.1	.5	.4	3.3	.2	.3	.4	5.3	.3	0.0	42.0	1.404
1010	47-44	AIR	19930.	7.093	732.	142.0	22.0	14.5	5.9	1.4	1.3	10.3	.7	.9	1.1	16.3	.9	0.0	75.4	1.882
1010	47-53	AIR	19960.	7.100	739.	135.0	22.0	14.5	5.9	1.4	1.3	10.2	.7	.9	1.1	16.3	.9	0.0	75.4	1.791
1010	48-01	AIR	20200.	7.093	747.	136.0	22.2	14.6	6.0	1.4	1.4	10.4	.7	.9	1.2	16.5	1.0	0.0	76.1	1.787
1010	48-52	AIR	29870.	6.861	955.	197.0	28.4	23.1	8.7	2.4	2.3	17.3	1.2	1.5	1.9	27.6	1.6	0.0	116.2	1.695
1010	49-01	AIR	29820.	6.861	968.	192.0	28.4	23.0	8.6	2.4	2.3	17.1	1.2	1.5	1.9	27.3	1.6	0.0	115.3	1.665
1010	49-09	AIR	29790.	6.867	980.	191.0	28.4	22.9	8.6	2.3	2.2	16.9	1.2	1.5	1.9	27.0	1.6	0.0	114.7	1.665
1010	50-00	AIR	20300.	7.063	986.	111.0	22.3	14.6	6.0	1.3	1.2	9.1	.7	.8	1.0	14.5	.9	0.0	72.4	1.534
1010	50-08	AIR	20440.	7.076	988.	120.0	22.3	14.7	6.0	1.3	1.2	9.1	.7	.8	1.0	14.6	.9	0.0	72.6	1.653
1010	50-59	AIR	10570.	7.299	833.	59.0	14.8	14.0	3.3	.4	.4	2.9	.2	.3	.3	4.7	.3	0.0	41.6	1.418
1010	51-08	AIR	10590.	7.306	830.	52.0	14.8	14.0	3.3	.4	.4	3.0	.2	.3	.3	4.7	.3	0.0	41.7	1.247
1010	51-16	AIR	10590.	7.306	829.	50.0	14.8	14.0	3.3	.4	.4	3.0	.2	.3	.3	4.7	.3	0.0	41.7	1.198

TABLE E-3: Revised Predicted Torques, Test 1010

MARK 19-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBG	TDFS	TFRS	T1DKU	T1DKD	T1BD	T1BM	T2DKU	T2DKD	T2BD	T2BM	TDM	TOTAL	TORQUE RATIO TEST/PRED
			TEST DATA				--PREDICTED TORQUES, IN-LB--													
2012	54-42	AIR	10130.	.708	635.	28.0	14.4	14.0	3.1	.1	.1	.5	.0	0.0	0.0	0.0	0.0	.0	32.3	.867
2012	54-51	AIR	10130.	.708	635.	26.0	14.4	14.0	3.1	.1	.1	.5	.0	0.0	0.0	0.0	0.0	.0	32.3	.805
2012	55-59	AIR	19940.	.757	653.	36.0	22.0	14.5	5.9	.3	.3	1.6	.1	0.0	0.0	0.0	0.0	.1	44.0	.840
2012	56-07	AIR	19930.	.757	653.	37.0	22.0	14.5	5.9	.3	.3	1.6	.1	0.0	0.0	0.0	0.0	.1	44.0	.826
2012	56-33	AIR	29770.	.730	679.	79.0	28.4	22.9	8.6	.5	.6	3.3	.3	0.0	0.0	0.0	0.0	.1	64.6	1.222
2012	57-07	AIR	20040.	.737	661.	30.0	22.5	14.7	6.1	.3	.3	1.7	.1	0.0	0.0	0.0	0.0	.1	45.7	.656
2012	57-15	AIR	20530.	.744	661.	36.0	22.4	14.7	6.0	.3	.3	1.7	.1	0.0	0.0	0.0	0.0	.1	45.6	.790

