71150

NUCLEAR ROCKET OPERATIONS

SACRAMENTO PLANT

REPORT NO. RN-S-0430

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

SUMMARY REPORT

BENDIX MODEL NT-D1 TURBINE POWER CONTROL VALVE ACTUATOR
QUALIFICATION TESTING

NERVA PROGRAM

CONTRACT SNP-1

JANUARY 1968

MASTER

NUCLEAR PRODUCTS AND SERVICES GROUP

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

REPORT NO. RN-S-0430

SUMMARY REPORT

BENDIX MODEL NT-D1 TURBINE POWER CONTROL VALVE ACTUATOR
QUALIFICATION TESTING

NERVA PROGRAM

CONTRACT SNP-1

NUCLEAR ROCKET OPERATIONS

JANUARY 1968

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

CLASSIFICATION CATEGORY

UNCLASSIFIED

EA Shendon
CLASSIFYING OFFICER

Jan 22, 1968
DATE

AEROJET - GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

12-2-68

50

BLANK

REPORT NO. RN-S-0430

SUMMARY REPORT
BENDIX MODEL NT-D1 TURBINE POWER CONTROL VALVE ACTUATOR
QUALIFICATION TESTING

W. P. Harris
K. E. Krauter
H. O. Suttkus

R. M. Rice
Program Manager
Nuclear Rocket Operations

BLANK

ABSTRACT

This report compiles several individual test reports which describe the Bendix Model NT-D1 TPCV actuator qualification program. The program consists of vibration, proof, humidity, shock, and endurance tests on the actuator alone; high-temperature-hydrogen-flow testing of the actuator-valve assembly; and the use of the actuator-valve assembly for turbine power control during an actual hot-firing test of the complete engine system. The results of the above tests demonstrate the qualification of the NT-D1 actuator for use in the Experimental Engine program.

This test program generated recommendations for (1) improvement of the NT-D2 and any subsequent actuators; (2) additional testing to be performed on the NT-D2 actuators; (3) upgrading the actuator performance criteria for future procurements.

Recommended hardware improvements include: (1) the possible addition of a mechanical feedback between first and second stages of the servovalve for improvement of performance in certain vibration environments; (2) increase in actuator output torque; (3) the improvement of current transmission gear tooth geometry; (4) improvement of servovalve discharge line bellows installation; and (5) the possible reduction of ullage between the actuator servovalve and gear motor (resulting in a "stiffer" system).

The recommended additional testing generally consists of breadboard tests of the hardware improvements noted above.

Updating of the performance criteria would consist mainly of (1) basing the actuator performance criteria on loaded dynamic conditions, and (2) specifying the actuator performance requirements in terms of its open loop characteristics.

BLANK

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	1
III. Technical Discussion	1
A. TPCV Actuator, Supplier (Bendix) Performance Test	1
1. Component Tests	2
2. Actuator System Acceptance Test	2
B. TPCV Actuator Test; H4-A Test Area with Heated Hydrogen	3
C. NRX/EST TPCV Actuator	4
1. Application	4
2. Post NRX/EST TPCV Actuator Evaluation	4
a. Performance Evaluation	4
b. Nuclear Radiation Exposure Evaluation	4
D. Component Irradiation Tests	6
E. NRO Laboratory Qualification Testing	7
1. Proof Pressure Test	7
2. Vibration Test	7
3. Mechanical Shock Test	8
4. Humidity Test	8
5. Endurance Test	9
IV. Conclusions and Recommendations	9
A. Conclusion	9
B. Recommendations	10

APPENDIXES

A	<u>CNPI-121, Assembly and Test Record of Turbine Power Control Valve Actuator, Model NT-D1, P/L 2775030, S/N 17, Bendix Products Aerospace Division (BPAD)</u>
B	<u>TPCV Actuator Test; H4-A Test Area with Heated Hydrogen</u>
C	<u>RN-DR-0082, Post NRX/EST Turbine Power Control Valve Actuator (S/N 18) Evaluation</u>

APPENDIXES (cont.)

- D RN-DR-0127, Proof-Pressure Test of Turbine-Power-Control-Valve Actuator
- E RN-DR-0128, Turbine Power Control Valve Actuator Performance Evaluation
Vibration Test
- F RN-DR-0129, Mechanical Shock Test-Turbine Power Control Valve Actuator
- G RN-DR-0130, Humidity Qualification Test Model NT-D1 Turbine Power-Control
Valve Actuator
- H RN-DR-0131, Report of Endurance Testing of Turbine Power Control Valve
Actuator, Model NT-D1
- I NDC-51A, NERVA Design Criteria, Actuator, Electro-Pneumatic, Rotary,
for Turbopump Power Control Valve

I. INTRODUCTION

This report summarizes the results of qualification tests on the Bendix Model NT-D1 Turbine Power Control Valve (TPCV) Actuator for acceptance as a technology engine component. The testing included an acceptance test at Bendix, valve/actuator heated hydrogen test, engine system test (NRX/EST), proof pressure test, vibration test, mechanical shock test, humidity test, and an endurance test. Results of these tests are reviewed in Section [II] with details of tests and supporting analyses presented as appendixes to this report. Conclusions and recommendations with regard to qualification of the actuator, additional testing, and desirable modifications to be incorporated in future designs are provided. It is concluded that the Bendix Model NT-D1 TPCV actuator is qualified for use in the technology engine program.

II. SUMMARY

Qualification of the Bendix Model NT-D1 TPCV Actuator for the Technology Engine Program was accomplished by three types of tests: (1) Laboratory tests (2) combined testing of valve/actuator with heated hydrogen and (3) the engine system test program. The actuator's performance in all of the above series of tests is considered to be adequate to qualify it for use in the technology engine program.

III. TECHNICAL DISCUSSION

A. TPCV ACTUATOR PERFORMANCE TEST (AT BENDIX)

Performance tests at Bendix were primarily in two categories: (1) component performance and (2) actuator acceptance test. The complete details of these tests are recorded in Bendix Report CNPI-121, which is included in this report as Appendix A.

1. Component Tests

The amplifier, torque motor, servo valve assembly, gear motor, transmission, output shaft dynamic seal, and potentiometer were performance tested as components. The torque motor-servo valve and servo motor (torque motor, servo valve, and gear motor) were performance tested as component subassemblies prior to being assembled into a complete actuator. Component assemblies were tested and the performance evaluated to assure compliance with the Bendix performance specification for components. Satisfactory component performance was obtained before each component was accepted for assembly into an actuator. The details of the component performance test data are given in Bendix Report CNPI-121 under Tests 1 through 8.

2. Actuator System Acceptance Test

The actuator performance exceeded all of the criteria of the source acceptance tests*, which were based on NDC 51A (Appendix I) and were performed initially at ambient laboratory conditions and then at cryogenic temperature (200°R). Actuator operation at the cryogenic temperatures met or exceeded the performance requirements of NDC-51A, although by a smaller margin than under ambient conditions. TPCV actuator system source acceptance test performance data are summarized in Table 1.

Copies of the original data from which the contents of Table 1 are derived are presented under Tests 9-2 and 9-3 of Appendix A.

*AGC-observed source acceptance tests were a condition of the Bendix Model NT-D1 TPCV Actuator Contract No. NP-000121.

TABLE 1

TPCV ACTUATOR SYSTEM ACCEPTANCE TEST
PERFORMANCE DATA

BENDIX MODEL NT-D1 S/N 17

	<u>NDC-51A</u> <u>Requirements</u>	<u>Ambient</u> <u>Temperature</u>	<u>200°R</u>
1. Transient Response			
a. Rise time (sec)	0.12	0.08	0.10
b. Settling time (sec)	0.3	0.25	0.3
c. Overshoot (degrees)	6.75	6.75	6.75
2. Resolution (degrees)	<u>+0.5</u>	<u>+0.1</u>	<u>+0.1</u>
3. Saturation velocity (degrees/sec, min)	360	520	360
4. Threshold (degrees, max.)	<u>+0.1</u>	<u>+0.04</u>	<u>+0.05</u>
5. Frequency response (CPS at -90° phase shift)	8	19.5	19
6. Linearity (degrees, max.)	<u>+1.8</u>	-0.35	-0.57

B. IPCV ACTUATOR TESTS; H-4A TEST AREA WITH HEATED HYDROGEN

A series of four TPCV actuator tests were run at AGC test area H-4A with the actuator assembled to a TPCV. Heated hydrogen was flowed through the TPCV at rates and temperatures which simulated engine system condition. The actuator was subjected to static resolution, frequency response, dynamic resolution, and transient response performance tests. The actuator's performance was evaluated with respect to NDC-51A; Appendix B documents the results of the evaluation. The performance during these tests was considered adequate to qualify the actuator system for use in the NRX/EST program.

C. NRX/EST TPCV ACTUATOR TEST

1. Application

After being subjected to the tests defined in Appendix B, a Bendix Model NT-D1 TPCV actuator was installed and used during the NRX/EST full power tests EP-III, EP-IV and EP-IVA. As noted in Aerojet-General Corporation Report RN-S-0322 (p. 45), the TPCV with the Bendix Model NT-D1 actuator performed satisfactorily in the NRX/EST engine pressure control loop.

2. Post NRX/EST TPCV Actuator Evaluation

a. Performance Evaluation

Post NRX/EST evaluation of the Bendix Model NT-D1 TPCV actuator was accomplished in the Aerojet-General Nucleonics hot cell at San Ramon. Listed in Table 2 are the performance tests to which the actuator was subjected along with the posttest performance data, pre-test Aerojet-General test data, Bendix measured performance data, and the NDC-51A performance criteria for comparison. The post-NRX/EST performance test of the turbine power control valve actuator assembly revealed no performance deterioration because of the NRX/EST use. A completely detailed discussion is contained in Appendix C of this report.

b. Nuclear Radiation Exposure Evaluation

The turbine power control valve actuator was located below the direct component shield (DCS) where the nuclear environment (Reference RN-S-0306) was approximately as follows:

TABLE 2

ACTUATOR PERFORMANCE VALUES

<u>Performance</u>	<u>Specification</u> NDC-51A <u>H₂ Amb. T</u>	<u>Bendix</u> <u>H₂ Amb. T</u>	<u>AGC Pre NRX/EST</u> <u>He Amb. T</u>	<u>San Ramon Post</u> <u>NRX/EST</u> <u>He Amb. T</u>
Closed Loop Frequency Response Cross Over	90° phase lag at or above 8 cps	18 cps	20.5 cps	17 cps
Step Response 1) Rise Time	t = 0.12 sec t = time to reach 62% of input step	0.08 sec	0.117 sec	0.115 sec
2) Settling Time	t < 0.3 sec t = time to settle within 5% of input step	0.24 sec	0.34 sec*	0.325 sec*
3) Overshoot	Less than 15% of input step	14%	15.6%*	13.6%
4) Saturation Velocity (max. slew vel.)	360 deg/sec	520 deg/sec	512 deg/sec	470 deg/sec
Dynamic Resolution	Output error <0.5 deg with 0.1 cps tri- angular wave input	0.2 deg	**	0.25 deg
Threshold Resolution	Min input <u>+0.1</u> deg to obtain output motion	<u>+0.033</u> deg	**	<u>+0.15</u> deg*

*Operation is on helium; volume flow rate of helium is less than hydrogen when temperatures, pressures, and physical parameters remain the same.

**Not measured because equipment was not available.

Radiation	Dose or Neutron Fluence
Gamma	2.0×10^8 ERGS/gm (c)
Thermal Neutron	3.8×10^{13} nvt
Fast Neutron ($E > 1.0$ Mev)	5.0×10^{13} nvt

D. COMPONENT IRRADIATION

The TPCV actuator components most susceptible to radiation damage are the potentiometers and the torque motor. Markite potentiometers, of the type used on the TPCV actuator, were irradiated in the ground test reactor at General Dynamics in Fort Worth. Exposure was 1.1×10^{17} nvt ($E > 1.0$ Mev) neutrons and a gamma dose of 1.6×10^{11} ERGS/gm (c). The potentiometers' performance remained within the limits of acceptability for use on a TPCV actuator, (Reference RN-S-0367).

Servotronics torque motors, of construction similar to those used on the TPCV actuator, were also irradiated in the ground test reactor. The exposure levels were 1.1×10^{17} nvt ($E > 1.0$ Mev) neutrons and a gamma dose of 1.6×10^{11} ERGS/gm (c). Some degradation of performance occurred in this test whereas no effect resulted from an exposure of 5.4×10^{16} nvt ($E > 1.0$ Mev) and a gamma dose of 1.4×10^{11} ERGS/gm (c). (Reference RN-S-0367)

The estimated integrated doses (*) for the technology engine series of tests is only 2×10^{12} nvt ($E > 1.0$ Mev) and a gamma dose of 1.5×10^7 ERGS/gm (c). By virtue of the similarity and the lower total flux it can be concluded that the TPCV actuator potentiometers and torque motors are suitable for use on the technology engine tests.

*Approximate for 3600 sec full power operation

E. NRO LABORATORY QUALIFICATION TESTING

The testing described in this section consisted of the proof pressure, vibration, mechanical shock, humidity, and endurance tests. These five tests were conducted in the NRO controls laboratory in accordance with a formal plan as outlined in Report No. RN-S-0425, entitled Qualification Test Plan, Bendix Model NT-D1 Turbine Power Control Valve Actuator, published September 1967. The test sample utilized for all tests in this section was Bendix Model NT-D1 TPCV actuator, Serial No. 17.

1. Proof Pressure Test

This test consisted of internally pressurizing the actuator with the exhaust port, inlet port, and the output shaft dynamic seal cavity connected to a common 250 psig helium pressure source for a period of 10 minutes. Prior to and following the pressurization period, performance reference tests were conducted, the results of which indicated that no deterioration in performance occurred during the test. Posttest visual examination, together with a torque check of the cover hold down screws (the most highly stressed structural component) revealed no distortion or permanent deformation resulting from the proof pressure test. It is concluded that the actuator performance was satisfactory during this test.

The detailed procedures and results of this phase of the qualification testing can be found in Report No. RN-DR-0127 which forms Appendix D of this report.

2. Vibration Test

This test consisted of subjecting the actuator to sinusoidal vibrations along three mutually perpendicular axes at frequencies up to 2000 cps and acceleration up to 5g. In addition, the actuator was subjected to random vibration in the Z axis with frequencies up to 2000 cps and power

spectral densities up to $0.06 \text{ g}^2/\text{cps}$. Performance tests which were conducted before and after each vibration test indicated no appreciable changes in performance. No deterioration in performance was noted during the vibration testing per the specification requirements. (Some performance deterioration was noted at resonant frequencies above the required maximum in the Y axis only.) Based on these results it is concluded that the actuator performed satisfactorily during this test. The detailed procedures and results of the vibration testing can be found in Report No. RN-DR-0128 which forms Appendix E of this report.

3. Mechanical Shock Test

This test consisted of subjecting the actuator to one shock in each direction along three mutually perpendicular axes for a total of six separate shocks at magnitudes ranging from 10 to 25g. Performance reference tests conducted before and after the shock tests indicated that no performance degradation was incurred by the test. Also, data traces of the position signal showed no perturbations at or following the instant of impact.

Detailed procedures and results of this phase of testing can be found in Report No. RN-DR-0129 which forms Appendix F of this report.

4. Humidity Test

This test consisted of subjecting the actuator to a relative humidity of 90 to 100%, at temperatures up to 165°F for a total time of approximately 20 hours which was accumulated in four test cycles.

Performance reference tests were conducted prior to, during, and after the humidity test to indicate any change in performance. The data show that performance of the actuator is not affected by the high humidity even though there was a decrease in the pin-to-pin resistance during the high humidity period. Actuator performance during this test was satisfactory.

Detailed procedures and results of this test are found in Report No. RN-DR-0130 which forms Appendix G of this report.

5. Endurance Tests

This test consisted of cycling the actuator at 0.3 cps (sinusoidal) against a resistance torque whose peak amplitudes were 400 lb in. and 80 lb in. in the opening and closing directions respectively. During the torque cycling, the temperature of the actuator mounting flange was first reduced to -230°F, then increased to 600°F, then cooled. Results of before test and after test performance indicated no significant change in performance. During testing, subsequent to the endurance test, the actuator was found to limit cycle at 25 cps with a 0.3° peak-to-peak amplitude. Later, the actuator was disassembled and found to have been hotter than the planned temperature on the input shaft. Also, the transmission gears exhibited considerable wear which was later found to be caused by design inadequacies. Corrections to the gear designs are now in process, and will be incorporated on the new NT-D2 actuators. The endurance achieved in this test is adequate for a technology engine test series.

The detailed procedures and results of this phase of testing can be found in Report No. RN-DR-0131 which forms Appendix H of this report.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

By virtue of the facts that (1) the actuator's performance during the tests discussed in this report met or exceeded the design criteria established for TPCV actuator performance, (2) it performed acceptably when tested in conjunction with the TPCV and (3) it performed satisfactorily during the full power runs of the NRX/EST program, it is concluded that the Bendix Model NT-D1 TPCV actuator is qualified for use in the technology engine program.

B. RECOMMENDATIONS

The recommendations which follow are in three categories; those pertaining to (1) hardware design; (2) additional testing; and (3) definition of actuator performance criteria.

1. Hardware Design

Definite improvement in the TPCV/TPCV actuator performance is possible and desirable by limited modification of the present actuator design. A more satisfactory performance match between the actuator and the TPCV would be desirable. It is recommended that the following modifications be considered for possible incorporation in the actuator design.

a. Servovalve

During vibration testing, some disturbance in the actuator output shaft position occurred at actuator resonant frequencies starting slightly above 500 Hz when the input excitation was applied along an axis parallel to the axis of the servovalve spool (Y axis). The present servovalve-torque motor design does not have a mechanical position feedback from servovalve spool to the torque motor output flapper. This design modification could result in appreciable performance improvement when the actuator is operated in a mechanical vibration environment. It is recommended that an investigation of this modification be made leading to improved performance of the TPCV actuator.

b. Transmission

(1) Torque Capability

Since the engine system design has included a turbine block valve to achieve emergency shutdowns, this actuator is

satisfactory for the Experimental Engine program. Future applications will require an increased actuator torque capability.

(2) Gear Tooth Geometry

At the completion of the first endurance cycle test it was discovered that the nutating gear had produced chips on the sides of the output gear teeth. A preliminary analysis by AGC of the gear design revealed a tooth geometry which appeared to be in error. At AGC's request, the supplier performed a detailed analysis of the design and concurred with AGC that an error did exist but of a lesser magnitude than shown by the preliminary analysis. The supplier recommended that the faces of the nutating gear teeth be remachined to achieve the correct pressure angle relationship. Prior to accepting the supplier's recommendation, AGC performed a spectrographic analysis of all the metal chips from the output gear. The chips were composed of silver which is one of the materials used in the solid film lubricating process. None of the gear tooth base material was present in the chips. AGC initially questioned the adequacy of the gear materials and heat treatment but concurred, after the analysis, with the supplier's recommendation to limit the rework to remachining the nutating gear for the Model NT-D2 actuator. However, AGC continues to recommend an extensive review of the available materials and heat treatments to achieve better life and performance of the transmission.

c. Bellows-Gearmotor Manifold

During the vibration test, one of the gearmotor manifold bellows ruptured. The initial cause of the failure was faulty instrumentation which permitted vibratory accelerations far in excess of the required magnitude

to be applied to the actuator. However, it was deduced that a major contributing factor in the bellows failure was the misalignment, during fabrication, of the bellows with the rigid tube to which it was brazed. This deduction is based on the fact that the other gear motor manifold bellows, correctly installed, survived all vibration, shock and endurance tests to which the actuator was subjected. A recommendation was made that the above fabrication operation have more stringent quality control before approval of the drawings pertaining to the Model NT-D2 actuators.

d. Component Arrangement

During the qualification testing it became apparent that the servovalve torque motor, gearmotor, and manifold arrangement was not optimum when actuator performance is considered because there is considerable wasted volume in the manifold and tubing leading from the servovalve to the gearmotor. A larger area in the servovalve opening is required to accommodate the storage effect of these line and manifold volumes. It is recommended that all future actuator designs be evaluated with regard to this condition to achieve the shortest flow path possible.

2. Additional Testing

A number of additional tests are recommended to enhance the qualification of the Model NT-D1 actuator and to establish a sound basis for performance improvement.

a. Transmission

(1) Nutating Gears

The two most important additional tests are
(1) testing of the actuator as an assembly to obtain additional data on the

life of the present transmission gear design, and (2) then to install gears of the modified design to determine the improvement in performance and life. This action is recommended and is being initiated.

b. Servovalve

It is recommended that the TPCV actuator be equipped with a commercially available servovalve which has mechanical feedback to the torque motor flapper incorporated in its design, and tested in the same vibration environment which degraded the performance of the present actuator.

c. Component Arrangement

It is recommended that the TPCV actuator servovalve gear-motor arrangement be modified in a breadboard approach to eliminate the manifold block and gear motor pneumatic supply tubes, thereby increasing the servo system stiffness.

3. Actuator Performance Criteria

a. Actuator-TPCV Performance Matching

In order to improve the operational matching of the actuator to the TPCV, the recommendation is made to formulate actuator performance criteria for use in future specifications on the basis of loaded dynamic conditions in contrast to the practice of reducing them to an equivalent static force or torque requirement.

b. Definition of Actuator Performance Criteria

Since the engine control system contains an amplifier to drive the TPCV actuator, it is recommended that definition of actuator performance criteria include both open and closed-loop characteristics.