MARK 19-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBG	TDFS	TFRS	T1DKU	T1DKD	T1BD	T1BM	T2DKU	T2DKD	T2BD	T2BM	TDM	TOTAL	TORQUE RATIO TEST/PRED
			TEST DATA				--PREDICTED TORQUES, IN-LB--													
2013	25-03	AIR	10160.	6.373	553.	38.0	14.4	14.0	3.1	.5	.6	3.3	.2	0.0	0.0	0.0	0.0	.1	36.3	1.047
2013	25-12	AIR	10160.	6.373	553.	36.0	14.4	14.0	3.1	.5	.6	3.3	.2	0.0	0.0	0.0	0.0	.1	36.3	.992
2013	26-20	AIR	14930.	6.314	579.	50.0	18.3	14.0	4.5	.9	1.1	6.5	.5	0.0	0.0	0.0	0.0	.2	46.0	1.088
2013	26-29	AIR	14960.	6.314	581.	47.0	18.3	14.0	4.5	.9	1.1	6.5	.5	0.0	0.0	0.0	0.0	.2	46.0	1.021
2013	27-29	AIR	19890.	6.248	621.	63.0	21.9	14.5	5.9	1.4	1.8	10.4	.7	0.0	0.0	0.0	0.0	.3	57.0	1.106
2013	27-37	AIR	19870.	6.248	624.	65.0	21.9	14.5	5.9	1.4	1.8	10.3	.7	0.0	0.0	0.0	0.0	.3	56.9	1.143
2013	28-28	AIR	25310.	6.142	678.	81.0	25.6	16.0	7.4	2.0	2.6	15.0	1.1	0.0	0.0	0.0	0.0	.5	70.8	1.144
2013	28-37	AIR	25260.	6.142	684.	83.0	25.5	16.7	7.4	2.0	2.6	14.8	1.0	0.0	0.0	0.0	0.0	.5	70.5	1.177
2013	29-20	AIR	25550.	6.155	717.	77.0	25.7	16.9	7.5	2.0	2.6	14.6	1.0	0.0	0.0	0.0	0.0	.5	70.8	1.088
2013	29-26	AIR	25570.	6.155	724.	74.0	25.7	17.0	7.5	2.0	2.6	14.5	1.0	0.0	0.0	0.0	0.0	.5	70.7	1.046
2013	30-19	AIR	20350.	6.255	708.	65.0	22.3	14.6	6.0	1.3	1.7	9.8	.7	0.0	0.0	0.0	0.0	.3	56.8	1.144
2013	30-28	AIR	20440.	6.255	710.	60.0	22.3	14.7	6.0	1.4	1.8	9.9	.7	0.0	0.0	0.0	0.0	.3	57.0	1.053
2013	31-02	AIR	15100.	6.340	692.	49.0	18.5	14.0	4.5	.8	1.0	5.8	.4	0.0	0.0	0.0	0.0	.2	45.2	1.083
2013	31-10	AIR	15110.	6.340	691.	45.0	18.5	14.0	4.5	.8	1.0	5.8	.4	0.0	0.0	0.0	0.0	.2	45.3	.994
2013	31-58	AIR	10370.	6.393	672.	36.0	14.4	14.0	3.2	.4	.5	3.0	.2	0.0	0.0	0.0	0.0	.1	36.1	.998
2013	32-01	AIR	10360.	6.393	670.	34.0	14.6	14.0	3.2	.4	.5	3.0	.2	0.0	0.0	0.0	0.0	.1	36.1	.943

TABLE E-4: Revised Predicted Torques - Tests 2012 and 2013

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TSB	TDFS	TFRS	T1DKU	T1DKD	T1SD	T1SH	T2DKU	T2DKD	T2SD	T2SH	TDH	TOTAL	TORQUE RATIO TEST/PRED
2011	21-27	AIR	5110.	14.223	547.	26.0	9.6	14.0	1.7	.3	.3	1.9	.1	0.0	0.0	0.0	0.0	.1	27.9	.931
2011	21-35	AIR	5090.	14.223	547.	26.0	9.5	14.0	1.7	.3	.3	1.8	.1	0.0	0.0	0.0	0.0	.1	27.9	.933
2011	21-44	AIR	5080.	14.223	547.	26.0	9.5	14.0	1.7	.3	.3	1.8	.1	0.0	0.0	0.0	0.0	.1	27.8	.934
2011	22-35	AIR	10030.	14.004	563.	51.0	14.7	14.0	3.2	.9	1.2	6.8	.5	0.0	0.0	0.0	0.0	.2	41.4	1.232
2011	22-43	AIR	10000.	14.004	564.	46.0	14.6	14.0	3.2	.9	1.2	6.7	.5	0.0	0.0	0.0	0.0	.2	41.3	1.114
2011	22-52	AIR	10010.	14.004	565.	46.0	14.7	14.0	3.2	.9	1.2	6.7	.5	0.0	0.0	0.0	0.0	.2	41.3	1.114
2011	23-35	AIR	15170.	13.891	594.	72.0	18.5	14.0	4.5	1.7	2.2	12.8	.9	0.0	0.0	0.0	0.0	.4	55.0	1.308
2011	23-43	AIR	15160.	13.891	597.	74.0	18.5	14.0	4.5	1.7	2.2	12.8	.9	0.0	0.0	0.0	0.0	.4	54.9	1.347
2011	23-52	AIR	15080.	13.891	600.	73.0	18.4	14.0	4.5	1.7	2.1	12.6	.9	0.0	0.0	0.0	0.0	.4	54.6	1.336
2011	24-43	AIR	20140.	13.672	649.	92.0	22.1	14.6	5.9	2.6	3.4	20.1	1.4	0.0	0.0	0.0	0.0	.6	70.7	1.302
2011	24-52	AIR	20080.	13.666	653.	92.0	22.1	14.6	5.9	2.6	3.3	19.9	1.3	0.0	0.0	0.0	0.0	.6	70.3	1.308
2011	25-00	AIR	20100.	13.666	661.	95.0	22.1	14.6	5.9	2.6	3.3	19.7	1.3	0.0	0.0	0.0	0.0	.6	70.1	1.354
2011	25-43	AIR	30140.	13.129	750.	142.0	28.6	23.8	8.7	4.7	6.1	36.5	2.5	0.0	0.0	0.0	0.0	1.1	112.8	1.260
2011	25-51	AIR	30020.	13.200	770.	159.0	28.5	23.5	8.7	4.6	6.0	35.7	2.4	0.0	0.0	0.0	0.0	1.1	110.6	1.438
2011	26-00	AIR	30000.	13.235	794.	149.0	28.5	23.4	8.7	4.6	5.9	35.2	2.4	0.0	0.0	0.0	0.0	1.1	109.8	1.357
2011	26-42	AIR	20410.	13.712	763.	91.0	22.3	14.6	6.0	2.4	3.1	18.3	1.3	0.0	0.0	0.0	0.0	.6	68.6	1.326
2011	26-51	AIR	20490.	13.719	763.	90.0	22.4	14.7	6.0	2.4	3.2	18.4	1.3	0.0	0.0	0.0	0.0	.6	68.9	1.306
2011	27-50	AIR	15330.	13.930	742.	59.0	18.6	14.0	4.6	1.5	1.9	11.1	.8	0.0	0.0	0.0	0.0	.3	52.9	1.116
2011	28-50	AIR	10430.	14.103	716.	41.0	14.7	14.0	3.2	.8	1.0	5.6	.4	0.0	0.0	0.0	0.0	.2	39.9	1.028
2011	29-49	AIR	5070.	14.216	695.	22.0	9.5	14.0	1.7	.2	.3	1.5	.1	0.0	0.0	0.0	0.0	.1	27.4	.803
2011	29-58	AIR	5070.	14.216	694.	26.0	9.5	14.0	1.7	.2	.3	1.5	.1	0.0	0.0	0.0	0.0	.1	27.4	.948