APPENDIX A

CNPI-121, ASSEMBLY AND TEST RECORD OF TURBINE POWER CONTROL VALVE ACTUATOR,
MODEL NT-D1, P/L 2775030, S/N 17, BENDIX PRODUCTS AEROSPACE DIVISION (BPAD)

CNPI-121

ASSEMBLY AND TEST RECORD
OF
TURBINE POWER CONTROL VALVE ACTUATOR

MODEL NT-D1, P/L 2775030

S/N 17

Submitted to:

Aerojet-General Corporation
Sacramento, California

By

The Bendix Corporation
Bendix Products Aerospace Division
South Bend, Indiana

SENDIX PRODUCTS AEROSPACE DIVISION

APPROVAL SHEET

PERFORMANCE TEST APPROVAL:

G. E. Ross
Laboratory Supervisor

R. P. Smith
Quality Control & Reliability

William A. Hengg
Project Engineer

DOCUMENT APPROVAL:

Approved:

William A. Hengg
Project Engineer

[Signature]
Quality Control

Released: 5 May 1965

Revised: 12 January 1966

Test Completed: 21 February 1966

Actuator Shipped: 24 February 1966

TABLE OF CONTENTS

	<u>Page</u>
TEST PLAN DIAGRAMS	
Component Assemblies	1
End Item Calibration	2
End Item Final Test	2
ACCEPTANCE AND RELEASE REGISTER	
Test 1 Torque Motor	3-4
Servo Valve Assembly	5
Test 2 Torque Motor-Servo Valve	6-7
Test 3 Gear Motor	8
Test 4 Servo Motor	9-10
Test 5 Transmission	11-14
Test 6 Dynamic Seal	15
Test 7 Potentiometer	16-19
ACTUATOR BUILD UP INSPECTION RECORDS	20-21
ACCEPTANCE AND RELEASE REGISTER	
Test 8 Servo Amplifier	22-25
ACTUATOR CALIBRATION	
Actuator System Test Outline	26
TPCV Electrical and Instrumentation Schematic	27
Test 9-1 Room Temperature - No Load	28
Test 9-2 Room Temperature - Design Load	29
END ITEM FINAL ACCEPTANCE TEST	
Test 9-3 Design Operating Load & Temperature Data and Records	30-32
CERTIFICATION SHEET	33
APPENDIX I - PARTS REMOVAL/REPLACEMENT RECORD	I-1
APPENDIX II - WAIVER AND DEVIATION TABULATION SHEET	II-1
APPENDIX III - HISTORY OF DIFFICULTIES ENCOUNTERED ON NT-D1 ACTUATORS	III-1

INSTRUCTIONS FOR COMPLETION OF LOG BOOK

The Acceptance and Release Register for each test shall contain the operating time/cycle record of the unit. Replacements necessary after the start of the end item test shall have separate test sheets for each unit. These sheets shall be numbered as 2.1, 3.1, etc.

Each Acceptance and Release Register shall contain a Narrative Discussion as necessary to provide pertinent information about the item not included in the assembly and test records. Additional numbered sub-sheets may be used for remarks as needed to adequately discuss items of concern for the tests.

Bendix

TEST PLAN FLOW CHART NO. 1
TPCV ACTUATOR MODEL NT-D1

- NOTES: 1) AGC notified of BPAD readiness to conduct End Item Test at least three days before start of test.
 2) End Item Test to require one day to conduct.
 3) Date of delivery to be five days after completion of End Item Test.

KEY: IP - In-Process Inspection
 V_D - Variable Data Collection
 C - Customer Buy-Off

TEST PLAN FLOW CHART NO. 2
 TPCV ACTUATOR MODEL NT-D1

Bendix

TEST 1: TORQUE MOTOR (P/N 2775833)

The Specification Control Drawing 2775833 and the Torque Motor Specification CNPD-125 shall be used as a guide during this test. The test data shall be recorded below:

Torque Motor Serial No. 5 Date of Test 6-29-65
Torque Motor Model No. 29-2A-62 Mfgr. Servotronics

(a) Coil Resistance (Specification: 10 $\pm$ 5% ohms at 70°F):

Coil Temperature 76 °F
Coil #1 Resistance 9.72 ohms
Coil #2 Resistance 9.78 ohms

(b) Flapper Thickness: .0321 inch (.0320-.0321 inch)

(c) Polarity Check (See Drawing): Correct X Incorrect

(d) Displacement Sensitivity:

		Specification
Maximum Positive Displacement	<u>+0.0119</u> inch	+0.013 inch
Maximum Negative Displacement	<u>-0.0128</u> inch	-0.013 inch
Minimum Differential Current for +.012 inch Displacement	<u>+213</u> ma	+200 ma
Minimum Differential Current for -.012 inch Displacement	<u>-184</u> ma	-200 ma
Maximum Hysteresis	<u>1.66</u> % (in./in.)	3% maximum

Attach curve of displacement sensitivity.

(e) Remarks: 13 Ma high for positive displacement will have only slight affect
end item test. This torque motor replaced with S/N 4 - See Appendix III

Page 15, Item 16

Total Running Time: 78 minutes.

 Test Operator Quality Control Engineering Approval

SERVO VALVE ASSEMBLY (P/N 2775032)

Valve S/N 3

-
- A. Flow Grind Date Completed 6-21-65
Flow grind servo valve per Engineering Instruction CNP-115
Inlet Underlap (Lands 2 & 3): 0.0000/0.0000 inch (-.0001 nominal)
Outlet (Lands 1 & 4): 0.0000/0.0000 inch (.0000 nominal)
Damping Tank (2775717) Clearance:
P₁ Tank End: 0.011 inch (0.0110 ±.0005 inch)
P₂ Tank End: 0.011 inch (0.0110 ±.0005 inch)
- B. Oxide Treatment Date Completed 6-29-65
Oxidize valve spool and sleeve per Engineering Instruction CNP-132.
Condition After Treatment: Oxide coating good

- C. Servo Valve Final Assembly Date Completed 7-13-65
Assemble in accordance with Drawing 2775032.
Remarks: Burrs found in filter channel of housing. Removed burrs. Servo
valve bore relapped and re-oxidized final diametral clearance .00048 to .000550.

A. E. Reed
Technician

Bliss
Quality Control

B. H. G.
Engineering Approval

TEST 2: TORQUE MOTOR - SERVO VALVE

Date of Test 9-2-65
Torque Motor (2775833) S/N 5 Servo Valve (2775032) S/N 3

- (a) Assembly: Clearance between torque motor flapper and each nozzle
.0020 inch (0.0020 ± 0.0001 inch). Adjust torque motor
to servo valve so that valve is slightly biased to P_1 side when
power to the torque motor is cut off ($P_1 > P_2$).
- (b) Current to Flow Sensitivity: Connect flowmeter in series with supply line.
Open servo valve ports to atmosphere. Supply 200 psia nitrogen
to valve.

Record following values:

Gas Temperature 70 °F

Flow @ -250 ma	<u>.0268</u>	lb./sec.	Flow @ 50 ma	<u>.00935</u>	lb./sec.
Flow @ -225 ma	<u>.0268</u>	lb./sec.	Flow @ 100 ma	<u>.0155</u>	lb./sec.
Flow @ -200 ma	<u>.0268</u>	lb./sec.	Flow @ 150 ma	<u>.022</u>	lb./sec.
Flow @ -150 ma	<u>.0249</u>	lb./sec.	Flow @ 200 ma	<u>.0282</u>	lb./sec.
Flow @ -100 ma	<u>.0175</u>	lb./sec.	Flow @ 225 ma		lb./sec.
Flow @ -50 ma	<u>.0099</u>	lb./sec.	Flow @ 250 ma	<u>.0292</u>	lb./sec.
Flow @ 0 ma	<u>.00462</u>	lb./sec.			

Plot curve and attach.

- (c) Remarks: This servo valve lapped out and re-oxidized diametral clearance
.000480 - .000550. All data run plotted curve Page 7.

- (d) Total Running Time: SV 546 min (60 min after relapping)
T.M. 504 minutes.

[Signature]
Test Operator

[Signature]
Quality Control

[Signature]
Engineering Approval

Bendix

FLOW SENSITIVITY

G. S. Koss
Test Operator

TEST 3: GEAR MOTOR (P/N 2775031)

Green Run
(Using Dry Nitrogen
and No Lubrication)

Date of Test 8-31-65

Motor S/N 1

	Speed Setting (RPM)	Cumul. Running Time (Min.)	Rotation	Actual Speed (RPM)	Actual Time (Min.)	Supply Pressure (PSI)
Start	500	0	CW	500	start	0.7
Finish	500	10	CW	500	10	0.7
Start	500	10	CCW	500	10	0.7
Finish	500	20	CCW	500	20	0.7
Start	1500	20	CW	1500	20	1.0
Finish	1500	30	CW	1500	30	1.0
Start	1500	30	CCW	1500	30	1.0
Finish	1500	40	CCW	1500	40	0.9
Start	2500	40	CW	2500	40	1.5
Finish	2500	50	CW	2500	50	1.4
Start	2500	50	CCW	2500	50	1.5
Finish	2500	60	CCW	2500	60	1.4

Breakaway Torque After Green Run: .77 in.-oz. (8 in.-oz. maximum)

Remarks: End plates changed from P-2003 to P-658 RC because of effect of humidity
on P-2003 material (both materials Pure Carbon Co.)

Total Running Time: .1512 minutes,
60 min. new end plates

G. E. Jones
Test Operator

W. E. Rich
Quality Control

B. J. Hagan
Engineering Approval

NT-D1 GEAR MOTOR S/N-1
GEAR INSTALLATION MARKS

TEST 4: SERVO MOTOR

Servo Motor Composed Of: Torque Motor S/N 5
 Servo Valve S/N 3
 Gear Motor S/N 1

Room Temperature Tests (Using Nitrogen) Date of Test 9-9-65
 Room Temperature 76 °F Gas Temperature 70 °F
 Gas Pressure: 200 psia

(a) Motor Deadband

Torque Motor Current for Clockwise Rotation: +0.002 amp
 Torque Motor Current for Counterclockwise Rotation: -0.003 amp
 Deadband: 0.005 amp

(b) No-Load Speed Sensitivity

Maximum Speed at +200 ma: 3355 rpm
 Maximum Speed at -200 ma: 3351 rpm

(c) Stalled Motor Pressure and Torque

T/M Current (ma)	P ₁ (psig)	P ₂ (psig)	Torque (lb.-in.)
-250	<u>20.5</u>	<u>171</u>	<u>11.3</u>
-150	<u>23.0</u>	<u>168</u>	<u>11.15</u>
-50	<u>45.5</u>	<u>113</u>	<u>5.4</u>
0	<u>33.0</u>	<u>37</u>	<u>0</u>
+50	<u>100</u>	<u>48</u>	<u>4.4</u>
+150	<u>163</u>	<u>30</u>	<u>10.5</u>
+250	<u>171</u>	<u>22</u>	<u>11.5</u>

Plot curve and attach.

(d) Total Running Time: T.M. 564
S.V. 606 minutes.

(e) Remarks: G.M. 1572 New carbon 120 min.
All data points run plotted on pages 10 and 10A.

[Signature]
 Test Operator

[Signature]
 Quality Control

[Signature]
 Engineering Approval

STALLED MOTOR CHARACTERISTICS

TORQUE VS MA.

9-9-65

T.M. S/N 5

S.V. S/N 3

GM S/N 1

HYST.

P₅ GN₂ 2.00PSIA

STALLED MOTOR CHARACTERISTICS

P_1 & P_2 VS MA

9-9-65

T.M. SN 5

S.V. SN 3

G.M. SN 1

HYGT

P_3 GN₂ 200 PSIA

10A

TRANSMISSION INPUT SHAFT ASSEMBLY - DYNAMIC BALANCING

The following components shall be made into an assembly and dynamically balanced:

<u>P/N</u>	<u>Name</u>
2775724	Bearing
2775776	Counterweight
2775777	Counterweight Clamp
2775477-4	Screws (2 required)
2775818	Shaft, Input
2775723	Bearing
2775725	Bearing (2 required)
2775817	Gear & Diaphragm Assembly

Counterweight 2775776 is deliberately made overweight and should be drilled to accomplish the dynamic balance.

Initial counterweight weight: 31.9 gms

Final counterweight weight: 24.7 gms

Remarks: _____

Date 6-23-65

W. J. Bondi
 Test Operator

J. P. Pink
 Quality Control

B. Hegg
 Engineering Approval

ASSEMBLY OF 2775033 TRANSMISSION

NOTE: All screws to be lockwired per MS-33540 using wire specified on parts list.

Completed

1. Assemble 2775725 and 2775723 Bearings tight against shoulders from small end of 2775818 Input Shaft. PJK
2. Remove 2775814 Diaphragm Assembly from 2775817 Diaphragm and Gear Assembly by removing 2775477-2 (6 screws). PJK
3. Assembly Item 1 into 2775816 Housing until 2775725 Bearing is bottomed. PJK
4. Reassembly 2775814 Diaphragm Assembly (riveted) to 2775818 Input Shaft. PJK
5. Assemble 2775725 Bearing tight against shoulder on 2775818 Input Shaft. PJK
6. Assemble 2775776 Counterweight to 2775818 Input Shaft tight against 2775723 Bearing, using 2775777 Retainer and 2775477-7 (2 required) Screws. PJK
7. Assemble 2775724 Bearing to 2775818 Input Shaft tight against shoulder of 2775798 Counterweight. PJK
8. Assemble entire dynamic balanced assembly of page 11 into output shaft assembly 2775781 being sure that gears are engaged and all parts are held. Compare relative mean distance of diaphragm mounting face from forward outer race of 2775726 bearing with distance between shoulder for forward bearing 2775726 in 2775825 housing and mounting face for diaphragm in 2775825 housing. The housing dimension will be greater. PJK

ASSEMBLY OF 2775033 TRANSMISSION (continued)

Completed

9. Remove dynamic balanced assembly and install 2775788-91 shims equivalent to difference in readings of paragraph 8 minus .003 under 2775728 gear. Shim Thickness .018 in. S E R

Note: This will establish proper diaphragm mounting allowing a slight tension on diaphragm.

10. Reinstall dynamic balanced assembly in output shaft assembly 2775781 and compare distance from forward 2775726 outer race to races of 2775725 bearing on input shaft with distance between shoulder for forward 2775726 bearing in housing 2775825. The difference in these dimensions will establish thickness of 2775821-24 shims required.

Shim Thickness .029 in. S E R

Note: After green run of transmission, the dimensions of paragraph 10 above should be rechecked. It may be necessary to increase shim stack do to wear in.

11. Assemble the dynamic balanced assembly into 2775825 housing assembly -- radially locate to slip over 2775826 pins (3 required) and line up bolt holes (> equally spaced - one offset). S E R

12. Assemble 2775819 screw and 2775820 lock cup from back surface of 2775825 housing assembly. Torque screws, and stake lock cup to screw and housing (staking and lockwiring applies to final assembly). S E R

13. Assemble 2775781 shaft assembly output into 2775825 housing assembly and over bearing 2775724, tight against shoulder, (a ring and plate may be used to hold 2775781 in place). S E R

14. Gage depth remaining from Bearing 2775726 (on 2775781 Shaft Assembly output) to top of flange on 2775825 Housing Assembly. Compare dimensions with pilot projection on 2775729 Housing Assembly-Base and grind 2775784 Retainer so 2775781 Shaft Assembly output will provide an axial compression of .0005 to .0015 on output installation.

2775784 Thickness .0538 in. S E R

15. Assemble 2775798 Metal "O" Ring to 2775760 Seal and drop into 2775729 Housing Assembly-Base. Bolt from inside surface 8 places using 2775478-4 Screws. S E R

ASSEMBLY OF 2775033 TRANSMISSION (continued)

Completed

16. Assemble 2775517-8 Seal in groove of 2775729 Housing Assembly-Base and assemble 2775729 Housing Assembly-Base to 2775825 Housing Assembly transmission using 2775479-40 (6 required) Screws. Mount 2775768 Bracket Assembly-Coupling (2 required) to back side of 2775825 Housing Assembly-Flange as shown on Drawing 2775033. Bolt with 2775479-42 (4 required) Screws.

See

17. Assemble 2775291 Screen Assembly to 2775825 Housing Assembly using 2775771 Ring-Retainer.

See

18. Assemble 2775712 Bleed as shown in Section C-C on 2775033.

See

19. Press in 2775808 Filter Assembly until bottomed in 2775825 Housing Assembly.

See

20. Check runout O.D. of spline.

Runout .0012 in.

See

TEST 5: TRANSMISSION (P/N 2775033)

Transmission S/N 3

Date of Test 1-13-66

(a) Run-In Procedure (Performed 7-6-65)

Set input speed at 1000 rpm and output torque at 300 in.-lbs. Run for fifteen minutes.

Input Torque at Start of Run: 4.32 lb.-in. Efficiency: 85 %

Input Torque at End of Run: 3.85 lb.-in. Efficiency: 95 %

NOTE: Efficiency = $\frac{100 \times \text{Torque Out (lb.-in.)}}{82 \times \text{Torque In (lb.-in.)}}$ (Efficiency: 70% minimum)

(b) Backlash

Backlash: 0.0004 radians (0.0005 radians maximum)

(c) Static Efficiency (Using input torque of 0.7 lb.-in.)

Forward Efficiency: 68-92 % (60% minimum)

Reverse Efficiency: 72-84.5 % (60% minimum)

(d) Breakout Torque

Breakout Torque: 0.7-1.5 oz.-in. maximum (Spec - 2.0 oz.-in. max.)

(e) Dynamic Efficiency

Set input speed at 1000 rpm and take following data:

<u>Output Torque</u> <u>(lb.-in.)</u>	<u>Input Torque</u> <u>(lb.-in.)</u>	<u>Efficiency (%)</u>
0		
300	<u>4.8</u>	<u>76.4</u>
750	<u>11.9</u>	<u>77.0</u>

(f) Remarks: The output bearings on this transmission were preloaded to require 2.5 to 3.5 in./lbs. torque.

(g) Total Running Time: 336 minutes.

Test Operator

Quality Control

Engineering Approval

TEST 6: DYNAMIC SEAL
BELLOWS ASSY. No. 2775854
SEAL PLATE No. 2775855

Bellows Assy. S/N 010
Seal Plate S/N 010

Manufacturer Cits Bros.

Mfg. No. Bellows Assy. 74-093-11
Seal Plate 08-093033

Date of Test 1-4-66

(a) Pressure Check

CAUTION: Use adequate safety precautions.

Apply 700 psig to seal I.D. for approximately 3 minutes.

Accept X Reject

(b) Leakage Check

Leakage at 650 psid: .00054 lb./sec. of N₂ gas.

Allowable Leakage: 0.001 lb./sec. gaseous Hydrogen, maximum.
0.0037 lb./sec. gaseous Nitrogen, maximum.

(c) Temperature Check

With seal at 1000°F, apply 650 psig to I.D. gradually. Hold for approximately 3 minutes (NOT necessary to hold seal at 1000°F for duration of test).

Leakage at 650 psid: .00035 lb./sec. of CN₂ gas.

Accept X Reject

With seal at -260°F, apply 650 psig to I.D. gradually. Hold for approximately 3 minutes (NOT necessary to hold seal at 260°F for duration of test).

Leakage at 650 psid: .00041 lb./sec. of CN₂ gas.

Accept X Reject

(d) Remarks

J. H. H.
Test Operator

Ad. Hick
Quality Control

B. H. H.
Engineering Approval

TEST 7: POTENTIOMETER (P/N 2775783)

NOTE: This is a two-gang potentiometer. Record data for shaft-end unit first. Example: 1470/1480 ohms.

Potentiometer Specification CNPD-161, shall be used as a guide in evaluating each potentiometer.

Potentiometer S/N 5G261 Manufacturer: Markite Corporation

Date of Test 5-20-65 Mfg. P/N Model 9580

(a) Active Range Resistance

Measure and record the resistance between potentiometer terminals 1 and 4. This should be 1500 ± 150 ohms.

Resistance: 1382/1392 ohms

(b) Active Angle

Connect the 10 VDC regulated power supply to potentiometer terminals 1 and 4 with terminal 1 negative and terminal 4 positive. Measure the voltage between potentiometer terminals 1 and 3.

Supply Voltage: 10.01 volts

The potentiometer position where the measured voltage suddenly rises from zero to 10 volts is defined as the zero degree position. Rotate the shaft counterclockwise until the voltage begins to drop. Measure and record this angle. This angle should be in the order of 113.5 degrees. The next 115 degrees from 113.5 to approximately 228.5 degrees is the active angular range of the potentiometer. Measure and record the voltage at each 3-degree increment of the potentiometer shaft until the measured voltage goes to zero. Stop here, and do not disturb the potentiometer shaft.

(1) Beginning of Active Range: 120/120 degrees

(2) End of Active Range: 233/233 degrees

Active Angle (2-1): 113/113 degrees

TEST 7: POTENTIOMETER (P/N 2775783) (continued)

(c) Total Electrical Angle

Reverse the polarity of the power supply and switch the voltmeter lead from potentiometer terminal 1 to potentiometer terminal 4. The voltmeter will now read 10 volts.

Rotate the potentiometer shaft counterclockwise until the 10-volt reading suddenly drops to zero. Measure and record this angle. This angle should be in the order of 342 degrees.

Total Electrical Angle: 354/354 degrees

(d) Relative Linearity

Calculate the slope of the line connecting the end points of the potentiometer voltage versus potentiometer angle over the active range of the potentiometer.

$$\frac{\Delta E}{\Delta \theta} = \underline{0.0887/0.0887} \text{volts/degree}$$

This slope multiplied by the angle from the beginning of the active range will result in the voltage that would be measured at this angle if the potentiometer were linear between the above end points. The difference between this voltage and the voltage measured at this same angle is the deviation in volts.

Calculate and plot the deviation versus potentiometer angle in the active range for each measured angle. The ratio in percent of the largest deviation in volts to the voltage at the beginning of the active range is the relative linearity. This should be within +0.5 and -1.5 percent.

Relative Linearity: +1.45/+1.24%

(e) Noise

The noise level is to be checked over the total electrical angle at both room temperature and -260°F.

TEST 7: POTENTIOMETER (P/N 2775783) (continued)

Apply 10 VDC to potentiometer terminals 1 (-) and 4 (+). Load the potentiometer wiper with 10K ohms resistance (terminals 1 and 3) and measure the potentiometer output voltage from these same terminals.

Drive the potentiometer shaft with a ramp function corresponding to a peak-to-peak angle of 25 degrees at a frequency of approximately 0.017 cycle/second beginning at the zero degree electrical angle. Drive the potentiometer four complete cycles at each nominal position over the full 342 degrees. Record the output of the test potentiometer and the calibration potentiometer on a four-channel Sanborn Recorder at a sensitivity of 0.05 volt/mm and a paper speed of 1 mm/second.

	Room Temp.	-260°F
Instantaneous Noise Amplitude	<u>0/0</u>	<u>0/0</u>
Noise Frequency	<u> </u>	<u> </u>

The instantaneous noise amplitude should be less than 0.02 volt, and the noise frequency should be greater than 125 cps.

(f) Remarks

No noise, relative linearity out of spec. but is acceptable for
use on actuator. Actuator spec. allows $\pm 2\%$

<u> </u> Test Operator	<u> </u> Quality Control	<u> </u> Engineering Approval
--	--	---

NOTE: Sanborn traces need not be retained after engineering approval of this data sheet.

ASSEMBLY OF ACTUATOR

Assemble actuator per Drawing 2775030. The usual precautions pertaining to cleanliness apply. For consistency in actuator assembly, the following orientation of components should be made, assuming we are viewing the actuator from the cover end (top view),

- (a) Actuator output shaft must rotate CW to close butterfly valve (Move toward the zero degree position).
- (b) Gear motor output shaft must rotate CCW to close butterfly valve.
- (c) Servo valve should be mounted with following hole pattern.

Completed

- (d) Torque motor shall be mounted with following pin pattern.

ASSEMBLY OF ACTUATOR (continued)

	<u>Completed</u>
With the coils connected as shown, and with B and D positive relative to A and C, the butterfly valve should close.	<u>S.O.K.</u>
(e) Potentiometer has a direct drive from the actuator output shaft. Potentiometer should be set at 1.25 volts ± 0.02 volt when the actuator is at the zero position and should be at 9.09 volts nominal at the 90° position.	<u>S.O.K.</u>
(f) All electrical connections requiring soldering shall be soldered with high temperature solder per AMS-4755.	<u>S.O.K.</u>
(g) Remarks: _____	
_____	
_____	
_____	

_____ Laboratory Technician	_____ Quality Control	_____ Engineering Approval
--------------------------------	--------------------------	-------------------------------

TEST 8: SERVO AMPLIFIER (P/N 2775842)

The servo amplifier specification (CNPD-192, Revision B) shall be used as a guide for evaluating the amplifier. Use torque motor P/N 2775833 as a load. Common mode voltage should be set at 10 V.D.C.

Amplifier S/N 153 Manufacturer Burr Brown Research Inc.
Date of Test 5-21-65 Mfg. P/N Model 9687

(a) Polarity

With pin C of the input signal connector J-6 positive relative to pin D of the same connector, pin D of the torque motor current connector J-4 should be positive with respect to pin C of the same connector.

Pin D relative to pin E; Positive X, Negative .

(b) Torque Motor Current Monitor Sensitivity

Gain: 1.0 A/V

(c) Static Gain

Torque motor current to differential input voltage through null

Maximum: 5.0 A/V

Minimum: 0.4 A/V

Attach plot of static gain.

(d) Torque Motor Current Saturation Level

Positive: 0.230 amps

Negative: 0.234 amps

(e) Null Adjustment

Torque motor current for zero input signal voltage for maximum gain of amplifier

Maximum CW: 0.089 amps

Maximum CCW: 0.021 amps

TEST 8: SERVO AMPLIFIER (P/N 2775842) (continued)

(f) Frequency Response (Uncompensated)

Torque motor current ± 100 ma, frequency range 0.1 to 100 cps.

Static gain: 14.0 db (20 log A/V)

At 50 cps: Gain: 13.8 db, Phase Shift: 0.0 degrees.

Attach plot of frequency response.

(g) Frequency Response (Compensated)

Torque motor current ± 100 ma, frequency range 0.1 to 150 cps.

Static gain: 14.0 db (20 log A/V)

At 0.1 cps: Gain: 13.3 db, Phase Shift: -14.4 degrees.

Minimum gain beyond 0.1 cps 0.0 db, at 2.7 cps, phase shift +7.0 degrees. Maximum gain beyond 0.1 cps 14.05 db,

at 70.0 cps, phase shift -2.0 degrees. Maximum phase

lead 36.0 degrees, at 11.0 cps.

Attach plot of frequency response.

(h) Remarks

Torque motor P/N 2775833 as amplifier load input circuit as defined
on drawing NFX 99-8

Test Operator

Quality Control

Engineering Approval

ACTUATOR SYSTEM TEST OUTLINE

Load Conditions: I. No-Load
 II. 1.5 in-lb./deg. Torsional
 + 60 in-lb Frictional

Gas: N₂ and H₂ @ 200 psi
 Ambient Temperature: Room Temp. & -260°F
 Base Pressure: 650 psi
 Back Pressure: 50 psi

Test	Forcing Function	Performance Criterion	Recorder Calibration	
			Input	Output
Transient Response	45° steps @ 0.3 cps from 20° to 65° (30 to 97.5 in.-lbs.)	Time to rise 62% of set point: 0.12 second	K = 1.0	K = 0.2 2°/min.
		0.3 sec. settling time (within ±2.25° of final position)		
		Overshoot: 6.75° (maximum)		
Dynamic Resolution	1°/sec. ramp @ 0.05 cps from 25° to 35°	±0.5° maximum step	K = 0.2 5 mm/sec.	K = 0.05
Slew Velocity	45° step 20° to 65° & 65° to 20°	360°/sec. (minimum)	K = 1.0 100 mm/sec.	K = 0.2
Static Resolution	0.1 cps sine wave	±0.1° (maximum). No specific requirement.	K = 0.005 1 mm/sec.	K = 0.001
Frequency Response	±2° sine wave (28° to 32°) 0.5 through 24 cps at frequencies of 0.5, 1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, and 24 cps	-90° phase shift at 8 cps (minimum)	K = 0.1 f=0.5 to 5.9 f= 6 to 10.9 f= 12 to 25	K = 0.02 25 mm/sec. 50 mm/sec. 100 mm/sec.
Linearity	0.1 cps ramp	±1.8° (maximum) from the nominal slope.

TPCV ELECTRICAL AND INSTRUMENTATION SCHEMATIC

TEST 9-1: ACTUATOR SYSTEM CALIBRATION

Date of Test 2-21-66 Actuator S/N 17
Supply Gas N₂ Amplifier S/N 153
Ambient Temperature Room Temp.
Loading Conditions No Load

(a) Transient Response

Rise Time: .16 second (Required: 0.12 second maximum)

Settling Time: .42 second (Required: 0.3 second maximum)

Overshoot: 7.88 degree (6.75 degrees maximum)

(b) Dynamic Resolution

Maximum Step Recorded: + .02 degree (± 0.5 degree maximum step)

(c) Slew Velocity

Maximum Slew Velocity: 194 degree/second (360 degree/second minimum)

(d) Static Resolution

Static Resolution: + 0.08 degree (± 0.1 degree maximum)

(e) Frequency Response*

-90 Degree Phase Shift at 18.5 cps (8 cps minimum)

(f) Linearity

Deviation from Nominal Slope: -0.15 degree (± 1.8 degree maximum)

(g) Remarks: For data traces refer to pages 28A, B, C, D & E.

(h) Running Time: 30 minutes.

* Attach plot of frequency response.

E. K. S.
Test Operator

[Signature]
Quality Control

Billy J. H.
Engineering Approval

SERVO MEDIUM - ROOM TEMP GN₂
 SHAFT SEAL PRESSURE - 650 PSIG
 SUPPLY PRESSURE - 200 PSIG
 EXHAUST PRESSURE - ~~40~~ PSIG
 LOAD SPRING RATE - 0 IN.-LB./DEG.
 STEADY STATE SHAFT POS. - 30 DEG.
 LOAD FRICTION - 0 IN.LB.

TPCV ACTUATOR MODEL NT-D1 S/N 17

CLOSED LOOP PERFORMANCE

TEST 9-1

287

TRANSIENT RESPONSE

MAXIMUM VELOCITY

SERVO MEDIUM - Room Temp. GN₂
 SHAFT SEAL PRESSURE - 650 PSIG
 SUPPLY PRESSURE - 200 PSIG
 EXHAUST PRESSURE - 40 PSIG
 LOAD SPRING RATE - 0 IN.LB./DEG.
 LOAD FRICTION - 0 IN.LB.
 STEADY STATE SHAFT POS. - 30 DEG.

FREQUENCY RESPONSE

SERVO MEDIUM - ROOM TEMP. GM₂
 SHAFT SEAL PRESSURE - 650 PSIG
 SUPPLY PRESSURE - 200 PSIG
 EXHAUST PRESSURE - 40 PSIG
 LOAD SPRING RATE - 0 in.lb./deg.
 LOAD FRICTION - 0 in.lb.
 STEADY STATE SHAFT POS. 30 Deg.

TPCV ACTUATOR MODEL NT-D1 S/N 17

CLOSED LOOP PERFORMANCE

TEST 9-1

28C

FREQUENCY RESPONSE (cont'd.)

SERVO MEDIUM - ROOM TEMP. GN₂
 SHAFT SEAL PRESSURE - 650 PSIG
 SUPPLY PRESSURE - 200 PSIG
 EXHAUST PRESSURE - 40 PSIG
 LOAD SPRING RATE - 0 in.lb./deg.
 LOAD FRICTION - 0 in.lb.
 STEADY STATE SHAFT POSITION - 30 deg.

TEST 9-2: ACTUATOR SYSTEM CALIBRATION

Date of Test 2-21-66 Actuator S/N 17
Supply Gas H₂ Amplifier S/N 153
Ambient Temperature _____ Room Temperature _____
Loading Conditions 2.5 in-lb/degree torsional + ~~6.75 in-lb/degree torsional~~

(a) Transient Response

Rise Time: 0.08 second (Required: 0.12 second maximum)
Settling Time: 0.25 second (Required: 0.3 second maximum)
Overshoot: 6.75 degrees (6.75 degrees maximum)

(b) Dynamic Resolution

Maximum Step Recorded: ± 0.1 degree (±0.5 degree maximum step)

(c) Slew Velocity

Maximum Slew Velocity: 520 degree/second (360 deg./sec. minimum)

(d) Static Resolution

Static Resolution: ± 0.04 degree (±0.1 degree maximum)

(e) Frequency Response*

-90° Phase Shift at 19.5 cps (8 cps minimum)

(f) Linearity

Deviation from Nominal Slope: -0.35 degrees (±1.8 degrees maximum)

(g) Remarks: For data traces refer to pages 29A, B, C, D, & E.

(h) Running Time: 30 minutes.

* Attach plot of frequency response.

E. E. R...
Test Operator

R. R. R...
Quality Control

Billy A. Hays
Engineering Approval

DYNAMIC RESOLUTION

STATIC RESOLUTION

SERVO MEDIUM - ROOM TEMP. GH_2
 SHAFT SEAL PRESSURE - 650 PSIG
 SUPPLY PRESSURE - 200 PSIG
 EXHAUST PRESSURE - 40 PSIG
 LOAD SPRING RATE - 2.5 IN.-LB./DEG.
 STEADY STATE SHAFT POS. - 30 Deg.
 LOAD FRICTION - 0 in.lb.

SERVO MEDIUM - ROOM TEMP. GH₂
 SHAFT SEAL PRESSURE - 650 PSIG
 SUPPLY PRESSURE - 200 PSIG
 EXHAUST PRESSURE - 40 PSIG
 LOAD SPRING RATE - 2.5 IN.LB./DEG.
 LOAD FRICTION - 0 IN.LB.
 STEADY STATE SHAFT POS. 30 Deg.

FREQUENCY RESPONSE

SERVO MEDIUM - ROOM TEMP. GH_2
 SHAFT SEAL PRESSURE - 650 PSIG
 SUPPLY PRESSURE - 200 PSIG
 EXHAUST PRESSURE - 40 PSIG
 LOAD SPRING RATE - 2.5 IN.LB./DEG.
 LOAD FRICTION - 0 IN.LB.
 STEADY STATE SHAFT POS. - 30 Deg.

TPCV ACTUATOR MODEL WT-D1 S/N 17

CLOSED LOOP PERFORMANCE

TEST 9-2

FREQUENCY RESPONSE (cont'd.)

SERVO MEDIUM	- ROOM TEMP. GH ₂
SHAFT SEAL PRESSURE	- 650 PSIG
SUPPLY PRESSURE	- 200 PSIG
EXHAUST PRESSURE	- 40 PSIG
LOAD SPRING RATE	- 2.5 IN.LB./DEG.
LOAD FRICTION	- 0 IN.LB.
STEADY STATE SHAFT POS.	- 30 Deg.

TEST 9-3: ACTUATOR SYSTEM TEST

Date of Test 2-21-66 Actuator S/N 17
Supply Gas H₂ Amplifier S/N 153
Ambient Temperature -260°F
Loading Conditions 2.5 in-lb/deg torsional

(a) Transient Response

Rise Time: 0.10 second (Required: 0.12 second maximum)
Settling Time: 0.3 second (Required: 0.3 second maximum)
Overshoot: 6.75 degrees (6.75 degrees maximum)

(b) Dynamic Resolution

Maximum Step Recorded: ± 0.1 degree (±0.5 degree maximum step)

(c) Slew Velocity

Maximum Slew Velocity: 360 degrees/second (360 deg./sec. minimum)

(d) Static Resolution

Static Resolution: ± 0.05 degree (±0.1 degree maximum)

(e) Frequency Response*

-90 Degree Phase Shift at 19 cps (8 cps minimum)

(f) Linearity

Deviation from Nominal Slope: -0.57 degrees (±1.8 degrees maximum)

(g) Remarks: For data traces refer to pages 30A, B, C, D & E

(h) Running Time: 30 minutes.

* Attach plot of frequency response.

E. E. K...
Test Operator

A. P. ...
Quality Control

Billy J. ...
Engineering Approval

SERVO MEDIUM	- 260°F GH ₂
SHAFT SEAL PRESSURE	+650 PSIG
SUPPLY PRESSURE	+200 PSIG
EXHAUST PRESSURE	+40 PSIG
LOAD SPRING RATE	+2.5 IN.LB./DEG.
LOAD FRICTION	+0 IN.LB.
STEADY STATE SHAFT POS.	+30 Deg.

TRANSIENT RESPONSE

MAXIMUM VELOCITY

SERVO MEDIUM	- 260° F GH_2
SHAFT SEAL PRESSURE	+ 650 PSIG
SUPPLY PRESSURE	+ 200 PSIG
EXHAUST PRESSURE	+ 40 PSIG
LOAD SPRING RATE	+ 2.5 IN.LB./Deg.
LOAD FRICTION	+ 0 IN.LB.
STEADY STATE SHAFT POS.	+ 30 Deg.

SERVO MEDIUM	- 260°F GH ₂
SHAFT SEAL PRESSURE	+ 650 PSIG
SUPPLY PRESSURE	+ 200 PSIG
EXHAUST PRESSURE	+ 40 PSIG
LOAD SPRING RATE	+ 2.5 IN.Lb./Deg.
LOAD FRICTION	+ 0 IN.LB.
STEADY STATE SHAFT POS.	+ 30 Deg.

TPCV ACTUATOR MODEL NT-D1 S/N 17

CLOSED LOOP PERFORMANCE

TEST 9-3

FREQUENCY RESPONSE (cont'd.)

SERVO MEDIUM	- 260° F GH ₂
SHAFT SEAL PRESSURE	+ 650 PSIG
SUPPLY PRESSURE	+ 200 PSIG
EXHAUST PRESSURE	+ 40 PSIG
LOAD SPRING RATE	+ 2.5 IN.LB./Deg.
LOAD FRICTION	+ 0 IN.LB.
STEADY STATE SHAFT POS.	+ 30 Deg.

BAE-990

CERTIFICATE OF INSPECTION

P. O. No. NP000121

CERTIFICATE SERIAL NO. _____

LOT NO. NONE

(Sub-Contractor)

CASE MARKING _____

DESTINATION Aerojet - General Corporation
Sacramento, California
Attn: Mr. T. C. Robb, Dept. 7470, Bldg. 2004

ITEM	IDENTIFICATION	DESCRIPTION OF ARTICLES	QUAN.	TEST REPORT #	REMARKS
1	2775030	TPCV Actuator subsystem including S/N 17 actuator and S/N 153 amplifier	ONE	CNPI-#121	This is the third subsystem being shipped of a total of four on order. (Ref. shipper No. P-36176)

CERTIFIED that the above items have been inspected and tested to comply in every way with the relevant specifications and/or drawings, in accordance with the requirements of the above Purchase Order.
 "Results of all chemical and physical tests as well as all other evidence which shows acceptability of raw materials and assembly components, are on file and available for inspection at any reasonable time."

DATE Feb. 23, 1966
 Sworn and Subscribed to before me this
23rd day of Feb., 1966.

SIGNED *R. Martin*
 Chief Inspector

T. C. Robb Notary Public

No. _____ Certificate serial numbers must run
 CONSECUTIVELY, irrespective of
 Purchase Order. Test report numbers
 must be quoted where applicable.

My Commission Expires October 1, 1968.

For and on behalf of Bendix Products Aerospace Division

THE BENDIX CORPORATION

South Bend 20, Indiana

Bendix

PARTS REMOVAL/REPLACEMENT RECORD

NOTE: This record to be originated prior to start of End Item Test.

APPENDIX II

WAIVER AND DEVIATION TABULATION SHEET

The following waivers and deviations have been applied to Turbine Power Control Valve Actuator as delivered.

S/N 17

APPENDIX I71

HISTORY OF DIFFICULTIES ENCOUNTERED
ON NT-D1 ACTUATORS

1. TORQUE MOTOR INTERFERENCE

A. Problem

On original assembly of S/N 15 actuator it was found that the terminals on torque motor 2775833 would interfere with the gear motor 2775031 and cover 2775745.

B. Reason

This unit was originally designed using a torque motor which would not interfere. Between time of design and build of NT-D1 units, the original company went out of torque motor business. These substitute torque motors did meet the envelope on the drawing which was not correct for this actuator.

C. Correction

The manifold block 2775735 between the servo valve housing and transmission housing was increased by .250 in thickness which moved terminals back of the gear motor. The terminals which interfered with the housing were shortened by .100 to provide a clearance of .060 with the housing.

2. Splitting of Locking Cups 2775820

A. Problem

Locking cups 2775820, which are used to lock screws 2775819 to transmission housing, cracked when they were stacked to lock the screws.

B. Reason

Wrong material type 410 Cres called out. It was not sufficiently ductile.

C. Correction

Changed material to AMS 5639 and solution annealed after finish machine. These new cups used in all actuators.

3. Shaft Potentiometer 2775786 Failures

A. Problem

Two shafts were failed in handling, one at vendors, and the other during installation.

B. Reason

Beryllium material too brittle for the small cross section shaft.

C. Correction

Changed material from Beryllium to type 410 Cres. New shafts installed in all actuators.

4. Failure Seal Plate 2775844

A. Problem

On the first attempt at an acceptance test of actuator the carbon failed after approximately 5.2 hours of operation.

B. Reason

The carbon seal face bore was smaller than carbon base which provided a stress riser. This plus high pressure and possibly vibration set up because of excessive force as a result of improperly balanced areas caused the seal to fail.

C. Correction

The seal was redesigned to a better balance condition and used a rectangular section of carbon, see sketch 1. This appeared to be a very good seal but was found to be unsatisfactory because of high wear rate. See Item 9.

5. Transmission Bind at Low Temperatures

A. Problem

On the second attempt to run an acceptance test on July 29 the test failed as temperature was being reduced because of exceedingly poor resolution as the inlet gas temperature reached -200°F (exhaust gas temp was -67°F). A return to room temperature gas cleared up the problem in a few minutes.

B. Reason

It appeared that the transmission was binding up because of differential expansion effects on the 2775726 output shaft bearings.

C. Correction

After considerable component testing of the transmission it was determined that the output bearings should be allowed more freedom and should be mounted as shown in sketch 2.

It was, however, determined later that this method of mounting allowed too much freedom resulting in poor nutating gear contact and runout of output shaft which may have contributed to seal problem. It was then established that the output bearings should be set up tighter than originally with a preload that would require 20 to 45 in.oz. of torque to rotate the pair. This condition was satisfactory for cryogenic operation.

The particular original set of bearings used on S/N 1 transmission actuator S/N 15 were definitely unsatisfactory and may have been a major contributor to this problem.

CARBON I.D. 1.080
THICK .173
SEAL SURFACE I.D. 1.100
" " OD 1.225

SKETCH 1

SKETCH GITS BROS. MFG CO.
REDESIGN OF DYNAMIC SEAL
FOR NT-D1 ACTUATOR

SCALE APPROX 2X'S

SKETCH 1

B. Hager
1-8-65

SKETCH 2

INSTALLATION CHANGES 2775726
OUTPUT SHAFT BEARINGS

6. Servo Valve Sticking

A. Problem

During two attempts to run cryogenic portion of the acceptance test (9.3) on 8-10-65 and 8-13-65, the servo valve would stick during warm up after completing the cryogenic data. This would cause the actuator to motorize.

B. Reason

A series of component cryogenic tests were run on various servo valves. These tests indicated that the spool would hang up on either fast cool down or warm up of the servo valve.

C. Correction

All servo valves were relapped to provide a diametral clearance of .0005 to .0006 inches. They were then reoxidized and proved to be capable of operation with extremely rapid changes in gas temperatures. Changes in inlet gas temperature at rates as $860^{\circ}/\text{min.}$ decreasing and $1800^{\circ}/\text{min.}$ increasing would not cause a spool seizure.

7. Motor End Plates 2775708

A. Problem

Gear motors 2775031 would, under certain conditions bind up after setting for various periods of time.

B. Reason

It was found that the P-2003 carbon plates 2775708 would under high humidity conditions bleed out some of the impregnate material which would bind the gears in place.

C. Correction

On the advice of the Pure Carbon Company the material was changed to P-658RC which had been used in earlier motors and Pure Carbon provided new plates since the P-2003 material had been originally recommended by their representative.