TABLE E-5: Revised Predicted Torques - Test 2011

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBS	TOPS	TPRS	T1DKU	T1DKD	T1BD	T1BH	T2DKU	T2DKD	T2BD	T2BH	TDW	TOTAL	TORQUE RATIO TEST/PRED
3014	38-56	AIR	9000.	14.221	534.	23.0	9.1	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	23.1	.996
3014	40-05	AIR	10200.	14.122	535.	29.0	14.5	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.3	28.8	1.006
3014	40-13	AIR	10100.	14.122	535.	30.0	14.5	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.3	28.8	1.042
3014	40-56	AIR	14990.	13.969	537.	33.0	18.4	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.7	33.1	.998
3014	41-04	AIR	14960.	13.969	537.	33.0	18.3	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.7	33.0	.999
3014	41-30	AIR	19990.	13.764	540.	39.0	22.0	14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	37.7	1.035
3014	41-47	AIR	19970.	13.771	541.	39.0	22.0	14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	37.7	1.035
3014	42-29	AIR	24920.	13.519	545.	44.0	25.3	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	43.4	1.013
3014	42-38	AIR	24900.	13.532	546.	45.0	25.3	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	43.4	1.036
3014	43-12	AIR	27630.	13.384	551.	49.0	27.0	19.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	48.1	1.019
3014	43-20	AIR	27690.	13.373	551.	47.0	26.9	18.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	47.8	.983
3014	44-11	AIR	20530.	13.764	548.	40.0	22.4	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	38.2	1.046
3014	44-19	AIR	20560.	13.758	548.	39.0	22.4	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	38.3	1.019
3014	45-02	AIR	15270.	13.969	546.	32.0	18.6	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.7	33.3	.961
3014	45-10	AIR	15300.	13.963	546.	32.0	18.6	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.7	33.3	.961
3014	45-27	AIR	10620.	14.102	544.	28.0	14.8	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.4	29.2	.959
3014	45-36	AIR	10320.	14.128	544.	25.0	14.6	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.4	28.9	.866
3014	46-35	AIR	9170.	14.215	543.	23.0	9.6	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	23.7	.969
3014	46-43	AIR	9100.	14.215	543.	23.0	9.6	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	23.7	.969

TABLE E-6: Revised Predicted Torques - Test 3014

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBB	TOFS	TPRS	T1DKU	T1DKD	T1BD	T1BM	T2DKU	T2DKD	T2BD	T2BM	TDM	TOTAL	TORQUE RATIO TEST/PRED
			TEST DATA				PREDICTED TORQUES, IN-LB													
3015	03-36	AIR	10190.	1.300	502.	28.0	14.5	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	28.5	.982
3015	03-44	AIR	10180.	1.300	502.	29.0	14.5	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	28.5	1.017
3015	04-10	AIR	14910.	1.287	503.	31.0	18.3	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	32.4	.957
3015	04-20	AIR	10190.	1.287	503.	31.0	14.5	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	28.5	1.087
3015	05-00	AIR	20190.	1.274	505.	36.0	22.2	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	36.9	.975
3015	05-09	AIR	20190.	1.274	505.	37.0	22.2	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	36.9	1.002
3015	05-59	AIR	25080.	1.250	507.	41.0	25.6	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	42.3	.970
3015	06-08	AIR	25090.	1.250	507.	40.0	25.4	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	42.3	.946
3015	06-41	AIR	27750.	1.241	508.	40.0	27.1	19.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.3	46.7	.857
3015	06-50	AIR	27700.	1.241	509.	40.0	27.1	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.3	46.6	.859
3015	07-49	AIR	25150.	1.250	508.	40.0	25.5	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	42.4	.944
3015	07-57	AIR	25100.	1.267	508.	38.0	25.5	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	42.3	.898
3015	08-47	AIR	20140.	1.267	506.	35.0	22.1	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	36.9	.949
3015	08-56	AIR	20150.	1.267	506.	35.0	22.1	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	36.9	.949
3015	09-21	AIR	14940.	1.280	505.	30.0	18.3	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	32.4	.925
3015	09-29	AIR	14930.	1.280	505.	31.0	18.3	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	32.4	.956
3015	10-11	AIR	10130.	1.294	504.	28.0	14.4	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	28.5	.984
3015	10-20	AIR	10140.	1.294	504.	28.0	14.4	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	28.5	.983