All four motors were changed and no further difficulties were experienced.

8. Dynamic Seal High Temperature Bonding

A. Problem

It was found during the high temperature cycle of the static test, that a residue would be bonded to the metal face of the seal on approximately 50% of the tests. This material had to be removed by lapping.

B. Reason

No clear cut reason was determined for the bonding of this residue. It was felt, however, that since the P-2003 material would bleed some of its impregnates under high humidity conditions that this material was being bonded to the metal (stellite 6) face.

C. Correction

The Pure Carbon Company advised that P-2003 material was a poor choice for this seal application although it had been recommended by their representative. They advised changing material to P 658RC or P5N to eliminate bleeding and improve wear life. See problem 7. P5N was selected since we have had good results with P5N previously. No further problems of this nature were encountered.

9. Dynamic Seal Carbon Wear

A. Problem

On 8-25-65 the dynamic seal failed as a result of carbon wear (2775844). This was S/N 1A plate seal using P-2003 carbon and had been used for 16.7 hours. A second 2775844 was worn out in 2.2 hours of operation on 9-9-65. A third plate seal using P 3310 (2775852) material failed after 2.8 hours.

B. Reason

Investigation of the wear problem indicated the following factors involved.

- (1) Material P-2003 and its tendency to bond to the metal face could set up an abrasive action. Ref: Problem 7.
- (2) Seal designed contrary to normal design with the metal face being narrower than the mating carbon face. Pure Carbon personnel felt this was main cause although Seal Vendor had experience with this seal configuration.

C. Correction

The carbon material was changed to P5N and the seal was redesigned to conform to drawing 2775854 for the Seal-Bellows and 2775855 for the Plate Seal in order to make the carbon face narrower than the metal face.

During this investigation it was found that by applying MoS_2 to both sealing surfaces that seal torque could be greatly reduced and that on a comparative life cycle test a 2775844 (P-2003 carbon) life could be increased from 20 minutes to more than 10 hours (this test was much more severe than operation in the actuator).

It was found during tests of actuators S/N 18 and S/N 16 that the MoS_2 application provided a good glazed surface after the following test times:

S/N 18	9.2 hours of test
S/N 16	16.5 Hours of test

S/N 16 plate seal had failed after a total time of 21.9 hours. It was, therefore, established that MoS_2 should be reapplied to both seal surfaces after a maximum test time of ten hours.

10. Dynamic Seal Bellows Failure

A. Problem

Considerable difficulty was experienced by Gits Brothers in obtaining satisfactory bellows welds on early seals. A change to electron beam welding indicated good bellows for the first three 2775670 Seal Bellows received. The fourth bellows, however, failed on high temperature test.

B. Reason

Investigation of the S/N 4 bellows indicated that cracks were evident at the juncture of the welded diaphragms. Further investigation and development of TIG welding by Gits showed considerable improvement but cracks were still in evidence.

C. Correction

It was determined that the best corrective action would be to increase diaphragm thickness from .004 stock to .008 stock. They demonstrated even better welding capability and a great reduction in crack penetration in the weld bead.

11. Pressure Balance of Dynamic Seals

A. Problem

Gits Brothers were continually in difficulty with pressure balance of their various seal designs as follows:

1. The first seal delivered would become unbalanced at 23 psi.
2. The second seal delivered was overbalance to close and resulted in high force on the carbon a contributing factor to failure (Refer - problem 4)
3. The first seal conforming to 2775854 and 2775855 would open at 25 psi. (Parts received Oct. 7)

B. Reasons

1. Gits had assumed that the high pressure was external rather than internal.
2. The seal was excessively loaded by changing balance on basis of original seal data.
3. It was found that the metal face would go concave with temperature rise. This would result in a gradient pressure increase tending to open the seal.

C. Corrective Action

1. The second seal was to correct for unbalance but was overdone.
2. The seal was redesigned sketch 1 page 4 and bellows balance area was determined.
3. The seal was redesigned to eliminate the skirt on the metal face adaptor (in process) in an effort to eliminate concave action.

12. Flatness of Bellows Seal Face

A. Problem

Seals would become unbalanced with increase in seal temperature greatly increasing leakage.

B. Reason

It was found that the bellows seal face was distorting and becoming concave at increasing temperature. This would change the pressure gradient across the seal faces. The prime reason was bimetal effect of Stellite 6 welded onto an Inconel X-750 plate.

C. Corrective Action

1. The bellows seal face was redesigned using a ring of Stellite 6 B brazed to an Inconel 600 O.D. ring which was in turn welded to the O.D. of the bellows. This change provided satisfactory sealing with no tendency to open at elevated temperatures.

13. Potentiometer Problems

A. Problem

On setting up S/N 16 on 12-16-65 it was noted that the instrumentation potentiometer did not indicate the same dynamic resolution as was being provided by the feedback potentiometer. Replacement of this unit S/N 5G355 with S/N 5G356 indicated similar results with the instrumentation section of the potentiometer.

B. Reason

Potentiometer S/N 5G355, 5G356 and 5G354 which all indicated a similar problem were returned to Markite for their examination, report and repair. S/N 5G355 was returned on 1-24-66 as a satisfactory unit. Subsequent tests at Bendix indicated that the problem had not been found. Markite reported that S/N 5G356 had a burned spot on the feedback potentiometer element caused by excessive current flow. Markite feels that minute burn spots may be cause for all potentiometer resolution problems.

C. Corrective Action

1. On S/N 16 actuator S/N 5G358 potentiometer was used with no resolution problem.
2. Markite replaced the resistive element in the feedback section of potentiometer S/N 5G356 and its component tests indicated satisfactory operation.
3. Bendix investigated all test procedures and all instrumentation setups to be certain that a high wiper current could not be produced. In no setup used could a wiper current in excess of 2 ma be applied. Markite states a maximum of 10 mAx

14. Amplifier**A. Problem**

During the cold test (9-3) on 12-30-65 the actuator became very unstable. An attempt at recompensation indicated that the amplifier gain had increased by a large amount.

B. Reason

The S/N 151 amplifier was returned to Burr Brown for examination report and repair. They thoroughly tested the unit including putting in all compensation components as had been used for S/N 16 actuator when the difficulty occurred. No problem or intermittent change in gain could be found.

C. Corrective Action

Amplifier S/N 151 was replaced with S/N 152 during cold test on S/N 16 actuator and room temperature tests were rerun with no problem. S/N 151 amplifier has been used with S/N 15 actuator for 16.1 hours with no reoccurrence of the gain shift problem.

15. Failure Seal Plate 2775855

A. Problem

After completing the acceptance test on actuator S/N 16, the seal was inspected. It was found that the carbon face had worn .005 to .006. The seal was still functional.

B. Reason

The coating of MoS_2 had been exhausted which resulted in carbon wear. The MoS_2 had a good glaze finish after 16.5 hours of test time. An additional 5.4 hours had been applied for a total time of 21.9 hours.

C. Corrective Action

The actuator was cleaned of all wear debris and seal plate S/N 009 was substituted for S/N 008. It should be noted that seal plate S/N 009 had completed the high temperature portion of test 6. In addition it was stabilized at -260°F .

This result further established the following drawing changes:

1. 2775030 actuator assembly IPCV - add a note 11 - Apply MoS_2 microsize to faces of 2775854 and 2775855 after a maximum of 10 hours test time per instructions on detail parts.
2. 2775854 seal assembly bellows - add application of microsize MoS_2 to seal face including application method.
3. 2775855 seal plate - add application of microsize MoS_2 to seal face including application method. In addition we will specify stabilize part at $1,000^\circ\text{F}$ and -260°F as an individual part or on assembly test with 2775854.

16. Torque Motor Stops

A. Problem

During compensation tests on S/N 17 actuator on January 17, 1966 it was noted that the slew velocity 0 to 90° was only 380°/sec. with hydrogen where it should have been approximately 530°/sec.

B. Reason

It was found on investigation that armature stop for max. travel in the 0 to 90° had loosened and shifted allowing only a maximum flapper movement of .006 instead of the nominal .012. See page 16.

C. Correction

Torque motor S/N 4 was substituted for torque motor S/N 5. The displacement vs ma curve was rechecked on T.M. S/N 4 and is shown on page 17 of this appendix. This corrected the speed variation bringing up the speed 0 to 90° to 530°/sec.

APPENDIX B

TPCV ACTUATOR TESTS
H4-A TEST AREA WITH HEATED HYDROGEN

(H. BENENSON)

I. INTRODUCTION

A series of four tests were run at AGC Test Area H-4A to qualify the TPCV actuator Bendix Model NT-D1 to meet NRX/EST test conditions. The actuator was evaluated for static resolution with a $\pm 0.1^\circ$ sine wave, for frequency response to a $\pm 2^\circ$ and $\pm 1^\circ$ amplitude sine wave, for dynamic resolution to a 10° peak-to-peak, 0.05 cps triangular wave, and for transient response to a 20° peak-to-peak square wave. In addition, a vibration frequency analysis was made and compared to actual vibration characteristics observed in the NRX/EST tests at Jackass Flats. A survey was made to compare the actuator gas temperatures to the actuator base temperatures for each run.

II. SUMMARY AND RESULTS

A. The actuator performance in this series of four tests was considered adequate to qualify the actuator for use in the NRX/EST full power tests.

B. One of the two position potentiometer signals became very erratic during Run 003. The potentiometer was disconnected from the circuit and was not utilized in Run 004. Extensive posttest evaluations indicate that the cause was associated with the facility cabling rather than the actuator potentiometer.

C. The actuator demonstrated the capability of responding to a $\pm 0.1^\circ$ sine wave input showing a variation of less than $\pm 0.03^\circ$ about the average output curve. However, the output of runs 002 and 004 in which 1200°R gas was used in the TPCV showed drifts with time. These drifts can be associated with soaking of the components or drifts in the data system.

D. The frequency response for sine wave inputs of $\pm 2^\circ$ and $\pm 1^\circ$ satisfied specification requirements for the first three runs. Run 004 showed an amplitude gain for both the $\pm 2^\circ$ and $\pm 1^\circ$ input that was much different from the

first three runs and not conforming to specification requirements. This mal-performance was thought to be related to the removal of the potentiometer that could introduce non-linearities and subsequent early rolloff of the amplitude gain.

E. The actuator system responded to a 10 degree peak-to-peak triangular wave to within 0.4° for the decreasing inputs and to within 1.0° for the increasing input. The difference can be traceable to differing data amplifier gain and zero balance setting. The nonlinearities of the system were less than the $\pm 0.1^\circ$ readability of the data system.

F. The transient response of the actuator was satisfactory for overshoot, settling time, and saturation velocity.

G. Vibration results for the same type actuator tested at Aerojet test area H and at NTO, Jackass Flats, showed essentially little vibration energy to 1000 cps. However, the accelerometers at NTO were not able to record beyond 1000 cps to verify the 4.0 g vibration observed at Aerojet between 1000 and 10,000 cps.

III. TEST DESCRIPTION

A. TEST AND TEST ARTICLE IDENTIFICATION

The formal identification of the test specimen is: TPCV Test Assembly, P/N 278100, S/N 015 with TPCV Actuator Model NT-D1, P/N 2775030, S/N 17 and Hot Gas Bypass Valve Assembly P/N 1116193-39, S/N 020.

The test conditions for each of the four tests were as follows:

Test Identification	TPCV				Actuator Supply		
	Position	Temp.	Pres.	Fluid	Temp.	Pres.	Fluid
	Degree	°R	PSIA			PSIA	
2.0-24-NNV-001	40°	700°	350	GH ₂	Ambient	215	GHe
2.0-24-NNV-002	60°	1200°	525	GH ₂	Cryogenic	215	GHe
2.0-24-NNV-003	40°	700°	350	GH ₂	Cryogenic	215	GHe
2.0-24-NNV-004	60°	1200°	525	GH ₂	Ambient	215	GHe

B. PERFORMANCE TESTS

Test description for all four tests are listed in Table 1.

TABLE 1

TPCV ACTUATOR PERFORMANCE TESTS

<u>Test Name</u>	<u>CPS</u>	<u>Wave Form</u>	<u>Amplitude P-F Deg.</u>	<u>Min. Cycles</u>	<u>Approximate Time, sec</u>
1. Static Resolution	0.1	Sine	0.2	5	50
2. Freq Response	0.025	Sine	4	2	80
	0.1	Sine	4	2	20
	0.25	Sine	4	2	8
	0.5	Sine	4	2	4
	0.8	Sine	4	2	4
	1.0	Sine	4	2	4
	2.0	Sine	4	2	4
	4.0	Sine	4	4	4
	8.0	Sine	4	4	4
	10.0	Sine	4	4	4
	14.0	Sine	4	4	4
	20.0	Sine	4	4	4
	24.0	Sine	4	4	4
	30.0	Sine	4	4	4

TABLE 1 (cont.)

<u>Test Name</u>	<u>CPS</u>	<u>Wave Form</u>	<u>Amplitude P-P Deg.</u>	<u>Min. Cycles</u>	<u>Approximate Time, sec</u>
3. Same as 2 but at 2° peak-to-peak amplitude.					
4. Dynamic Resolution	0.05	Triangular	10	2	40
5. Transient Response	0.25	Square	20	4	16

C. TEST SETUP

Figures 14, 15 and 16 show the AGC test area H-4A setup for this series of tests.

IV. TEST ANALYSIS AND RESULTS

A. STATIC RESOLUTION

The actuator demonstrated the capability of responding to a $\pm 0.1^\circ$ input. Figure 1 is a facsimile of the reduced data from the digital printout shown to demonstrate the static resolution capability. It can be seen in Figure 1 that there is a variation of approximately $\pm 0.03^\circ$ about the output sine curve. The phase relationship is excellent in all runs. For the two 1200°R TPCV gas temperature runs, significant trends in opposing directions were observed. Run 002 showed a decreasing trend such that the final cycle was 0.06° lower than the original reference. Run 004 showed an increasing trend such that the final cycle was displaced more than 0.10° from the original reference. The trends observed in Runs 002 and 004 occurred with the 1200°R TPCV temperature condition. It is likely that a temperature soaking of the potentiometer or possibly a slight drift in the data system could account for the observed changes.

Figure 1

The static resolution results must be evaluated with caution since later tests on similar actuators did not exhibit this level of resolution. It is believed that noise imposed on the signal introduces dither and that this dither permits the detection of a 0.1° signal. It is very possible that without the presence of noise the signal may not have been detected.

B. FREQUENCY RESPONSE

Bode plots were prepared for each of the four actuator runs to evaluate frequency response. Inputs of 4° and 2° peak-to-peak sine waves were utilized for each test for 14 frequencies. Facsimiles of the data plots are shown in Figures 2 through 5. The amplitude gain plots show a characteristic increase at 8-10 cps, followed by a break point at approximately 15-20 cps (as compared to specification requirements of 8.0 cps minimum at 90° phase lag).

The $\pm 1^\circ$ sine wave showed a maximum 1.5 db difference in Runs 001 and 002 as compared to the $\pm 2^\circ$ sine wave amplitude. This difference is not evident in Runs 003 and 004.

The frequency at which the phase lag was 90° is as follows for each of the runs.

<u>Run</u>	<u>Amplitude</u>	<u>Frequency for Phase Lag 90°</u>
001	$\pm 2^\circ$	21 cps
	$\pm 1^\circ$	22 cps
002	$\pm 2^\circ$	18 cps
	$\pm 1^\circ$	18 cps
003	$\pm 2^\circ$	19 cps
	$\pm 1^\circ$	19 cps
004	$\pm 2^\circ$	18 cps
	$\pm 1^\circ$	18 cps

Figure 2

Figure 3

Figure 5

The frequency response for Run 004 shows that the system has a large attenuation after a frequency of 1 cycle per sec, as seen in the amplitude gain plot. A possible factor that could account for the excessive rolloff at 1 cps may be the absence of noise due to the elimination of the erratic potentiometer signal after Run 003.

C. DYNAMIC RESOLUTION

A triangular wave with a 10 degree peak-to-peak input was utilized to evaluate dynamic resolution. Facsimiles of the reduced dynamic resolution data are presented as Figures 6 to 9 to show the capability of the TPCV actuator to respond to this input. These figures demonstrate that any nonlinearities that may exist are less than the readability of the data ($\pm 0.1^\circ$). The capability of responding to the triangular peaks is shown below:

<u>Run</u>	<u>+5°</u>	<u>-5°</u>	<u>+5°</u>	<u>-5°</u>
001	-0.8°	-0.2°	-1.0°	-0.2°
002	-0.2°	-0.1°	-0.6°	-0.1°
003	-0.2°	-0.2°	-0.2°	-0.2°
004	-0.4°	-0.4°	-0.3°	-0.4°

The differences observed from each of the runs are similar to differences one would expect from differing gain and/or zero balance settings of the data acquisition system. The actual gain and zero balance settings were not available to verify this contention. Since these differences existed in this test, it is recommended that calibration of the amplifier gain and zero balance settings be made prior to each test.

D. TRANSIENT RESPONSE

A 20° peak-to-peak square wave was inputted to evaluate transient response. Transient response data were evaluated in terms of saturation

Figure 6

Figure 7

Figure 10

Figure 8

velocity, overshoot and settling time; a facsimile of which is shown in Figure 10. (Note: No transient response data was achieved on Run 004 because hydraulic power to the bypass valve actuator was lost.) The overshoot specification of a minimum of 15% of ordered output level (3.0° for a 20° step) was satisfied in each run. The average settling time was within the 0.3 sec requirement although one of the six observations had a settling time of 0.33 sec.

E. VIBRATION ANALYSIS

The vibration of the TPCV actuator was evaluated at AGC; a similar analysis was made of a same model actuator during NRX/EST EP III test at Jackass Flats. Figure 11 shows a facsimile of the RMS amplitude vibration spectrum. There is evidence of high frequency (greater than 1000 cps) vibration as high as 4 g's. A facsimile of the graph of maximum frequencies was plotted in Figure 12 showing instantaneous maximum peaks of 10 and 14 g's. Thus, it is apparent that the actuator can operate successfully under these levels of environment. Unfortunately, the frequency response of the TPCV actuator during actual test conditions as shown in Figure 13 is inconclusive since the accelerometer and data system response were limited to 1000 cps and for these levels the amplitude was less than 0.5 g's, similar to that observed during the test area H tests. Since higher frequency results are not available, no further comparison can be made.

F. TEMPERATURE AND PRESSURE COMPARISONS

The range of temperatures observed during the four tests is presented for documentation purposes. The range of temperatures was taken during the time intervals of the test program. The pressures for the tests are also included.

Figure 9

Figure 11

Figure 12

Figure 13

Actuator Base Temperatures °R

<u>Test</u>	<u>Start</u>	<u>Min.</u>	<u>Max.</u>
001	509	509	515
002	210	130	494
003	335	218	335
004	517	517	565

TPCV Gas Temperatures and Pressures

<u>Start</u>		<u>Min.</u>		<u>Max.</u>	
<u>T</u>	<u>P</u>	<u>T</u>	<u>P</u>	<u>T</u>	<u>P</u>
895	354	802	197	931	421
1256	525	1151	267	1281	563
979	364	899	350	995	380
1239	526	1195	421	1278	530

Figure 14 - Test Set-up-TPCV/Actuator

Figure 15 - Test Set-up-TPCV/Actuator

Figure 16 - Test Set-up-TPCV/Actuator

APPENDIX C

RN-DR-0082, POST NRX/EST TURBINE POWER CONTROL
VALVE ACTUATOR (S/N 18) EVALUATION

REPORT NO. RN-DR-0082

POST NRX/EST TURBINE POWER CONTROL VALVE
ACTUATOR (S/N 18) EVALUATION

K. E. Krauter
H. O. Suttikus

C. M. Rice
Program Manager
Rocket Engine Operations - Nuclear

ABSTRACT

Post-NRX/EST performance tests of the Bendix Model NT-D1 turbine power control valve-actuator assembly (TPCV S/N 18 and actuator S/N 18) did not reveal any performance deterioration because of NRX/EST use. Electrical noise in the amplifier (which probably existed prior to NRX/EST testing) may have contributed to what appeared to be actuator problems during EP-IVA. While this specific problem can be solved, engine and test-stand noise (electrical and mechanical) can seriously affect TPCV actuator performance. The actuator-system noise characteristics must be improved by changing the amplifier compensation. When changing this compensation, system dynamic and static resolution also should be improved. The actuator operation time was estimated to be about 65 hours. The magnetic amplifier driving the diluent control valve actuator was found to be inoperative: consequently, no performance tests were conducted. Considerable radioactive contamination was found on TPCV and DCV actuator surfaces.

CONTENTS

	<u>Page</u>
I. Technical Discussion	1
A. Visual Inspection	1
B. AGC Test Facility	1
C. Radiation Levels	1
D. Frequency Response	6
E. Transient Response	15
F. Dynamic Resolution	15
G. Threshold Response	31
H. Special Open-Close Test	31
I. Operating Time	35
J. Diluent Control Valve	35
K. Conclusions	35
Appendix A - Test Material and Evaluation Procedure	37
Appendix B - Bendix Turbine Power Control Valve Actuators	40

ILLUSTRATIONS

	<u>Page</u>
1. IPCv and Actuator - Valve Open	3
2. IPCV and Actuator - Valve Closed	4
3. Aerojet-General Nucleonics Remote Handling Facility	5
4. Post NRX/EST Frequency Response Data (0.1 CPS - 0.025 CPS)	7
5. Post NRX/EST Frequency Response Data (0.5 CPS - 0.25 CPS)	8
6. Post NRX/EST Frequency Response Data (1 CPS)	9
7. Post NRX/EST Frequency Response Data (2.5 CPS)	10
8. Post NRX/EST Frequency Response Data (5 CPS)	11
9. Post NRX/EST Frequency Response Data (10 CPS - 12 CPS)	12
10. Post NRX/EST Frequency Response Data (20 CPS - 16 CPS)	13
11. Post NRX/EST Frequency Response Data (24 CPS - 20 CPS)	14
12. Original and "Noise-Free" System	16
13. Post NRX/EST "Noise-Free" Frequency Response Data (0.025 CPS - 0.01 CPS)	17
14. Post NRX/EST "Noise-Free" Frequency Response Data (0.1 CPS - 0.05 CPS)	18
15. Post NRX/EST "Noise-Free" Frequency Response Data (0.4 CPS - 0.2 CPS)	19
16. Post NRX/EST "Noise-Free" Frequency Response Data (2 CPS - 1 CPS)	20
17. Post NRX/EST "Noise-Free" Frequency Response Data (6 CPS - 4 CPS)	21
18. Post NRX/EST "Noise-Free" Frequency Response Data (12 CPS - 10 CPS)	22
19. Post NRX/EST "Noise-Free" Frequency Response Data (18 CPS - 15 CPS)	23
20. Post NRX/EST "Noise-Free" Frequency Response Data (22 CPS - 20 CPS)	24
21. Post NRX/EST "Noise-Free" Frequency Response Data (26 CPS - 24 CPS)	25

ILLUSTRATIONS (cont.)

	<u>Page</u>
22. Post NRX/EST "Noise-Free" Frequency Response Data (Feedback No. 1, 10 MV/Line Only)	26
23. TPCV Actuator Closed-Loop Response	27
24. TPCV Actuator Closed-Loop Response (With and Without Valve Load)	28
25. Post NRX/EST "Noise-Free" Step Response	29
26. Post NRX/EST "Noise-Free" Step Response	30
27. Post NRX/EST "Noise-Free" Dynamic Resolution	32
28. Post NRX/EST "Noise-Free" Threshold Response	33
29. Actuator Opening and Closing Test Trace	34

I. TECHNICAL DISCUSSION

The actuators of the NRX/EST turbine power control valve (TPCV) and the diluent control valve (DCV) were sent to Aerojet-General Nucleonics (AGN) for post-operational tests*. In Table 1 the various post-test performance values are listed and compared with the specification values, Bendix-measured values, and with pre-test Aerojet-General values. The test material and evaluation procedure are defined in Appendix A while a listing of Bendix actuators and usage is given in Appendix B.

A. VISUAL INSPECTION

A grinding wheel was used during NRX/EST disassembly to sever the electrical and pneumatic lines. Visual inspection at AGN showed that metal particles and what was believed to be carborundum dust had been injected into the actuator pneumatic lines. A radiation monitoring system was modified to "vacuum-clean" exhaust lines and the actuator input line. The radiation-monitor filter showed that metal particles and carborundum dust were present.

B. AGC TEST FACILITY

Figures 1 and 2 show the TPCV and actuator as they were tested at the AGN facility. Figure 1 shows the valve in the open position: Figure 2 shows the valve in the closed position. Figure 3 shows the remote handling facility and test equipment used.

C. RADIATION LEVELS

Actuator radiation levels measured at AGN were:

<u>Before Cleaning</u>	<u>After Cleaning</u>
1000 mr/hr (beta)	300 mr/hr (beta)
30 mr/hr (gamma)	30 mr/hr (gamma)

*Test procedures and test equipment are listed in Appendix A.

TABLE 1
ACTUATOR PERFORMANCE VALUES

Performance	Specification NDC-51A H ₂ Amb. T	Bendix H ₂ Amb. T	AGC Pre NRX/EST He Amb. T	San Ramon Post NRX/EST He Amb. T*
Closed Loop Frequency Response Cross Over	90° phase lag at or above 8 cps	18 cps	20.5 cps	17 cps
Step Response 1) Rise Time	t ≤ 0.12 sec t = time to reach 62% of input step	0.08 sec	0.117 sec	0.115 sec
2) Settling Time	t ≤ 0.3 sec t = time to settle within 5% of input step	0.24 sec	0.34 sec**	0.325 sec**
3) Overshoot	Less than 15% of input step.	14%	15.6%**	13.6%
4) Saturation Velocity (max. slew vel.)	> 360 deg/sec	520 deg/sec	512 deg/sec	470 deg/sec
Dynamic Resolution	Output error ≤ 0.5 deg with 0.1 cps tri- angular wave input	0.2 deg	***	0.25 deg
Threshold Resolution	Min. input ± 0.1 deg to obtain output motion	± 0.033 deg	***	± 0.15 deg**

*Performance Data with a "noise free" system (See Figure 12).

**Does not meet specification.

***Not measured because equipment was not available.

Figure 1
TPCV and Actuator - Valve Open

Figure 2

TPCV and Actuator - Valve Closed

Figure 3
Aerojet-General Nucleonics Remote Handling Facility

The higher beta-level indicates that the surface of the actuator was contaminated by fission particles from the valve after the TFCV was removed from the NRX/EST assembly. Radiation values recorded are the same as those measured on the valve itself. Swipes made on the actuator surface recorded 1,000,000 disintegrations per minutes and 20 mr/hr. These levels of contamination preclude use of the actuator at Aerojet-General's Sacramento Plant. Plans are being made, however, to decontaminate the actuator.

D. FREQUENCY RESPONSE

The performance of the valve-actuator assembly as returned from the Nuclear Rocket Development Station (NRDS) was extremely erratic. Sample sections of frequency response data are presented in Figures 4 through 11. These data show a high-frequency noise in the torque-motor current monitor-trace. An oscilloscope trace of this noise identifies it as 400 cps with random low-frequency modulations. These data further show: (1) unacceptable actuator performance; and (2) that performance deteriorated considerably from data recorded at Sacramento and at NRDS prior to NRX/EST testing. It is difficult to compare pre-test and post-test data with that recorded during EP-IVA because: (1) the actuator subloop was evaluated as a part of the closed pressure-loop portion of the engine control system; and (2) the TPCV position data channel had a 3.2 cps roll-off filter in series with the signal. Noise similar to that recorded during AGN testing could possibly account for the poor data gathered during EP-IVA.

Recent tests at Sacramento of the other three NT-D1 actuators revealed the same noise problem in the servo-amplifier, although operation of the actuator systems appeared normal. This noise (predominately 400 cps) was observed as a ± 10 volt saturated square-wave at the third-stage operational amplifier output. The noise was traced to inductive, capacitive, and/or ground-loop coupling of the 400 cps signal from the Burr-Brown ac-to-dc converter into the amplifier.

The noise problem was corrected by substituting an external ± 15 volt dc supply for the internal converter.* This "noise free" system is illustrated in

*Data discussed below will be that taken with the amplifier operating on an external ± 15 v dc power supply.

Figure 4

Post NRX/EST Frequency Response Data
(0.1 CPS - 0.025 CPS)

TORQUE MOTOR CURRENT 10 MA/LINE

COMMAND 10 MV/LINE

FB #2 10 MV/LINE

FB #1 10 MV/LINE

0.5 CPS

0.25 CPS

4.4°

Figure 5
Post NRX/EST Frequency Response Data
(0.5 CPS - 0.25 CPS)

TORQUE MOTOR CURRENT 10 MA/LINE

COMMAND 10 MV/LINE

FB #1 10 MV/LINE

FB #2 10 MV/LINE

4.4°

1 CPS

Figure 6
Post NRX/EST Frequency Response Data
(1 CPS)

Figure 7
Post NRX/EST Frequency Response Data
(2.5 CPS)

Figure 8

Post NRX/EST Frequency Response Data
(5 CPS)

TORQUE MOTOR CURRENT 10 MA/LINE

BRUSH INSTRUMENT

Figure 9

Post NRX/EST Frequency Response Data
(10 CPS - 12 CPS)

TORQUE MOTOR CURRENT 10 MA/LINE

COMMAND 10 MV/LINE

FB #1 10 MV/LINE

FB #2 10 MV/LINE

Figure 10
Post IIR/1 LF frequency, 2 cps
(0 cps - 10 cps)

Figure 11

Post MRX/EST Frequency Response Data
(24 CPS - 20 CPS)

Figure 12. The "noise-free" frequency response on the valve-actuator assembly at AGN presents an improved and much more acceptable system. Sections of the frequency response data are shown in Figures 13 through 22. A Bode plot of the frequency response data is presented in Figure 23. Also included in Figure 23 is the response of a smaller input (1.9 degree peak-to-peak) signal. On all data, stair steps of about 0.2 degree are easily seen at low frequencies. The torque-motor current required to overcome deadband is about 5 milliamperes.

Frequency response of the actuator without the unpressurized TPCV was also taken. Data with and without the valve are shown in Figure 24. The unpressurized valve does not appreciably affect the actuator response.

E. TRANSIENT RESPONSE

The saturation velocity of the actuator, measured during two 80-degree steps, was 470 degrees/sec opening and closing. A minimum saturation velocity of 360 degrees/sec is acceptable. These data are presented in Figures 25 and 26. This test was conducted with a "noise-free" system and with an unpressurized TPCV.

While rise-time and overshoot are within specification values, settling time is slightly higher than that stated in the specification. It should be noted that all specification values are for both gaseous hydrogen actuation and a specified load. AGN testing, however, was conducted with helium and essentially no load. Settling time would be within specification if hydrogen was used in conjunction with a valve underload.

F. DYNAMIC RESOLUTION

The dynamic resolution of the TPCV actuator was determined by driving the actuator with a low-frequency (0.01 cps) triangular wave signal of 4 degrees peak-to-peak amplitude.

"NOISE-FREE" SYSTEM

ORIGINAL SYSTEM

Figure 12

Original and "Noise-Free" System

TORQUE MOTOR CURRENT 1 MA/LINE

Figure 13

Post NRX/EST "Noise-Free" Frequency Response Data
(0.025 CPS - 0.01 CPS)

TORQUE MOTOR CURRENT 1 MA/LINE

Figure 14

Post NRX/EST "Noise-Free" Frequency Response Data
(0.1 CPS - 0.05 CPS)

TORQUE MOTOR CURRENT 1 MA/LINE

Figure 15

Post NRX/EST "Noise-Free" Frequency Response Data
(0.4 CPS - 0.2 CPS)

Figure 16

Post NRX/EST "Noise-Free" Frequency Response Data
(2 CPS - 1 CPS)

Figure 17

Post MRX/EST Noise-Free' Frequency Response Data
(6 CPS - 4 CPS)

Figure 18

Post NRX/EST "Noise-Free" Frequency Response Data
(12 CPS - 10 CPS)

TORQUE MOTOR CURRENT 10 MA/LINE

TORQUE MOTOR CURRENT 1 MA/LINE

COMMAND 10 MV/LINE

FB #1 10 MV/LINE

FB #2 10 MV/LINE

4.1°

18 CPS

15 CPS

Figure 19

Post NRX/EST "Noise-Free" Frequency Response Data
(18 CPS - 15 CPS)

Figure 20

Post NRX/EST "Noise-Free" Frequency Response Data
(22 CPS - 20 CPS)

Figure 21

Post NRX/EST "Noise-Free" Frequency Response Data
(26 CPS - 24 CPS)

Figure 22

Post NRX/EST "Noise-Free" Frequency Response Data
(Feedback No. 1, 10 MV/Line Only)

Figure 23

TPCV Actuator Closed-Loop Response

Figure 24
TPCV Actuator Closed-Loop Response
(With and Without Valve Load)

Figure 25

Post NRX/EST "Noise-Free" Step Response

Figure 26

Post NRX/EST "Noise-Free" Step Response

The resolution (or stair-step) amplitude ranges from 0.1 to 0.25 degree. A maximum step of 0.5 degree is acceptable. The data trace of this triangular wave is shown in Figure 27. The dynamic resolution measured by Bendix was 0.2 degree.

G. THRESHOLD RESPONSE

The threshold test indicates a threshold sensitivity of about 0.3 degree peak-to-peak input. Threshold data are shown in Figure 28. An approximately equivalent test at Bendix measured resolution as 0.017 degree peak-to-peak input.* This is the test which deviated the most from the original data. The difference is probably caused by the 400 cps noise which acted like dither.

H. SPECIAL OPEN-CLOSE TEST

A special test was performed to check the ability of the valve actuator to consistently close. Data on the last NRX/EST test indicated that the TPCV did not close below 10 degrees. At AGN the valve moved to zero degrees 34 times at triangular wave-shape frequencies of 0.2 and 0.5 cps. At no time during the tests did the valve fail to close. Several oscillations into the closed and open stops are shown in Figure 29. No attempt was made to drive the valve to the closed position with the original NRX/EST system. However, when the valve was separated from the actuator, the torque required to move the valve appeared normal; thus, it is questionable whether the actuator noise problem was the reason the valve failed to close during EP-IVA.

*The Bendix test differed to the degree that the noise problem was not considered, that loading was not applied, and that gaseous hydrogen was used instead of helium.

Figure 27

Post NRX/EST "Noise-Free" Dynamic Resolution

TORQUE MOTOR CURRENT 1 MA/LINE

Figure 28

Post NRX/EST "Noise-Free" Threshold Response

Figure 29

Actuator Opening and Closing Test Trace

I. OPERATING TIME

The following operating times were recorded on the actuator:

Bendix pre-shipment	3.0 hours
Aerojet-General pre-NRX/EST	0.2 hours
NRDS NRX/EST	60 hours (estimated)
AGN post-NRX/EST	<u>1.5</u> hours
Approximate Total Operating Time:	65 hours

J. DILIGENT CONTROL VALVE

Tests on actuator S/N 12 (used with DCV S/N 19) were not attempted because of the faulty magnetic amplifier driver. A careful check of the amplifier was made, verifying proper 400 cps 115 volt excitation, variable input command-signal, proper wiring to the torque motor, and continuity through the torque-motor coil. The amplifier output always remained at a balanced and saturated level regardless of input command.

K. CONCLUSIONS

Post-NRX/EST testing of actuator S/N 18 indicates that performance did not deteriorate because of its use in the NRX/EST test program. However, an electrical noise problem does exist in the actuator amplifier, causing unacceptable actuator operation. This noise was traced to capacitive, inductive, and/or ground-loop coupling from the ac-to-dc inverter into the amplifier. The problem was solved by the use of an external ac-to-dc power supply.

The compensation used in this actuator system makes the system very sensitive to both internal and external 60 to 600 cps noise. Actuator operation characteristics noted with 400 cps amplifier noise at the AGN facility were duplicated almost exactly during mechanical vibration tests on the "noise-free" actuator (S/N 17). The mechanical resonant frequency band was from 400 to 600 cps.

These vibrations were introduced in the axis of the servo-valve spool, indicating that the 400 cps noise moves the servo-valve and/or torque-motor flapper in the same manner as mechanical vibration. The degraded system performance during or after NRX/EST testing was caused apparently by either the 400 cps electrical noise-coupling increasing, the actuator mechanical resonance frequency decreasing, and/or system dynamics changing with actuator use.

This theory could also explain the deteriorated performance of the two NT-C2 actuators used during NRX/EST testing. Testing of these actuators at Bendix did not reveal mechanical wear which would account for its performance problems. While rework of the NT-C2 magnetic amplifiers somewhat improved performance, only with a transistor amplifier did the NT-C2 actuator performance become similar to the "noise-free" NT-D1 actuators (S/N 15, 16, 17 and 18). The 400 cps noise (typical of the magnetic amplifiers) is similar to the 400 cps coupled noise of the original NT-D1 actuator amplifiers.

Table 1 compares the performance of TPCV actuator model NT-D1 (S/N 18) with specification requirements, Bendix performance tests, Aerojet-General tests conducted prior to NRX/EST testing and AGN post-NRX/EST tests. As noted, two performance specifications are not met: settling time and threshold. This is because: (1) Aerojet-General tests were conducted with helium instead of gaseous hydrogen in the step response test; and (2) 400 cps noise was present and functioned much like dither during the threshold resolution tests. Apparently the engine-system actuation threshold is marginal and steps should be taken to improve the level. The specification for threshold resolution should be changed from ± 0.1 degree to ± 0.05 degree.

Future NFIS disassembly procedures should be established which would maintain actuator cleanliness during severance of the actuator supply lines and removal of the actuator from the TPCV. After disassembly, the actuator should be isolated from other radioactively contaminated parts.

Appendix A
TEST MATERIAL AND EVALUATION PROCEDURE

I. MATERIAL FURNISHED

- A. COMPONENT HARDWARE: TPCV Assembly 278100, S/N 018
TPCV Actuation System
Actuator Assembly
Bendix P/N 2775030, S/N 018
Amplifier
Bendix P/N 2775842, S/N 150
Bendix P/N 2775020, S/N 009
DCV Actuator
Bendix P/N 2775022, S/N 012
- B. TEST EQUIPMENT: Portable Test Console, 092165
Mark 200 Brush Recorder, RF 1783 (8 channel)
Torque Meter, Type A-1
- C. REFERENCES
Bendix Drawing 2775030
Bendix Drawing 2775022
Bendix Report CNP1-121, Assembly and Test Record of
Turbine Power Control Valve Actuator S/N 018
AGC Drawing 278100, Valve Assembly - Turbine Power
Control
AGC Drawing 092165, Portable Test Console
Log Book, TPCV Actuator, Bendix P/N 2775030

II. EVALUATION PROCEDURE

A. VISUAL

1. Measure radiation levels at TPCV-end and actuator-end of the assembly.
2. Inspect TPCV interior with butterfly in 90° position. (If valve is in closed position it may be opened by applying force to edge of butterfly.)

Appendix A

B. PERFORMANCE

1. Conditions

TPCV

Temperature	Ambient
Base	525 $\pm$ 25 psia (GN ₂)

Actuator Supply

Temperature	Ambient
Pressure	215 $\pm$ 10 psia
Fluid	GHe
Back Pressure	0 psig

<u>Evaluation</u>	<u>CPS</u>	<u>Wave Form</u>	<u>Amp P-P Deg.</u>	<u>Min. Cycles</u>	<u>Position Degrees</u>
Full open- Full closed	2.0	Triangular	90	10	45
Threshold Response	0.1	Sine	0.2	5	50
Frequency Response	0.025	Sine	4	5	50
(Closed Loop)	0.1	Sine	4	5	50
	0.25	Sine	4	5	50
	0.5	Sine	4	5	50
	0.8	Sine	4	5	50
	1.0	Sine	4	10	50
	2.5	Sine	4	10	50
	5.0	Sine	4	10	50
	8.0	Sine	4	10	50
	10.0	Sine	4	10	50
	16.0	Sine	4	10	50
	24.0	Sine	4	10	50

Appendix A

<u>Evaluation</u>	<u>CPS</u>	<u>Wave Form</u>	<u>Amp P-P Deg.</u>	<u>Min. Cycles</u>	<u>Position Degrees</u>
Frequency Response	Same as Threshold Response except at 2 degrees peak-to-peak amplitude				
Dynamic Resolution	0.05	Triangular	10	2	50
Transient Response	0.25	Square	20	4	50

Appendix B

BENDIX TURBINE POWER CONTROL VALVE ACTUATORS PART NUMBER, MODEL, SERIAL NUMBER

<u>Part Number</u>	<u>Model Number</u>	<u>Serial Number</u>	<u>Past Usage or Assignment</u>
2775022	NT-C2	11	EST Backup TPCV
2775022	NT-C2	12	EST Diluent Valve
2775022	NT-C2	13	EST TPCV
2775022	NT-C2	14	Eng. Evaluation
2775030	NT-D1	15	XECF
2775030	NT-D1	16	XE-1
2775030	NT-D1	17	Qualification
2775030	NT-D1	18	EST-TPCV, Qualification

APPENDIX D

RN-DR-0127, PROOF-PRESSURE TEST OF TURBINE-POWER-CONTROL-VALVE ACTUATOR

REPORT NO. RN-DR-0127

PROOF-PRESSURE TEST OF
TURBINE-POWER-CONTROL-VALVE ACTUATOR

H. O. SUTTKUS

ABSTRACT

A Model NT-D1 turbine-power-control-valve actuator (TPCVA) was subjected to a proof-pressure test to determine if increases in internal pressure would adversely affect the integrity of the structural components or the performance of the unit. Posttest performance was within specification requirements, and visual examination of the structural components revealed no damage.

CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	1
III. Technical Discussion	1
IV. Conclusions	8

TABLES

<u>Number</u>	<u>Title</u>	<u>Page</u>
1	Actuator-Housing Proof-Pressure-Test; Torque Check of Actuator Cover Screws	2
2	Proof-Pressure-Test Specimen Identification and Equipment List	4

FIGURES

<u>Number</u>	<u>Title</u>	<u>Page</u>
1	Actuator Mounted on the Test Fixture	5
2	Gain and Phase Angle vs Frequency, TPCV Actuator SN 17, Before Proof-Pressure Tests	6
3	Gain and Phase Angle vs Frequency, TPCV Actuator SN 17, After Proof-Pressure Test	7

APPENDIXES

A	Stress Analysis, Bendix TPCV Actuator for XE-Engine
B	Schematic Diagram and Photograph of Console and Diagram of Pneumatic Supply

I. INTRODUCTION

This report describes the proof-pressure test of the Bendix Model NT-D1 (Part Number 2775030, Serial Number 17) turbine-power-control-valve actuator (TPCVA). This TPCVA model will be used in the XE-1 and XECF nuclear-rocket-engine tests.

II. SUMMARY

Performance reference tests were conducted before and after the test to indicate changes in performance caused by the test. Posttest performance was within specification requirements, and visual examination of the structural components revealed no damage.

III. TECHNICAL DISCUSSION

Before the actuator was proof-pressure-tested, a stress analysis (Appendix A) was performed that indicated that the strength of the screws used to retain the cover was the limiting factor and that an internal pressure of 535 psi was allowable. This test specified a pressure of 250 psi, and the normal operating pressure is 55 psi maximum.

A. OBJECTIVE

The purpose of the proof-pressure test was to determine the effect of an increase in internal pressure on the structural components and on performance of the actuator.