TABLE E-7: Revised Predicted Torques - Test 3015

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBG	TOFS	TFRS	T1DKU	T1DKO	T1SD	T1SM	T2DKU	T2DKO	T2SD	T2SM	TDM	TOTAL	TORQUE RATIO TEST/PRED
TEST DATA							PREDICTED TORQUES, IN-LB													
3016	17-00	AIR	10000.	7,300	548.	28,0	14,6	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,2	28,9	,970
3016	17-10	AIR	10330.	7,315	548.	28,0	14,6	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,2	28,8	,972
3016	18-00	AIR	15010.	7,288	550.	31,0	18,4	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,4	32,8	,946
3016	18-08	AIR	14990.	7,288	550.	32,0	18,4	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,4	32,8	,977
3016	18-50	AIR	20000.	7,109	553.	37,0	22,0	14,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,7	37,2	,994
3016	18-58	AIR	20000.	6,668	553.	36,0	22,0	14,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,6	37,2	,968
3016	19-32	AIR	25060.	7,249	556.	40,0	25,4	16,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	43,0	,931
3016	19-40	AIR	25000.	7,089	557.	43,0	25,4	16,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	42,9	1,003
3016	19-48	AIR	25020.	7,096	557.	42,0	25,4	16,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	42,9	,979
3016	20-30	AIR	20360.	7,202	555.	38,0	22,3	14,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,7	37,6	1,011
3016	20-39	AIR	20300.	7,215	555.	33,0	22,2	14,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,7	37,5	,879
3016	21-20	AIR	15120.	7,300	553.	32,0	18,5	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,4	32,9	,973
3016	21-29	AIR	15130.	7,300	553.	32,0	18,5	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,4	32,9	,973
3016	22-02	AIR	10210.	7,387	552.	29,0	14,5	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,2	28,7	1,011
3016	22-10	AIR	10230.	7,387	552.	28,0	14,5	14,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	,2	28,7	,975

TABLE E-8: Revised Predicted Torques - Test 3016

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBS	TOFS	TPRS	T1DKU	T1DKD	T1BD	T1BM	T2DKU	T2DKD	T2BD	T2BM	TDM	TOTAL	TORQUE RATIO TEST/PRED
4020	45-55	AIR	5090.	1.270	582.	25.0	9.5	14.0	1.7	.0	.0	.2	.0	.0	.0	.4	0.0	0.0	26.0	.961
4020	46-03	AIR	5160.	1.270	582.	25.0	9.6	14.0	1.7	.0	.0	.2	.0	.0	.0	.4	0.0	0.0	26.1	.957
4020	47-02	AIR	10150.	1.250	557.	34.0	14.4	14.0	3.1	.1	.1	.8	[illegible]	.1	.1	1.3	0.0	0.0	34.2	.995
4020	47-11	AIR	10100.	1.250	550.	36.0	14.4	14.0	3.1	.1	.1	.8	.1	.1	.1	1.3	0.0	0.0	34.1	1.056
4020	48-02	AIR	15110.	1.231	587.	45.0	18.5	14.0	4.5	.2	.2	1.6	.1	.2	.2	2.6	0.0	0.0	42.1	1.068
4020	48-10	AIR	15100.	1.224	591.	43.0	18.5	14.0	4.5	.2	.2	1.6	.1	.2	.2	2.5	0.0	0.0	42.1	1.022
4020	49-01	AIR	20140.	1.184	634.	51.0	22.1	14.6	5.9	.4	.4	2.5	.2	.2	.3	4.0	0.0	0.0	50.6	1.007
4020	49-09	AIR	20110.	1.184	639.	53.0	22.1	14.6	5.9	.4	.4	2.5	.2	.2	.3	4.0	0.0	0.0	50.5	1.049
4020	49-59	AIR	25140.	1.164	699.	69.0	25.5	16.6	7.3	.5	.5	3.5	.3	.3	.4	5.5	0.0	0.0	60.5	1.141
4020	50-08	AIR	25110.	1.164	703.	65.0	25.4	16.6	7.3	.5	.5	3.5	.3	.3	.4	5.5	0.0	0.0	60.4	1.077
4020	52-05	AIR	20190.	1.184	702.	47.0	22.2	14.6	6.0	.4	.3	2.3	.2	.2	.3	3.7	0.0	0.0	50.1	.937
4020	52-14	AIR	20170.	1.184	699.	46.0	22.1	14.6	5.9	.4	.3	2.3	.2	.2	.3	3.7	0.0	0.0	50.1	.918
4020	53-29	AIR	15220.	1.210	665.	43.0	18.5	14.0	4.6	.2	.2	1.5	.1	.1	.2	2.3	0.0	0.0	41.8	1.029
4020	53-38	AIR	15080.	1.210	664.	39.0	18.4	14.0	4.5	.2	.2	1.4	.1	.1	.2	2.3	0.0	0.0	41.6	.938
4020	54-28	AIR	10100.	1.224	637.	35.0	14.4	14.0	3.1	.1	.1	.7	.1	.1	.1	1.1	0.0	0.0	33.8	1.035
4020	54-36	AIR	10180.	1.230	636.	35.0	14.5	14.0	3.2	.1	.1	.7	.1	.1	.1	1.2	0.0	0.0	33.9	1.031
4020	55-35	AIR	9210.	1.230	617.	26.0	9.7	14.0	1.8	.0	.0	.2	.0	.0	.0	.3	0.0	0.0	26.1	.995
4020	55-43	AIR	5180.	1.230	616.	23.0	9.6	14.0	1.8	.0	.0	.2	.0	.0	.0	.3	0.0	0.0	26.1	.882