B. PROCEDURE

The Bendix TPCV actuator, PN 2775030, SN 17, was examined for physical evidence of previous damage; and the screws that retain the cover, Bendix PN 2775745, were retorqued as shown in Table 1. The screws retaining

TABLE 1

ACTUATOR-HOUSING PROOF-PRESSURE TEST; TORQUE CHECK OF
ACTUATOR COVER SCREWS

<u>Screw No.</u>	<u>Torque, lb-in.</u>	
	<u>Pretest</u>	<u>Posttest</u>
1	25	25
2	25	25
3	25	25
4	25	25
5	25	25
6	25	25
7	25	25
8	25	25
9	25	25
10	25	

TORQUE CHECK, TRANSMISSION HOUSING SCREWS

<u>Screw No.</u>	<u>Torque, lb-in.</u>	
	<u>Pretest</u>	<u>Posttest</u>
1	25	25
2	25	25
3	25	25
4	25	25
5	25	25
6	25	25
7	25	25
8	25	25
9	25	25
10	25	25

the transmission housing, Bendix PN 2775795, were also retorqued as shown in Table 1.

The actuator was then mounted on the test fixture as shown in Figure 1. The actuator was connected to a pneumatic supply and test console as shown in Appendix B; a list of associated equipment is shown in Table 2. New gaskets were used at all pneumatic connections. All clamps and connectors were torqued to their design values. A reference thermocouple junction was connected to the thermocouple junction on the potentiometer base in the actuator, and the reference junction was placed in an ice bath. The actuator exhaust was blocked, and a 250-psi pressure was applied to the shaft seal cavity of the actuator test stand. Pressure was then applied to the inlet port of the actuator. The pressure was increased at a rate of 20 psi/min until a final pressure of 249 psi was achieved. The thermocouple located on the potentiometer base indicated no change in temperature. The pressure was maintained for 10 min before it was released. All screws were checked to determine if the torque values had changed.

C. RESULTS

A performance reference test was conducted before the proof-pressure test, and the results are shown in Figure 2. Another performance reference test was conducted after the proof-pressure test, and test data are presented in Figure 3. The torque readings on the screws were unchanged (Table 1).

TABLE 2

PROOF-PRESSURE-TEST SPECIMEN IDENTIFICATION AND
EQUIPMENT LIST

<u>Actuator</u>				
Manufacturer		Bendix		
Part Number		2775030		
Model Number		NT-D1		
Serial Number		17		

<u>Component</u>	<u>Manufacturer</u>	<u>Part/Model Number</u>	<u>Serial Number</u>	<u>Calibration Expiration Date</u>
Millivoltmeter	Fluke	825A	835	6/28/66
Torque wrench	Sturdivant	F100-1	4900437	8/5/66
Torque wrench	Torque meter	TQ-50-A	52716	8/5/66
Gage	Heise

Figure 1 - Actuator Mounted on the Test Fixture

Figure 2 - Gain and Phase Angle vs Frequency, TPCV
Actuator SN 17, Before Proof-Pressure Tests

Figure 3 - Gain and Phase Angle vs Frequency, TPCV
Actuator SN 17, After Proof-Pressure Test

IV. CONCLUSIONS

A stress analysis performed before the proof-pressure test indicated that the cover screws, which were the weakest component, would withstand a test pressure of 535 psi. The comparative performance of the actuator, as indicated by posttest data, showed no deterioration (Figures 2 and 3).

The actuator design was concluded to be adequate to withstand the applied proof pressure.

APPENDIX A

STRESS ANALYSIS, BENDIX TPCV ACTUATOR
FOR XE-1 ENGINE

(J. Jellison)

Appendix A

I. INTRODUCTION

The purpose of this appendix is to present results of the analysis performed to determine the maximum allowable pressure that the TPCV actuator housing and flanges can withstand. The cover assembly (PN 2775745, Figure 1) will be the governing component and will be analyzed in detail.

II. DESIGN DATA

A. REFERENCE DRAWINGS

2775745 - Cover Assembly

2775747 - Insert

2775748 - Screw, Captive, Drilled Socket Head

2775746 - Cover

B. MATERIAL AND STRENGTHS AT AMBIENT TEMPERATURE

Cover, insert, and stainless-steel screws, Type 410:

$$F_{TY} = 103 \text{ ksi}; F_{TU} = 124 \text{ ksi};$$

$$F_{SU} = 90 \text{ ksi}.$$

C. LOADS AND ENVIRONMENT

Determine the maximum internal pressure that the cover assembly can withstand.

III. ANALYSIS

Before a complete discontinuity analysis is accomplished, it is necessary to check other modes of failure to determine if they affect the maximum pressure.

Appendix A

Figure 1 - Actuator Cover

Appendix A

A. SCREW LOADS

BENDIX PN 2775746

CRES. 410 ROCKWELL "C" 26 - 33

$$\begin{aligned}\text{Load per screw} &= F = \pi R_1^2 P / N \\ &= \pi (2.346)^2 P / 10 = 1.73 P\end{aligned}$$

Assuming a factor of 1.5 on this calculated screw ejection load, to include screw preload and extra screw load due to flange bending, gives a total screw load of;

$$F_T = 1.5 (1.73 P) = 2.59 P \text{ lb/Bolt}$$

$$\text{Screw Stress } \frac{F_T}{A}$$

$$A = \frac{\pi d^2}{4} = \frac{\pi (.142)^2}{4} = 0.0158$$

Appendix A

$$\sigma = \frac{2.59P}{0.0158} = 163.5P$$

$$\therefore P_{ult. \text{ allow}} = \frac{124,000 * (.8^{**})}{163.5} = 606 \text{ psi.}$$

*Assume CRES 410 and 416 give same allowable
 **SNPO-C-imposed design factor

B. THREAD SHEAR

Appendix A

$$\tau = \frac{F_T}{A_S} .$$

$$A_S = 0.6 \pi DL = 0.6 \pi (0.19 \times 0.264) = 0.0945 \text{ in.}^2$$

$$\tau = \frac{2.59P}{0.0945} = 27.4 P .$$

$$P_{\text{ult allow.}} = \frac{90,000 (0.8)}{27.4} = 2,630 \text{ psi.}$$

C. INSERT SHEAR THROUGH FLANGE

$$\tau = \frac{F_T}{A_S} ;$$

$$A_S = \pi DL = \pi (0.3425) (0.057) = 0.0613 \text{ in.}^2 ;$$

$$\tau = \frac{2.59 P}{0.0613} = 42.2 P ;$$

$$P_{\text{ult allow.}} = \frac{90,000 (0.8)}{42.2} = 1,710 \text{ psi.}$$

D. CONSIDER FLAT CLOSURE PORTION OF COVER (BENDIX PN 2775745) AS A SIMPLY SUPPORTED FLAT PLATE

Appendix A

$$\sigma_{\text{Max. [at center]}} = 1.24 P \left(\frac{R}{t} \right)^2 = 1.24 \left(\frac{1.096}{0.093} \right)^2 P = 172 P;$$

$$P_{\text{ult allow.}} = \frac{124,000 (.8)}{172} = 577 \text{ psi.}$$

However, if plate is considered fixed at the edges,

$$\sigma_{\text{max. [at edge]}} = 0.75 P \left(\frac{R}{t} \right)^2 = 104P;$$

$$\therefore P_{\text{ult allow.}} = 954 \text{ psi.}$$

Since the actual case is somewhere between these two conditions,

$$P_{\text{ult allow.}} > 577 \text{ psi.}$$

$$\therefore \text{say } \sigma_{\text{max.}} = P \left(\frac{R}{t} \right)^2 = 139 P;$$

$$\therefore P_{\text{ult allow.}} = \frac{124,000 (0.8)}{139} = 714 \text{ psi.}$$

E. CONSIDER CYLINDRICAL PORTION OF COVER CLAMPED RIGIDLY TO HOUSING

$$\sigma_M = \frac{PR}{2t} + \frac{6M}{t^2},$$

where $M = 0.257 PRt$;

Appendix A

$$\therefore \sigma = \frac{PR}{2t} + \frac{6 (.257) PR}{t} = (0.5 + 1.54) \frac{PR}{t}$$

$$= 2.04 \frac{PR}{t} = \frac{2.04 (2.346)}{0.093} \quad P = 51.5 \text{ P;}$$

$$P_{\text{ult allow.}} = \frac{124,000 (0.8)}{51.5} = 1925 \text{ psi.}$$

This is less critical than the other end of the cover; i.e., previously calculated flat plate stresses.

Check to see if cover cylindrical portion may be considered a long cylinder.

$$\text{Cyl. length } L > 2 \left(\frac{5}{\beta} \right);$$

$$\beta = \frac{1.285}{\sqrt{RT}} = \frac{1.285}{\sqrt{2.39 (.093)}} = 2.73;$$

$$\therefore 2 \left(\frac{5}{\beta} \right) = \frac{10}{2.73} = 3.66 \text{ in.}$$

But $L = 2.625$; $\therefore$ cylinder is a short cylinder.

However, the cylindrical portion is long enough that the discontinuities, where they overlap, will be sufficiently damped so that the previously calculated stresses govern.

IV. RESULTS AND CONCLUSIONS

The screw stresses govern in predicting an ultimate allowable pressure of 606 psi.

$$\therefore P_{\text{yield allow.}} = 606 \times \frac{103}{124} \times \frac{0.85}{0.80} = 535 \text{ psi.}$$

This pressure gives a zero M.S. on yield when using the criterion of 85% of yield strength.

APPENDIX B

SCHEMATIC DIAGRAM AND PHOTOGRAPH OF
CONSOLE AND DIAGRAM OF PNEUMATIC SUPPLY

Appendix B

Figure 1, an electrical schematic diagram of the TPCV actuator test console, shows the electrical connections necessary to operate and control the TPCV actuator. The components indicated in Figure 1 are shown installed in the test console in Figure 2. The actuator is powered by a pneumatic supply that is connected to the actuator as shown in Figure 3.

The electrical supplies and signal sources shown in Figure 1 are connected to the actuator through harnesses and connectors. The electrical signals are turned on prior to application of the pneumatic supply pressures. Detailed operating procedures are contained in Report RN-S-0348, Operating and Maintenance Instructions for XE-1 Turbine Power Control Valve (TPCV) Actuation Subsystem.

Figure 2 - Test Console and Recorder Equipment

Appendix B

Figure 3 - TPCV-Actuator Pneumatic-Supply Diagram

APPENDIX E

RN-DR-0128, TURBINE POWER CONTROL VALVE ACTUATOR
PERFORMANCE EVALUATION VIBRATION TEST

REPORT NO. RN-DR-0128

TURBINE POWER CONTROL VALVE ACTUATOR
PERFORMANCE EVALUATION
VIBRATION TEST

H. O. Suttkus

A handwritten signature in cursive script, appearing to read "C. M. Rice", followed by a small horizontal line.

C. M. Rice
Program Manager
Nuclear Rocket Operations

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	1
III. Technical Discussion	1
A. Objective	1
B. Test Setup	2
C. Procedure	2
D. Results	11
E. Conclusions	12

Appendix I	Environmental Dynamic Analysis of the Turbine Power Control Valve and the Turbine Inlet Line
------------	--

FIGURE LIST

<u>Figure</u>		<u>Page</u>
1	TPCV Acuator Test Console, Schematic Diagram	3
2	Test Console and Recorder	4
3	Actuator Installed on Test Fixture	5
4	Helium Supply Line to Actuator	7
5	Actuator Mounted on Vibration Table in X Axis Direction	9
6	Actuator Mounted on Vibration Table in Z Axis Direction	10
7	Actuator Mounted on Vibration Table Showing Fractured Bellows (Mounted in X Axis)	13
8	Close-Up Showing Fractured Bellows	14
9	Bode Plot; Pre-Vibration Performance Reference Test	15
10	Bode Plot; During X Axis Input Vibration Test	16
11	Bode Plot; During Z Axis Input Vibration Test at 658 cps	17
12	Bode Plot; During Z Axis Input Vibration Test at 1505 cps	18
13	TPCV Actuator S/N 17 Vibration Test Data Gain vs Frequency	19
14	Bode Plot; Performance Reference Test, Before Random Vibration Test	20
15	Bode Plot; Performance Reference Test, During Random Vibration Test	21
16	Bode Plot; Performance Reference Test, After Random Vibration Test	22

I. INTRODUCTION

This report describes the vibration test of the Bendix Model NT-D1 Turbine Power Control Valve Actuator (TPCVA), Serial No. 17. The vibration test is part of the overall qualification test and was performed in accordance with the requirements of RN-S-0425, Qualification Test Plan, Bendix Model NT-D1 Turbine Power Control Valve Actuator.

II. SUMMARY

Prior to performing the vibration test described in this report, a vibration test was started but not completed due to faulty instrumentation and consequent minor damage to the actuator. After the test equipment and the actuator were repaired, the entire test was conducted through completion using both sinusoidal and random vibrations.

Performance tests which were conducted before and after each vibration test indicated no appreciable changes in performance.

No deterioration in performance was noted during the vibration testing (either sinusoidal or random) when conducted in accordance with the applicable specification. In the Y axis only, performance deterioration was noted during dwell at a 573 cps resonant point. However, the maximum input vibration frequency for the Y axis, specified in NDC-51A, Actuator, Electro-Pneumatic, Rotary, for Turbopump Power Control Valve, is 500 cps at 1 g.

III. TECHNICAL DISCUSSION

A. OBJECTIVE

The purposes of the sinusoidal vibration test were: (1) to obtain data which would show the frequencies at which the actuator had resonant peaks; (2) to determine if continued excitation at the resonant

frequencies would cause damage to, or permanently degrade the performance of the actuator; and (3) to determine the nature and magnitude of any performance degradation which might occur during vibration at the resonant frequencies.

The random vibration test was made to determine (1) if random-input frequencies were of sufficient magnitudes to cause the development of high accelerations at the resonant frequencies determined during the sinusoidal vibration test noted above; and (2) the nature and magnitude of any performance degradation which might occur during the test.

B. TEST SETUP

The electrical power and control for the actuator is supplied from a console which is shown schematically in Figure 1 and pictorially in Figure 2. The actuator was installed in a special vibration test fixture for adaptation to the vibration table as shown in Figure 3.

The vibration table and its associated instrumentation and control equipment is noted in Table 1.

C. PROCEDURE

The Bendix TPCVA was examined and then mounted on its test fixture, using prescribed torque values and procedures. A supply of helium gas was provided and the actuator was connected to the operating console (see Figure 4). A performance reference test was conducted both prior to and following the vibration tests. The performance reference test consisted of (1) threshold test, (2) frequency response test, and (3) step response test. Detailed procedures for the 3 noted tests which comprise the performance reference test may be found in Report No. RN-DR-0084, entitled Electro-Pneumatic Servo Valve Actuator Evaluation Procedure, March 1967

Figure 1 - TPCV Actuator Test Console, Schematic Diagram

Figure 2 - Test Console and Recorder

Figure 3 - Actuator Installed on Test Fixture

TABLE 1

TEST EQUIPMENT LIST

<u>Item</u>	<u>Manufacturer</u>	<u>Part No./ Model No.</u>	<u>Serial No.</u>	<u>Calibration Plates</u>
Shaker	Ling	B 290	108	4/28/66 10/15/66
Vibration Console	Ling	SCO-3	Ling #1	3/30/66 9/18/66
Oscilloscope	Tecktronix	502A	22889	5/20/66 8/25/66
Oscillograph	Consolidated Electrodynamics	1588-51	7286	7/10/66 8/28/66
Tape Recorder	Ampex	FR1300	505	2/25/66 8/28/66
Differential Voltmeter	John Fluke	825A	835	6/5/66 9/1/66
Function Generator	Hewlett Packard	202A	325-13248	3/29/66 9/6/66
Brush Recorder	Brush	MARK 20	634	5/10/66 8/15/66
Preamp	Brush	13-4485-10773	115	5/20/66 9/25/66
15 Volt Power Supply	Power Design	TW4005	T409062	3/15/66 9/8/66
10 Volt Power Supply	Power Design	2015R	V406021	6/15/66 11/7/66
Frequency Response Analyzer	Weston, Boonshaft & Fuchs	DA410A	6001	7/23/66 10/20/66
Servo Amplifier	Burr-Brown	Dwg. No. 2775842 (Modified)		
Test Console	AGC	Dwg No. 1118758		
Torque Wrench	Snap On Tools Corp.	50-14	4900457	6/15/66 9/25/66

Figure 4 - Helium Supply Line to Actuator

The accelerometers were calibrated and ranged on the recorder. The actuator was installed on the vibration stand as shown in Figure 5. The accelerometers were placed on the actuator as shown in Figure 6. The servo-valve spool central axis and the output shaft central axis were chosen as the basis of the coordinate system for the definition of the three mutually perpendicular vibration input axes. The cross-spool axis was designated as the X axis, the spool central as the Y axis, and the output-shaft central axis as the Z axis (see Figure 6). Electrical and pneumatic power was applied to the actuator, and the sweep portion of the vibration test in the X axis was conducted using the following values: From 5 to 17 cps the double amplitude (D.A.) was maintained at 0.135 inch, and between 17 and 2000 cps, the 2 g input was kept constant. During the entire frequency sweep from 5 to 2000 to 5 cps, the actuator command signal input consisted of a triangular wave function, at 0.1 cps and approximately 60° peak-to-peak amplitude, while resonant peaks, as indicated by the various accelerometers, were noted. At the end of the sweep phase, the frequencies producing major (high-amplitude) resonances were determined by examination of the data. The vibration table was then operated at the major resonance point, with an input sufficient to impart a 1 g acceleration to the actuator. The actuator was subjected to this input acceleration for 10 minutes, during which time the performance of the actuator was checked by running a performance reference test as described above.

Following the X-axis vibration test the entire procedure noted above was repeated using the Y axis of the actuator as the input axis.

Following the Y-axis vibration, a similar procedure was followed for the Z axis of the actuator except that the vibration was from 16 to 2000 to 16 cps at the following values: From 16 to 45 cps at an amplitude sufficient to produce 1.33 g acceleration; from 45 to 87 cps, at a constant amplitude of 0.013 inch (D.A.); and from 87 to 2000 cps at sufficient amplitude to produce 5 g input acceleration. After the resonant peaks had been established, the 10-minute dwell test was evenly divided between the two most prominent resonant points, using a 5 g input acceleration.

Figure 5 - Actuator Mounted on Vibration Table in X Axis Direction

Figure 6 - Actuator Mounted on Vibration Table in Z Axis Direction

D. RESULTS

Midway through the Z-axis dwell of the first vibration test, the performance of the actuator deteriorated and a fractured gear-motor pressurization-line bellows was discovered (see Figures 7 and 8), at which point the test was discontinued pending investigation. The ensuing investigation revealed that the accelerometer controlling the feedback to the vibration-table amplifier had been damaged during installation and its output was thus materially reduced. This output error caused the input excitation to the actuator to be correspondingly higher than specified (by an estimated factor of 4). The higher than normal input excitation due to the damaged accelerometer and misalignment of the brazed joint between the tubular elbow and bellows, which was introduced during its manufacture, is believed to have contributed to the failure. It should be noted that the bellows on the other gear-motor pressurization line was subjected to the same vibration and had not failed and did not fail in the testing that followed the repair.

Vibration at the major resonant points in the X and Z axis produced no appreciable effect on actuator performance, as evidenced by the performance reference tests conducted prior to and during the vibration (see Figures 9 through 12 for Bode Plots and Figure 13 for resonance data).

In the Y axis, during vibration at the 573 cps major resonant point actuator performance was deleteriously affected causing noise on the torque motor current and position feedback voltage. Thus, preventing detailed data interpretation for this dwell condition.

The random vibration test was conducted using the same test configuration as in the Z-axis sinusoidal vibration test. The actuator was subjected to a random frequency excitation with a power-spectral density

of 0.06 g^2 per cps, ± 3 decibels. The spectrum was from 100 through 2000 cps. The data collected during the random-vibration input in the Z axis indicated no resonant peaks or operational problems. (See Figures 14 through 16 for Bode plots).

E. CONCLUSIONS

The TPCVA suffers no permanent ill effects resulting from subjecting the actuator to either the sinusoidal or random vibration testing in conformance with parameters specified by NDC-51A.

The TPCVA exhibits no appreciable performance degradation during the noted vibration testing.

In the Y axis only, performance deterioration was noted at a 573 cps major resonant; however, this is above the specified vibration spectrum maximum of 500 cps. In addition, an analysis of the TPCVA vibration environment during engine operation indicates that input frequencies as well as amplitudes from the XE turbine inlet line will be well below the maximum specified frequencies and amplitudes. A complete report of the noted analysis is given in 7730:002R entitled "Environmental Dynamic Analysis of the Turbine Power Control Valve and the Turbine Inlet Line". A facsimile of this report is included herein as Appendix I.

With regard to the aborted test, even though the vibration was considerably in excess of the specified values, it served to define the misaligned bellows as a weak point of the actuator. Therefore, action was taken by way of appropriate drawing changes to prevent future reoccurrence of the misalignment.

Figure 7 - Actuator Mounted on Vibration Table Showing Fractured Bellows (Mounted in X Axis)

Figure 8 - Close-Up Showing Fractured Bellows

Figure 9 - Bode Plot; Pre-Vibration Performance Reference Test

Figure 10 - Bode Plot; During X Axis Input Vibration Test

Figure 11 - Bode Plot; During Z Axis Input Vibration Test
at 658 cps

Figure 12 - Bode Plot; During Z Axis Input Vibration Test
at 1505 cps

Figure 13 - TPCV Actuator S/N 17 Vibration Test Data Gain vs Frequency

Figure 14 - Bode Plot; Performance Reference Test, Before
Random Vibration Test

Figure 15 - Bode Plot; Performance Reference Test, During Random Vibration Test

Figure 16 - Bode Plot; Performance Reference Test, After
Random Vibration Test

APPENDIX I

ENVIRONMENTAL DYNAMIC ANALYSIS OF THE TURBINE POWER
CONTROL VALVE AND THE TURBINE INLET LINE

(P. Soo)

TABLE OF CONTENTS

	<u>Page</u>
I. Summary	I-1
II. Introduction	I-1
III. Summary of Results	I-3
IV. Method of Dynamic Analysis	I-6
V. Discussion	I-8
VI. Calculations	I-9

I. SUMMARY

This report summarizes the preliminary study on the environmental structural dynamic analysis of the X-E Turbine Power Control Valve (TPCV) and the turbine inlet line. The critical speed of the turbopump, the natural frequencies of bell-mode vibration of the nozzle, the resonant frequencies of the TPCV torque motor component, the natural frequencies of the turbine inlet line, and the estimated dynamic response of the TPCV due to external excitations from both the turbopump and nozzle are determined.