TABLE E-9: Revised Predicted Torques - Test 4020

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST DATA							PREDICTED TORQUES, IN-LB													TORQUE
TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBB	TDFS	TFRS	T1DKU	T1DKD	T1BD	T1BH	T2DKU	T2DKD	T2BD	T2BH	TDH	TOTAL	RATIO TEST/PRED
4021	01-56	AIR	5170.	6.120	620.	31.9	9.6	14.0	1.7	.1	.1	.8	.1	.1	.1	1.3	0.0	0.0	28.0	1.106
4021	02-54	AIR	10360.	6.054	641.	54.0	14.6	14.0	3.2	.4	.4	2.9	.2	.3	.3	4.7	0.0	0.0	41.1	1.315
4021	03-03	AIR	10340.	6.061	643.	53.0	14.6	14.0	3.2	.4	.4	2.9	.2	.3	.3	4.7	0.0	0.0	41.0	1.293
4021	03-45	AIR	15410.	5.942	688.	88.0	18.7	14.0	4.6	.8	.8	5.7	.4	.5	.6	9.1	0.0	0.0	55.3	1.592
4021	03-53	AIR	15300.	5.935	692.	88.0	18.6	14.0	4.6	.8	.8	5.6	.4	.5	.6	9.0	0.0	0.0	54.8	1.605
4021	04-35	AIR	19930.	5.889	760.	107.0	22.0	14.5	5.9	1.2	1.1	8.5	.6	.8	1.0	13.5	0.0	0.0	69.1	1.549
4021	04-43	AIR	19870.	5.883	766.	118.0	21.9	14.5	5.9	1.2	1.1	8.4	.6	.8	.9	13.4	0.0	0.0	68.7	1.718
4021	04-52	AIR	19920.	5.883	772.	107.0	22.0	14.5	5.9	1.2	1.1	8.4	.6	.8	.9	13.4	0.0	0.0	68.7	1.557
4021	05-33	AIR	27080.	5.798	897.	151.0	26.7	18.4	7.9	1.8	1.7	13.1	.9	1.2	1.5	20.9	0.0	0.0	94.1	1.604
4021	05-42	AIR	26880.	5.798	908.	159.0	26.6	18.2	7.8	1.8	1.7	12.8	.9	1.1	1.4	20.4	0.0	0.0	92.8	1.713
4021	05-50	AIR	26740.	5.788	917.	161.0	26.5	18.0	7.8	1.8	1.7	12.6	.9	1.1	1.4	20.0	0.0	0.0	91.8	1.754
4021	06-57	AIR	20400.	5.909	877.	103.0	22.3	14.6	6.0	1.1	1.1	8.0	.6	.7	.9	12.8	0.0	0.0	68.2	1.511
4021	07-05	AIR	20470.	5.909	879.	100.0	22.3	14.7	6.0	1.1	1.1	8.0	.6	.7	.9	12.8	0.0	0.0	68.4	1.463
4021	07-30	AIR	14670.	5.994	844.	67.0	18.1	14.0	4.4	.6	.6	4.5	.3	.8	.5	7.2	0.0	0.0	50.8	1.319
4021	07-39	AIR	14890.	6.001	843.	69.0	18.3	14.0	4.5	.7	.6	4.7	.3	.8	.5	7.4	0.0	0.0	51.5	1.341
4021	08-37	AIR	10240.	6.067	816.	52.0	14.5	14.0	3.2	.3	.3	2.4	.2	.2	.3	3.8	0.0	0.0	39.3	1.324
4021	08-46	AIR	10250.	6.081	815.	53.0	14.5	14.0	3.2	.3	.3	2.4	.2	.2	.3	3.8	0.0	0.0	39.3	1.348
4021	09-36	AIR	5200.	6.115	794.	30.0	9.7	14.0	1.8	.1	.1	.7	.1	.1	.1	1.1	0.0	0.0	27.6	1.085
4021	09-44	AIR	5350.	6.115	790.	30.0	9.8	14.0	1.8	.1	.1	.7	.1	.1	.1	1.2	0.0	0.0	28.0	1.072