II. INTRODUCTION

The X-E turbine control valve is located immediately below the upper elbow of the turbine inlet line as shown in Figure 1. The function of this unit is to control the flow rate of hot gas to the turbine. The valve is opened or closed to a certain extent depending upon what the "error sign" input feeds into the torque motor. The electric-pneumatic actuator functions the transmission shaft which in turn operates the "butterfly" valve.

The performance of the TPCV servo control unit can be affected seriously by undesirable vibration inputs, resulting from the valve supporting structure or the adjacent structures. Since the TPCV is closely related to the structures such as the turbopump, the turbine inlet line, the diluent line as well as the X-E nozzle, an attempt has been made to study the basic vibration characteristics of the TPCV in this environment. Of specific interest are the resonant frequencies of each structural component and the dynamic response of the valve. A summary of the analytical results is given in the next section.

Figure 1 - Propellant Feed System Components X-Engine

III. SUMMARY OF RESULTS

A. NATURAL FREQUENCIES OF THE X-E TURBINE INLET LINE, SYMMETRICAL MODE

<u>Mode</u>	<u>Frequency (cps)</u>
1st	10.1
2nd	29.9
3rd	38.4
4th	49.0
5th	61.0

B. NATURAL FREQUENCIES OF THE FLAPPER ARM TPCV TORQUE MOTOR COMPONENTS

<u>Mode</u>	<u>Frequency (cps)</u>
1	6,700
2	40,190
3	81,393
4	132,440
5	253,000

C. NATURAL FREQUENCIES OF THE ARMATURE CYLINDER, TPCV FLAPPER ARM

<u>Mode</u>	<u>Frequency (cps)</u>
1st	7
2nd	10
3rd	13
4th	24
5th	36

D. NATURAL FREQUENCIES OF THE X-E NOZZLE, BELL-MODE TYPE

<u>Mode</u>	<u>Anal Frequency (cps)</u>
1st	800
2nd	650
3rd	300-240 Test
4th	570
5th	910

E. UNCOUPLED CRITICAL SPEEDS, X-E TURBOPUMP

<u>Mode</u>	<u>Critical Speed (RPM)</u>
1st	38,000
2nd	48,000
3rd	146,000

F. NATURAL FREQUENCIES OF THE X-E TURBOPUMP
SUPPORTING STRUCTURE

<u>Mode</u>	<u>Natural Frequencies (cps)</u>
1st	111
2nd	180
3rd	315

G. NATURAL FREQUENCIES OF THE X-E TURBOPUMP TURBINE DISK AT
22,000 RPM AND NORMAL TEMPERATURE GRADIENT - 1ST STAGE ROTOR

<u>Mode**</u>	<u>Natural Disk Frequencies (cps)</u>	<u>Critical Shaft Speed RPM</u>
N=0, S=0	911	54,660
N=1, S=0	624	37,440
N=2, S=0	936	28,080
N=3, S=0	1,328	26,520
N=4, S=0	1,828	27,420

H. COUPLED CRITICAL SPEEDS, X-E TURBOPUMP

<u>Mode</u>	<u>Coupled Critical Speeds</u>
1st	6,000
2nd	9,500
3rd	16,500

I. NATURAL FREQUENCIES OF THE ENTIRE X-E ENGINE

<u>Mode</u>	<u>Natural Frequencies (cps)</u>
1st	6
2nd	34
3rd	115
4th	246
5th	450

IV. METHOD OF STRUCTURAL, ENVIRONMENTAL DYNAMIC ANALYSIS

A. CRITICAL SPEED OF THE X-E TURBOPUMP

The turbopump, like all rotational machinery, will vibrate violently at speeds known as the critical speeds. This phenomenon occurs when the pump angular speed coincides with one of the lateral natural frequencies of the rotating shaft together with its rotating elements. Attempt has been made to classify the critical speed analysis into two categories: (1) uncoupled critical speed of the turbopump, and (2) coupled critical speed of the turbopump.

The uncoupled critical speeds refer to those not associated with any pump supporting structure, whereas the coupled critical speeds refer to those associated with pump supporting structure.

The uncoupled critical speed analysis was based on the partial differential equations of motion of a laterally vibrated shaft. This equation includes the internal shear, rotary inertia, and gyroscopic effects. The general solutions of this equation for deflection, slope, moment, and shear at one end of a typical beam segment can be written in terms of those at the other end in matrix form. The static and dynamic properties of the beam can be completely represented by a number of these transfer matrices, which when fitted together provide the static and dynamic properties of the entire system. Setting the final matrix equation to zero yields the natural frequencies of the system.

The coupled critical speed analysis for the NERVA turbopump was based on the equations of motion for the structural interaction of the pump and its supporting structure. In the case of the X-E pump, the structural rigidity of the six rib-panels was determined and the coupling critical speeds were executed by computer program 14071.

B. TURBINE INLET LINE RESONANT FREQUENCIES

The turbine inlet line of the X-E engine is a three dimensional space frame. As a result the frequency analysis for this system is relatively complicated compared with a continuous beam of multi-elastic supports.

The initial step for analyzing the X-E turbine inlet line is to reduce this system from three dimensional space structure into two dimensional plane structure. Notice that there is a lower elbow near the nozzle section and an upper elbow is located near the turbopump section. For symmetrical modes this plane structure is equivalent to a one dimensional continuous beam with additional elastic supports near the elbow.

C. TURBINE DISK VIBRATION ANALYSIS

In addition to the lateral vibration of the shaft of the turbopump, turbine disk vibration is another problem for the NERVA turbopump. When one of the natural frequencies of the turbine disk coincides with the angular speed of its shaft, resonant condition occurs. This resonant phenomenon of a disk has been studied for some time, and a generalized analytical model for computing turbine disk frequencies has been written in a digital computer program 10062. Raleigh-Ritz method was utilized for the analysis.

D. NOZZLE VIBRATION

Since the lower end of the turbine inlet line is attached to the conical nozzle of the X-E engine, some forcing vibrational input to the TIL is expected and it is desirable to study the resonant frequencies of the conical nozzle.

A considerable amount of time has been devoted to investigating the resonant frequencies of the nozzle. Method of nozzle vibration analysis is given in Paragraph VI, E.

V. DISCUSSION

Two types of vibration have been considered for the Turbine Power Control Valve (TPCV). The first is due to the resonance of the valve itself, and the second is due to its structural environment, i.e., vibration arising from external sources other than the valve itself. As an example of environmental vibration, if the turbopump were operated near or at one of its critical speeds, the turbine inlet line could then be expected to vibrate which could induce vibration into the TPCV, since it is mounted in the line. Also, vibration at the nozzle end of the turbine inlet line would be transmitted to the valve.

In either case, the natural frequencies of a subsystem are closely related to the external forcing function. As a result, an attempt has been made to look into the natural frequencies of the nozzle, the inlet line and the critical speeds of the turbopump, as well as the resonant frequencies of the various structural components within the TPCV.

The preliminary investigation shows it is unlikely that the turbine inlet line will encounter a resonant condition, because its first natural frequencies are under 65 Hz, whereas the operational speed of the turbopump is above 20,000 rpm or 330 Hz (the uncoupled critical speed of the turbopump is 32,000 rpm or 630 Hz). The first coupled critical speed of the X-E turbopump with its supporting structure has also been studied. In this case, the first critical coupled speed is expected to be near 6,000 rpm or 100 Hz, which is still far above the first five turbine-inlet-line resonant frequencies. Therefore no danger of resonant vibration is expected from the turbopump. The natural frequencies of the X-E nozzle are also high (varies from the 240 cps to 910 cps for the first five bell modes), comparing with 3 g at 240 cps as the nozzle forcing function. Therefore, no extremely severe vibration is expected from the nozzle which would transmit to the TPCV. Furthermore, there

are flexible bellows on the turbine inlet which will all absorb a relatively large amount of vibration during operation. As a result, the TPCV is somewhat protected to a certain extent from environmental vibration standpoint.

The natural frequencies of the TPCV armature cylinder is extremely low (under 40 Hz for the first five bending modes). The flapper arm is very rigid (first bending mode frequency is above 6500 cps). These resonant frequencies of the flapper are all remote from the forcing functions of the TPA or the nozzle.

Vibration shake tests on the TPCV have been performed in the Aerojet Vibration Test Lab. Test results indicate that the TPCV has a relatively large dynamic response at 545 Hz and 575 Hz. The TPCV transmission shaft's lateral vibration could have been responsible for the resonant condition. If the shaft is non-uniform in cross section and hence in area moment of inertia with respect to two principal mutual axes, two lateral resonant frequencies will be expected, although the possible source of vibration of the oscillating spool in the TPCV unit is not yet discarded.

VI. CALCULATIONS

A. UNCOUPLED CRITICAL SPEED AND SPACE FRAME ANALYSIS

Equation of Motion

$$EI \frac{\partial^3 Y_b}{\partial X^2} + \mu AG \frac{\partial Y_s}{\partial X} - \rho I \frac{\partial^3 Y}{\partial X \partial t^2} = 0$$

$$M \frac{\partial^2 Y_b}{\partial t^2} + M \frac{\partial^2 Y_s}{\partial t^2} - \mu AG \frac{\partial^2 Y_s}{\partial X^2} = 0$$

Transfer Matrix

$$\begin{aligned}
 W & \quad C_o - \sigma C_2 \quad \ell[C_1 - (\sigma + \tau)C_3] \quad aC_2 \quad \frac{a\ell}{\beta^4} \quad [\beta_{14}] \\
 O & \quad C_3\beta^4/\ell \quad C_o - \tau C_2 \quad \frac{a}{\ell}(C_1 - \tau C_3) \quad aC_2 \\
 = & \\
 M & \quad C_2\beta^4/a \quad \frac{\ell}{a}[-\tau C_1 + (\beta^4 + \tau^2)C_3] \quad C_o - \tau C_2 \quad \ell[\beta_{34}] \\
 V & \quad \beta^4(C_\ell - \sigma C_3)/a\ell \quad \beta^4 C_2/a \quad \beta^4 C_3/\ell \quad C_o - \sigma C_2
 \end{aligned}$$

B. BASIC EQUATION FOR ANALYZING FORCED VIBRATION OF CONTINUOUS BEAM

Equation of Motion

$$\frac{\partial^2}{\partial X^2} \left(EI \frac{\partial^2 Y}{\partial X^2} \right) + M \frac{\partial^2 Y}{\partial t^2} = \sum_j \int F_j m \bar{X}_n(\chi) \bar{X}_n(\chi_j)$$

LaGrange Equation

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i$$

C. BASIC EQUATION FOR ANALYZING COUPLED CRITICAL SPEEDS OF THE TURBOPUMP

$$m_1 x_1 = -k_1 (x - \xi - e \cos wt)$$

$$m_1 y_1 = -k_1 (y - \zeta - e \cos wt)$$

$$m_2 \xi = -k_2 \xi + k_1 x = -ek \cos wt$$

$$m_2 \ddot{\zeta} = -k_2 \zeta + k_1 y = -ek \cos \omega t$$

$$[(\omega_{CR}^2 - \omega^2)(\omega_n^2 - \omega^2) \frac{m_2}{m_1} - \omega^2 \omega_{CR}^2] = 0$$

D. BASIC EQUATIONS FOR ANALYZING NON-UNIFORM TURBINE DISK

$$V = \int_0^{2\pi} \int_a^b \frac{D(r)}{2} \nabla^4 w - 2(1-\mu) \frac{\partial^2 w}{\partial r^2} \left(\frac{1}{r} \frac{\partial w}{\partial r} + \frac{1}{r^2} \frac{\partial^2 w}{\partial \theta^2} \right) + \\ + 2(1-\mu) \left[\frac{\partial}{\partial r} \left(\frac{1}{r} \frac{\partial w}{\partial \theta} \right) \right]^2 \} r dr d\theta$$

$$T = \int_0^{2\pi} \int_a^b \frac{\pi \gamma \Omega}{2} \rho(r) h(r) \left(\frac{\partial w}{\partial t} \right)^2 r dr d\theta$$

Displacement

$$w = \sum_{s=1}^k A_s (r-r_o)^{s+1} \sin n\theta \cos \omega t$$

Rotation Stresses

$$\sigma_n = \frac{\phi}{h(r)r}, \quad \sigma_\theta = \frac{d\phi}{h(r)dr} + \rho \omega^2 r^2$$

$$\phi = m r^{n+3} + C_1 r^\alpha + C_2 r^\beta$$

$$m = (3+\mu) \rho \omega^2 c / (\mu n + 3n + 3)$$

$$X^2 = n x + \mu n - 1 = 0 \quad \text{for } \alpha, \beta$$

Thermal Stress

$$\frac{\partial^2 w}{\partial r^2} + (1+n) \frac{1}{r} \frac{\partial u}{\partial r} - (1-n\mu) \frac{u}{r^2} = (1+\mu) \alpha \cdot$$

$$\cdot \left[\frac{nT(r)}{r} + \frac{\partial T(r)}{\partial r} \right]$$

E. BASIC EQUATION FOR ANALYZING FREE VIBRATION OF CONICAL SHELL OF REVOLUTION - NOZZLE.

Strain-displacement Equations

$$\epsilon_1 = \frac{1}{A_1} \frac{\partial u}{\partial \alpha_1} + \frac{1}{A_1 A_2} \frac{\partial A_1}{\partial \alpha_2} v + \frac{w}{R_1}$$

$$\epsilon_2 = \frac{1}{A_2} \frac{\partial v}{\partial \alpha_2} + \frac{1}{A_1 A_2} \frac{\partial A_2}{\partial \alpha_1} u + \frac{w}{R_2}$$

$$\omega = \frac{A_2}{A_1} \frac{\partial}{\partial \alpha_1} \left(\frac{v}{A_2} \right) + \frac{A_1}{A_2} \frac{\partial}{\partial \alpha_2} \left(\frac{u}{A_1} \right)$$

Curvature Equation

$$K_1 = -\frac{1}{A_1} \frac{\partial}{\partial \alpha_1} \left(\frac{1}{A_1} \frac{\partial w}{\partial \alpha_1} + \frac{u}{R_1} \right) - \frac{1}{A_1 A_2} \frac{\partial A_1}{\partial \alpha_2} \left(\frac{1}{A_2} \frac{\partial w}{\partial \alpha_2} - \frac{v}{R_2} \right)$$

$$K_2 = -\frac{1}{A_2} \frac{\partial}{\partial \alpha_2} \left(\frac{1}{A_2} \frac{\partial w}{\partial \alpha_2} + \frac{v}{R_2} \right) - \frac{1}{A_1 A_2} \frac{\partial A_2}{\partial \alpha_1} \left(\frac{1}{A_1} \frac{\partial w}{\partial \alpha_1} - \frac{u}{R_1} \right)$$

$$\tau + - \frac{1}{A_1 A_2} \left(\frac{\partial^2 w}{\partial \alpha_1 \partial \alpha_2} - \frac{1}{A_1} \frac{\partial A_1}{\partial \alpha_2} \frac{\partial w}{\partial \alpha_1} - \frac{1}{A_2} \frac{\partial A_2}{\partial \alpha_1} \frac{\partial w}{\partial \alpha_2} \right) +$$

$$+ \frac{1}{R_1} \left(\frac{1}{A_2} \frac{\partial u}{\partial \alpha_2} - \frac{1}{A_1 A_2} \frac{\partial A_1}{\partial \alpha_2} u \right) + \frac{1}{R_2} \left(\frac{1}{A_1} \frac{\partial v}{\partial \alpha_1} - \frac{1}{A_1 A_2} \frac{\partial A_2}{\partial \alpha_1} v \right)$$

Potential Energy

$$V = \frac{Eh}{\alpha(1-\mu^2)} \int \int [(\epsilon_1 + \epsilon_2)^2 - 2(1-\mu)(\epsilon_1 \epsilon_2 - \frac{\omega^2}{4})]$$

$$A_1 A_2 d\alpha_1 d\alpha_2 + \frac{Eh^3}{\alpha^4(1-\mu^2)} \int \int [(k_1 + k_2)^2 - 2$$

$$\cdot (1-\mu)(k_1 k_2 - \tau^2)] A_1 A_2 d\alpha_1 d\alpha_2$$

Kinetic Energy

$$T = \frac{h}{\alpha} \int \int (\dot{u}^2 + \dot{v}^2 + \dot{w}^2) A_1 A_2 d\alpha_1 d\alpha_2$$

APPENDIX F

RN-DR-0129, MECHANICAL SHOCK TEST-TURBINE POWER CONTROL VALVE ACTUATOR

REPORT NO. RN-DR-0129

MECHANICAL SHOCK TEST

TURBINE POWER CONTROL VALVE ACTUATOR

H. O. Suttkus

C. M. Rice
Program Manager
Nuclear Rocket Operations

BLANK

ABSTRACT

A Turbine Power Control Valve Actuator, Bendix Model NT-D1, was subjected to a mechanical shock test to determine the effect of shock accelerations on the performance of the actuator. Comparison of pretest and posttest performance data indicated that the shock test had no detectable effect on actuator performance.

BLANK

CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	1
III. Technical Discussion	1
IV. Conclusion	2
Appendix	

FIGURE LIST

	<u>Figure</u>
Actuator Mounted on Test Fixture	1
Actuator and Test Fixture Mounted on Specimen Table	2
Actuator on Specimen Table with Electrical Pneumatic Connections	3
Diagram Showing Accelerometer Locations	4
Data Traces of Shock Impulses	5
Data Traces of Output Shaft Rotation	6
Performance Reference Test Prior to Mechanical Shock Test	7
Performance Test After Mechanical Shock Test	8

I. INTRODUCTION

This report describes the shock tests performed on the Bendix Part Number 2775030 Model NT-D1 Turbine Power Control Valve Actuator (TPCVA) that will be used on the XE-1 and XECF nuclear rocket engine tests.

II. SUMMARY

The shock test was conducted using the Serial Number 17 actuator. Performance reference tests made before and after the shock test did not indicate any change in the performance of the component. Data traces of the position signal showed no perturbation at or following the instant of impact.

III. TECHNICAL DISCUSSION

A. OBJECTIVE

The purpose of the shock test was to determine the effect of shock acceleration on the performance and structure of the actuator.

B. PROCEDURE

The Bendix TPCV Actuator, P/N 2775030, S/N 17, was mounted on the test fixture, Figure 1, and the assembly was attached to the specimen table shown in Figure 2. The appendix shows the electrical and pneumatic connections between the actuator, test console, and helium supply presented in Figure 3. A performance reference test was run before and after the shock testing to determine if actuator performance was adversely affected. The accelerometers were attached as shown in Figure 4.

The actuator was then subjected to one triangular shock pulse in each direction on each of the three axes for a total of six applied shocks. During the shock testing, the actuator was being driven at 0.1 cps 90 degree peak-to-peak triangular wave command signal.

C. RESULTS

The magnitudes, durations, and related directions of application are shown in the oscillograph reproductions of the accelerometer outputs, Figure 5. Typical traces of the actuator output shaft position data are presented in Figure 6. As a comparison of the performance reference data in Figures 7 and 8 indicates, actuator performance was not significantly affected by the application of mechanical shocks below 25 g.

IV. CONCLUSION

Actuator performance is not adversely affected by shock acceleration with amplitude and duration equal to or less than those used in this test. The mechanical shock environment as defined in NDC-123 for the XE-1 will not adversely affect the performance of the TPCV actuator.

Figure 2 - Actuator and Test Fixture Mounted on Specimen Table

Figure 1 - Actuator Mounted on Test Fixture

Figure 3 - Actuator on Specimen Table with Electrical Pneumatic Connections

Figure 4 - Diagram Showing Accelerometer Locations

FRAME NO. 66

DROP NO. 1099

Z AXIS SHOCK, BASE DOWN

33.5g/IN. CALIBRATION FACTOR
 ACTUATOR ACCELERATION = $.66 \times 33.5 = 22.1g$

63 IN/SEC (PAPER SPEED)

Figure 5 - Data Traces of Shock Impulses

FRAME NO. 67

DROP NO. 1100
Z AXIS SHOCK, BASE UP

33.5 g/in. CALIBRATION FACTOR
ACTUATOR ACCELERATION = $(.7)(33.5) = 23.5 \text{ g}$

Figure 5 - Data Traces of Shock Impulses

FRAME NO. 74

DROP NO. 1104

X AXIS HELIUM, CONNECTOR UP

18.4 g/IN CALIBRATION FACTOR
 ACTUATOR ACCELERATION = $.70 \times 18.4 = 12.9g$

Figure 5 - Data Traces of Shock Impulses

FRAME NO. 73

DROP NO. 1103

Y AXIS SHOCK, ELECTRICAL CONNECTOR UP

18.4 g/IN. CALIBRATION FACTOR
 ACTUATOR ACCELERATION = $.7 \times 18.4 = 13g$

63 IN/SEC (PAPER SPEED)

Figure 5 - Data Traces of Shock Impulses

FRAME NO. 72

DROP NO. 1102

Y AXIS SHOCK, ELECTRICAL CONNECTOR DOWN

18.4 g/IN. CALIBRATION FACTOR
 ACTUATOR ACCELERATION = $.66 \times 18.4 = 12.2g$

63 IN/SEC (PAPER SPEED)

Figure 5 - Data Traces of Shock Impulses

FRAME NO. 67

DROP NO. 1105

X AXIS HELIUM, CONNECTOR DOWN

18.4 g/IN. CALIBRATION FACTOR
 ACTUATOR ACCELERATION = $.70 \times 18.4 = 12.9 \text{ g}$

Figure 5 - Data Traces of Shock Impulses

Figure 6 - Data Traces of Output Shaft Rotation

Figure 6 - Data Traces of Output Shaft Rotation
Sheet 2 of 3

Figure 6 - Data Traces of Output Shaft Rotation
Sheet 3 of 3

12-2-66 TPCV ACTUATOR S/N 17 SHOCK TEST NO LOAD

GASEOUS He AMB. TEMP.