TABLE E-10: Revised Predicted Torques - Test 4021

MARK 15-E3-2 WINDAGE TORQUE TESTS

APPENDIX E REVISED PREDICTED TORQUES AND TORQUE RATIOS

TEST	TIME	FLUID	SPEED RPM	PCAV PSIA	TCAV R	TORQ IN-LB	TBS	TDFS	TFRS	T1DKU	T1DKD	T1BD	T1SH	T2DKU	T2DKD	T2BD	T2SH	TDM	TOTAL	TORQUE RATIO TEST/PRED
4022	15-52	AIR	4870.	14.168	643.	33.0	9.3	14.0	1.7	.2	.2	1.5	.1	.1	.2	2.4	0.0	0.0	29.7	1.113
4022	16-00	AIR	4880.	14.168	643.	32.0	9.3	14.0	1.7	.2	.2	1.5	.1	.1	.2	2.4	0.0	0.0	29.7	1.078
4022	16-43	AIR	10420.	13.969	664.	81.0	14.7	14.0	3.2	.8	.8	5.9	.4	.5	.6	9.4	0.0	0.0	50.4	1.608
4022	16-52	AIR	10360.	13.969	665.	82.0	14.6	14.0	3.2	.8	.8	5.8	.4	.5	.6	9.3	0.0	0.0	50.1	1.637
4022	17-34	AIR	15290.	13.711	718.	142.0	18.6	14.0	4.6	1.5	1.4	11.2	.8	1.0	1.2	17.8	0.0	0.0	72.1	1.970
4022	17-43	AIR	15240.	13.725	722.	138.0	18.6	14.0	4.6	1.5	1.4	11.1	.8	1.0	1.2	17.7	0.0	0.0	71.7	1.925
4022	18-17	AIR	20370.	13.454	793.	211.0	22.3	14.6	6.0	2.3	2.2	17.4	1.2	1.5	1.9	27.7	0.0	0.0	97.2	2.171
4022	18-25	AIR	20250.	13.467	802.	206.0	22.2	14.6	6.0	2.3	2.2	17.1	1.2	1.5	1.8	27.3	0.0	0.0	96.1	2.144
4022	19-50	AIR	26770.	13.250	1003.	272.0	26.5	18.1	7.8	3.2	3.1	24.0	1.7	2.1	2.6	38.2	0.0	0.0	127.2	2.138
4022	19-59	AIR	26710.	13.263	1012.	266.0	26.5	18.0	7.8	3.2	3.1	23.7	1.7	2.1	2.6	37.8	0.0	0.0	126.4	2.105
4022	20-33	AIR	20410.	13.593	951.	171.0	22.3	14.6	6.0	2.1	2.0	15.4	1.1	1.3	1.7	24.6	0.0	0.0	91.1	1.876
4022	20-41	AIR	20460.	13.579	953.	164.0	22.3	14.7	6.0	2.1	2.0	15.4	1.1	1.3	1.7	24.6	0.0	0.0	91.3	1.796
4022	21-24	AIR	15480.	13.804	908.	115.0	18.7	14.0	4.6	1.3	1.3	9.7	.7	.9	1.1	15.4	0.0	0.0	67.7	1.700
4022	21-32	AIR	15510.	13.804	906.	118.0	18.8	14.0	4.6	1.3	1.3	9.7	.7	.9	1.1	15.5	0.0	0.0	67.8	1.739
4022	22-23	AIR	10360.	14.029	878.	65.0	14.6	14.0	3.2	.7	.6	4.8	.3	.4	.5	7.6	0.0	0.0	46.8	1.389
4022	22-32	AIR	10410.	14.029	875.	65.0	14.7	14.0	3.2	.7	.6	4.8	.3	.4	.5	7.7	0.0	0.0	47.0	1.382
4022	23-14	AIR	5140.	14.174	866.	34.0	9.6	14.0	1.7	.2	.2	1.3	.1	.1	.2	2.1	0.0	0.0	29.5	1.152
4022	23-22	AIR	5200.	14.168	867.	34.0	9.7	14.0	1.8	.2	.2	1.3	.1	.1	.2	2.2	0.0	0.0	29.7	1.145
4022	23-31	AIR	5810.	14.168	866.	32.0	9.7	14.0	1.8	.2	.2	1.4	.1	.1	.2	2.2	0.0	0.0	29.7	1.077

TABLE E-11: Revised Predicted Torques - Test 4022

REFERENCES

REFERENCES

[1]Rocketdyne Report RSS-8626 High Speed Rotating Diagnostic Laboratory Testing, R. F. Sutton, November 1978, Rockwell International

[2]Copies available from Rocketdyne Division of Rockwell International, 6633 Canoga Ave., Canoga Park, CA 91304, Attention: R. F. Sutton

[3]ITR-80-076, available through Rocketdyne Division of Rockwell International, 6633 Canoga Ave., Canoga Park, CA 91304, Attention: R. F. Sutton

[4]Dailey, J. W., and Nece, R. E., "Chamber Dimension Effects on Induced Flow and Frictional Resistance of Enclosed Rotating Disks", Journal of Basic Engineering, Transactions of the ASME, Series D, Volume 82, Number 1, March 1960, pages 217-232.

[5]Balje, O. E., and Binsley, R. L., "Axial Turbine Performance Evaluation. Part A - Loss-Loss-Geometry Relationships", Journal of Engineering for Power, Transactions of the ASME, October 1968, pages 341-348.

[6]Bilgen, E., and Boulos, R., "Functional Dependence of Torque Coefficient of Coaxial Cylinders on Gap Width and Reynolds Number", Journal of Fluids Engineering, Transactions of the ASME, March 1973, pages 122-126.

☆U.S.Government Printing Office: 1981 757-002/465

ATE

LMED

-8