PRETEST REFERENCE

THRESHOLD $.17^\circ$ P-P

TRANSIENT RESPONSE DATA $\pm 41^\circ$ STEP INPUT

MAX. VEL. IN $470^\circ/\text{SEC}$

OUT $470^\circ/\text{SEC}$ OVERSHOOT 21% SETTLE .375 SEC

Figure 7 - Performance Reference Test Prior to Mechanical Shock Test

1-19-67

TPCV ACTUATOR S/N 17

SHOCK TEST
POST TEST REF.

NO LOAD

GASEOUS He AMB. TEMP.

THRESHOLD 0.17 P-P

TRANSIENT RESPONSE DATA $\pm 35^\circ$ STEP INPUT

MAX. VEL. IN $517^\circ/\text{SEC}$

OVERSHOOT 20%

SETTLE .35 SEC

OUT $488^\circ/\text{SEC}$

Figure 8 - Performance Test After Mechanical Shock Test

APPENDIX

Drawing 1116842, (Figure 1) an electrical schematic diagram of the TPCV-actuator test console, shows the electrical connections necessary to operate and control the TPCV actuator. The components shown schematically in Figure 1 are shown installed in the test console in Figure 2. The actuator is powered by a pneumatic supply that is connected to the actuator, shown in Figure 3. The TPCV-actuator electrical schematic is shown in Figure 4.

The electrical supplies and signal sources shown in Figure 1 are connected to the actuator through harnesses and connectors. The electrical signals are applied prior to application of the pneumatic supply pressures. Detailed operating procedures are described in Aerojet Report RN-S-0348, dated February 1967.

Figure 1 - Electrical Schematic Diagram of TPCV-Actuator Test Console

Appendix

Figure 2 - Test Console and Recorder Equipment

Appendix

Figure 3 - TPCV Actuator Pneumatic Supply Diagram

Figure 4 - Schematic Wiring Turbine Power Control Actuator

APPENDIX G

RN-DR-0130, HUMIDITY QUALIFICATION TEST
MODEL NT-D1 TURBINE POWER-CONTROL VALVE ACTUATOR

BLANK

REPORT NO. RN-DR-0130

HUMIDITY TEST
MODEL NT-D1 TURBINE-POWER-CONTROL-VALVE ACTUATOR
QUALIFICATION

H. O. Suttkus

C. M. Rice
Program Manager
Nuclear Rocket Operations

BLANK

ABSTRACT

A Bendix Model NT-D1 turbine-power-control-valve actuator was subjected to a humidity test to determine if elevated temperature and moisture would adversely affect the performance of the unit. Test data indicated that actuator performance was not significantly affected by the humidity test.

BLANK

CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	1
III. Technical Discussion	1
IV. Conclusions	4

TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Electrical-Resistance Measurements	3
2	Humidity-Test Equipment List	3
3	Humidity Cycle No. 1	4
4	Humidity Cycle No. 2	5
5	Humidity Cycle No. 3	6
6	Humidity Cycle No. 4	7

FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Actuator Mounted on the Test Fixture	8
2	Actuator and Test Fixture Installed in Humidity Chamber	9
3	Temperature and Humidity Profile Relative to Time	10
4	Data Trace, Dry-Bulb and Wet-Bulb Temperatures During Test Cycle	11
5	Humidity Test Cycles; TPCV Actuator	12
6	Bode Plot; Performance Reference Test Before Humidity-Test	13
7	Bode Plot; Performance Reference Test During Humidity-Test	14
8	Bode Plot; Performance Reference Test After Humidity-Test	15

APPENDIX

I. INTRODUCTION

This report describes the humidity test performed on the turbine-power-control-valve actuator (Bendix Part Number 2775030, Model NT-D1) that will be used in the XE-1 and XECF nuclear-rocket-engine tests.

II. SUMMARY

The humidity test was conducted with Serial Number 17 actuator. A performance reference test was conducted before, during, and after the humidity test to indicate any change in performance. The data show that performance of the actuator was not affected by the high humidity, even though the pin-to-pin resistances decreased during the high-humidity period.

III. TECHNICAL DISCUSSION

A. OBJECTIVE

The objective of the humidity test was to determine if high humidity would adversely affect the performance of the actuator.

B. PROCEDURE

The turbine-power-control-valve actuator was assembled to the test fixture as shown in Figure 1. Torque values as specified in Report RN-DR-0084 were used to tighten the clamps and seals. The actuator and test fixture were then installed in the humidity chamber as shown in Figure 2. The installation was arranged so the actuator could be operated and the output-shaft seal could be pressurized at any time during the test. The resistances between pins on the electrical connector were measured, and a performance reference test was conducted.

The temperature and humidity controls to the chamber were turned on and were set to control temperature and humidity as indicated in Figure 3. The chamber temperature and humidity were raised as shown, maintained for approximately 6 hr, and then allowed to cool without controlling the humidity. The above cycle was completed four times. Figure 4 is a typical recording of the wet- and dry-bulb temperatures inside the chamber during one cycle.

While the temperature and humidity were at high values, the resistances between the pins of the electrical connector were measured and performance reference tests were run. At the end of the test, the resistance measurements were repeated and a performance reference test was again conducted.

C. RESULTS

The pins used in making the electrical measurements were selected so that the measurements would not cause damage to internal electrical components of the actuator. The resistance measurements between pins of the electrical connector were taken as shown in Table 1. Although the pin-to-pin resistances decreased to about 2% of their original values, the actuator continued to function satisfactorily. Furthermore, the resistances later returned to approximately the same values as were measured before the start of the humidity cycling.

Tabulations of wet-bulb temperatures, relative humidity, and time for each of the humidity cycles are given in Tables 2, 3, 4, 5, and 6. Relative humidity vs time is shown for each of the cycles in Figure 5.

The results of the performance reference tests conducted before, during, and after the humidity test are shown in Figures 6, 7, and 8 respectively.

IV. CONCLUSIONS

The data show that the performance of the actuator was not significantly affected by the humidity test.

TABLE 1

ELECTRICAL-RESISTANCE MEASUREMENTS

<u>Between Pins</u>	<u>Resistance Megohms</u>			
	<u>Before Test</u>	<u>During Test</u>		<u>After Test</u>
		<u>First Reading</u>	<u>Second Reading</u>	
1 and 16	7500	100	200	8000
5 and 17	6500	200	200	5000
4 and 18	6500	200	200	5000

TABLE 2

HUMIDITY-TEST EQUIPMENT LIST

<u>Nomenclature</u>	<u>Manufacturer</u>	<u>Part No./Model No.</u>	<u>Serial Number</u>	<u>Calibration Expiration Date</u>
Insulation tester	Weston	Mod. 799		10 April 1967
Humidity chamber	Blue M & Co.	Mod. CF-7502HA	A-2291	
Portable console	AGC	N/A	N/A	

TABLE 3

HUMIDITY CYCLE NO. 1

<u>Time, hr</u>	<u>Dry-Bulb Temperature, °F</u>	<u>Wet-Bulb Temperature, °F</u>	<u>Relative Humidity, %</u>
0.0	66.2	59.0	67
0.25	86.0	77.0	67
0.50	149.0	140.0	78
0.75	158.0	158.0	100
1.0	158.0	158.0	100
2.0	158.0	158.0	100
3.0	149.0	149.0	100
4.0	136.4	136.4	100
5.0	128.3	128.3	100
6.0	123.8	122.0	100
7.0	120.2	113.0	78
8.0	117.5	109.4	75
9.0	115.7	107.0	72
10.0	113.9	104.9	71
11.0	113.0	102.2	65
12.0	113.0	101.7	66
13.0	112.1	100.8	66
14.0	112.1	100.6	66
15.0	111.6	100.4	66
16.0	111.4	100.4	66
17.0	111.2	100.0	66
18.0	111.0	99.6	66

TABLE 4

HUMIDITY CYCLE NO. 2

<u>Time, hr</u>	<u>Dry-Bulb Temperature, °F</u>	<u>Wet-Bulb Temperature, °F</u>	<u>Relative Humidity, %</u>
0.0	109.4	99.5	72
0.25	151.7	146.3	86
0.50	154.0	149.9	90
0.75	155.3	151.7	92
1.0	156.2	151.7	89
2.0	157.0	154.4	94
3.0	161.6	156.2	85
4.0	163.4	156.2	85
5.0	163.4	156.2	85
6.0	163.4	154.4	79
6.5	158.0	156.2	96
7.0	149.0	147.2	97
8.0	138.2	136.4	95
9.0	131.0	127.4	90
10.0	127.4	116.6	75
11.0	127.0	113.0	72
12.0	119.0	110.0	75
13.0	116.0	107.6	71
14.0	114.8	104.9	67
15.0	113.9	104.0	71
16.0	113.0	102.2	71
17.0	113.0	102.2	71
18.0	111.2	101.3	73
19.0	111.2	100.4	69
20.0	111.2	100.4	69
21.0	111.2	100.4	69
22.0	110.3	99.5	70
23.0	109.4	99.5	71
24.0	109.4	99.5	72

TABLE 5HUMIDITY CYCLE NO. 3

<u>Time, hr</u>	<u>Dry-Bulb Temperature, °F</u>	<u>Dry-Bulb Temperature, °F</u>	<u>Relative Humidity, %</u>
0.0	109.4	98.6	67
0.25	136.4	136.4	100
0.50	158.0	158.0	100
0.75	162.5	162.5	100
1.0	164.3	164.3	100
2.0	162.5	162.5	100
3.0	161.6	161.6	100
4.0	161.6	161.6	100
5.0	161.6	158.9	100
6.0	161.6	158.0	100
6.5	156.2	156.2	100
7.0	149.0	148.1	95
8.0	127.4	125.6	95
9.0	123.8	120.2	88
10.0	122.0	109.4	65
11.0	118.4	106.7	66
12.0	116.6	104.0	65
13.0	114.8	103.1	65
14.0	113.0	102.2	72
15.0	112.1	101.3	67
16.0	111.2	100.4	67
17.0	110.3	99.5	67
18.0	110.3	99.5	67
19.0	110.3	99.5	67
20.0	110.3	99.5	67
21.0	109.4	98.6	66
22.0	109.4	98.6	66
23.0	109.4	98.6	66
24.0	109.4	98.6	66

TABLE 6

HUMIDITY CYCLE NO. 4

<u>Time, hr</u>	<u>Wet-Bulb Temperature, °F</u>	<u>Wet-Bulb Temperature, °F</u>	<u>Relative Humidity, %</u>
0.0	108.5	98.6	70
0.25	149.0	149.0	100
0.50	162.6	162.6	100
0.75	163.4	163.4	100
1.0	164.3	164.3	100
2.0	163.4	163.4	100
3.0	163.4	163.4	100
4.0	163.4	163.4	100
5.0	162.5	162.5	100
6.0	162.5	162.5	100
7.0	158.9	158.9	100
8.0	142.7	142.7	100
9.0	130.1	130.1	100
10.0	124.7	124.7	100
11.0	119.3	119.3	100
12.0	116.6	108.5	75
13.0	114.8	104.9	71
14.0	113.0	102.0	68
15.0	111.2	101.3	71
16.0	110.3	100.4	71
17.0	110.3	99.5	70
18.0	109.4	98.6	68
19.0	108.5	98.6	70
20.0	108.5	98.6	70
21.0	108.5	97.7	69
22.0	108.5	97.7	69
23.0	108.5	97.7	69
24.0	108.5	97.7	69

Figure 1 - Actuator Mounted on the Test Fixture

Figure 2 - Actuator and Test Fixture Installed in Humidity Chamber

Figure 3 - Temperature and Humidity Profile Relative to Time

Figure 5 - Humidity Test Cycles; TPCV Actuator

Figure 6 - Bode Plot; Performance Reference Test Before Humidity-Test

Figure 7 - Bode Plot; Performance Reference Test During Humidity-Test

Figure 8 - Bode Plot; Performance Reference Test After Humidity-Test

APPENDIX

Drawing 1116842, (Figure 1) an electrical schematic diagram of the TPCV-actuator test console, shows the electrical connections necessary to operate and control the TPCV actuator. The components shown schematically in Figure 1 are shown installed in the test console in Figure 2. The actuator is powered by a pneumatic supply that is connected to the actuator, shown in Figure 3. The TPCV-actuator electrical schematic is shown in Figure 4.

The electrical supplies and signal sources shown in Figure 1 are connected to the actuator through harnesses and connectors. The electrical signals are applied prior to application of the pneumatic supply pressures. Detailed operating procedures are described in Aerojet Report RN-S-0348, dated February 1967.

Figure 1 - Electrical Schematic Diagram of TPCV-Actuator Test Console

Appendix

Figure 2 - Test Console and Recorder Equipment

Appendix

Figure 3 - TPCV Actuator Pneumatic Supply Diagram

Figure 4 - Schematic Wiring Turbine Power Control Actuator

APPENDIX H

RN-DR-0131, REPORT OF ENDURANCE TESTING OF
TURBINE POWER CONTROL VALVE ACTUATOR, MODEL NT-D1

BLANK

REPORT NO. RN-DR-0131
ENDURANCE TESTING OF TURBINE POWER CONTROL
VALVE ACTUATOR BENDIX MODEL
NO. NT-D1, SN 17

W. P. Harris

C. M. Rice
Program Manager
Nuclear Rocket Operations

CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	1
III. Technical Discussion	3
A. Test Conditions	3
B. Endurance Test Setup	3
C. Sequence of Operations	12
D. Procedures and Results	13

APPENDIX

Bendix Failure Analysis of the Nutator Transmission of Turbine
Power Control Valve Actuator Model NT-D1, Serial No. 17

TABLES

Table

1	Summary of Operational Time on Actuator No. 17 Prior to the Endurance Tests	4
---	--	---

FIGURES

<u>Figure</u>		<u>Page</u>
1	Actuator Test Fixture Drawing and Photos	5-7
2	Schematic of Test Console	8
3	Schematic of Actuator Servoamplifier	9
4	Block Diagram of Endurance Test Setup	10
5	Inland Torque Motor Command Signal Input	11
6	Amplifier Gain Tests Before and After Temperature- Torque Cycling	14
7	Gain and Phase Lag vs Frequency Before TPCV Temperature-Torque Cycling Test	16
8	Gain and Phase Lag vs Frequency After TPCV Temperature-Torque Cycling Test	17
9	Amplitude Ratios Before and After Temperature- Torque Cycling Test	18

FIGURES (CONT.)

<u>Figure</u>		<u>Page</u>
10	Phase Angle Before and After Temperature-Torque Cycling Test	19
11	Time-Temperature Profile, TPCV Actuator Temperature-Torque Cycling Test, 14 June 1967	22
12	Beginning of Temperature-Torque Cycling Test	23
13	Low-Temperature Portion of Temperature-Torque Cycling Test	24
14	High-Temperature Portion of Temperature-Torque Cycling Test	25
15	End of Temperature-Torque Cycling Test	26
16	Actuator Output Shaft After Temperature-Torque Cycling Test	28
17	Transmission Gear Teeth After Temperature-Torque Test, High Torque (400-in.-lb) Side	30
18	Transmission Gear Teeth After Temperature-Torque Test, Low Torque (80-in.-lb) Side	31
19	Closeup of Gear Teeth After Temperature-Torque Test	32
20	Gear Motor Body Showing Posttest Scratch	33
21	Potentiometer Posttest Schematic and Results (Terminals 1, 2, and 3)	35
22	Potentiometer Posttest Schematic and Results (Terminals 16, 17, and 18)	36
23	Posttest Views of Input Shaft Flange and Corresponding Temperature Samples	37

I. INTRODUCTION

The data in this report were obtained from the Endurance Test portion of the qualification test program, which was performed on the Bendix Model NT-D1 Turbine Power Control Valve Actuator, Serial No. 17 and completed in the NRO Controls Laboratory on 15 June 1967.

The objectives of the actuator life test are to determine the service life of the actuator under functional and environmental conditions, with the exception of radiation, that simulate those expected during actual engine operating conditions and to determine the rate of deterioration of the actuator's performance in these environments (Reference RN-S-0425).

II. SUMMARY

Prior to this test, the test actuator had been subjected to 60.4 hours of usage under various conditions. The endurance test consisted of sinusoidal cycling of the actuator at 0.3 cps against a resistive torque whose peak amplitudes were 400 lb-in. in the clockwise (opening) direction, and 80 lb-in. in the counterclockwise direction (looking into the actuator output shaft end). During the torque cycling, the actuator mounting flange temperature was reduced during a 1-hr period to -230°F; increased to +600°F during a 2 to 2-1/2 hr period, then was cooled to 400°F, at which point the torque cycling was stopped. Later information revealed that the output shaft had inadvertently reached temperatures of approximately 1000°F (1460°R). Total time of endurance test cycle, including the time to return to ambient temperature and to complete the performance reference test was 8 hr. Total time of operation for this test actuator is 68.4 hr; NDC51A, the criterion to which this model TPCV actuator was procured, established the operating life at 20 hr.

Pretest and posttest data, as well as data recorded during the test, were not significantly different. In view of this fact and the extensive

prior usage, the actuator is considered to have exhibited sufficient endurance for application in the technology engine program.

Following the endurance test and during a test stand torque calibration test, it was discovered that the actuator exhibited limit cycling when stepped to a certain position. Further investigation revealed that the actuator was prone to limit cycling at intervals of 1.3° of actuator position, while operation between these positions appeared normal. The limit cycling was at a frequency of 25 cps and at a 0.3° peak-to-peak amplitude. Subsequent disassembly of the actuator revealed transmission gear wear and rough-running bearings. This bearing and gear wear may have resulted from temperatures at the input shaft that were higher than originally planned. Discoloration of the shaft and seal was evidence of the high temperature. However, inadequacies in the transmission gearing design appear to be major and possibly more significant contributing factors.

III. TECHNICAL DISCUSSION

A. TEST CONDITIONS

The test item was a Turbine Power Control Valve (TPCV) Actuator, Bendix Model No. NT-D1, Bendix Part No. 2775030, Serial No. 17, (referred to as the actuator in this report).

Prior to the endurance test described in this report, the assembly had been subjected to a total of 60.4 hr of actuation under various conditions and for various purposes. Table 1 presents a summary of the data.

Included in the preceding value of 60.4 hr is a 4-hr endurance test stand calibration period, during which the actuator was sinusoidally cycled at 0.1 cps against an opposing torque of approximately ± 80 lb-in. In addition, during the last 1-1/2 hr of cycling, the actuator temperature was reduced to -155°F before being returned to room temperature.

B. ENDURANCE TEST SETUP

Figure 1 shows the test fixture assembly. Schematics of the test console, actuator servoamplifier, and a block diagram of the test setup are shown in Figures 2, 3, and 4. The actuator output shaft is coupled to a shaft that passes through a dummy valve body to an Inland torque motor. The Inland torque motor is capable of providing a resistive torque that can be modified to simulate actual TPCV resistive torque while the actuator is being subjected to the simulated environments of temperature, pressure, and flow. Figure 5 shows a schematic of the Inland torque motor electrical system

The whole Inland torque motor is enclosed in a pressure vessel and is sealed to the dummy TPCV body on the side opposite from the actuator mounting flange to preclude the need for a high-pressure rotating seal interface between the two.

TABLE 1

SUMMARY OF OPERATIONAL TIME ON ACTUATOR NO. 17
PRIOR TO THE ENDURANCE TESTS

<u>Activity</u>	<u>Hours</u>	<u>Comments</u>
Assembly, Run-In, and Performance Tests	1.5	Performed at Bendix
Acceptance Tests	2.5	*
Vibration Tests	13.3	
Hot TPCV Valve Testing	20.7	Performed in "H" area
Humidity Test	1.5	
Drop Test	0.3	
Computer Work (Analog Engine Simulation)	7.5	
Miscellaneous Pressure, Torque Tests	9.1	
Endurance Test Stand Calibration	<u>4.0</u>	
Total Testing Prior to Endurance Test	60.4	

*Unless otherwise noted all tests were performed in the
NRO Controls Laboratory at the Aerojet Nimbus facility

Figure 1 - Actuator Test Fixture Drawing and Photos
Sheet 1 of 3

Figure 1 - Actuator Test Fixture Drawing and Photos

Sheet 2 of 3

Figure 1 - Actuator Test Fixture Drawing and Photos
Sheet 3 of 3

AMPL	SIN		
ACT	SIN		
15	16	17	18
R1	20K	18K	20K 13.3K
R2	11K	11K	11K 11K
R3	10.5	2.3	1.5 15K
R4	500Ω	210Ω	20Ω 510Ω
C1	8.7	15	10
C2	3.9	4.0	3.9 3.9
C3	8.7	15	10 10
C4	3.9	4.0	3.9 3.9
C5	1	1	1 1
C7			1 1
T1	233	278	36 286
T2	156	143	158 15
T3	0451	046	0453 045
T4	0082	00204	00242 002
T5	004343	0000	0000 0000
F1	5.9	5.01	442 556
F2	1.02	1.1	1.01 1.06
F3	9.50	5.46	5.32 3.84
F4	32.5	78.0	62.8 78.6
F5	16.9	16.9	181 116
K	182	169	182 171

$$\text{COMPENSATION GAIN} = \frac{K(T_{2P}+1)(T_{3P}+1)}{(T_{1P}+1)(T_{2P}+1)(T_{3P}+1)}$$

$$F_n = \frac{1}{2RT_0}$$

$$\begin{aligned} T_1 &= C_1(R_1 + R_2) + R_1 C_2 \\ T_2 &= C_1 R_3 \\ T_3 &= C_2(R_2 + R_3) \\ T_4 &= C_2 R_1 \\ T_5 &= \frac{2C_2 R_2}{1 + \frac{R_2}{R_1} + \frac{C_2}{C_1}} \end{aligned}$$

Figure 3 - Schematic of Actuator Servoamplifier

Figure 4 - Block Diagram of Endurance Test Setup

Figure 5 - Inland Torque Motor Command Signal Input

The dummy TPCV body is fitted with a collar in the vicinity of the actuator mounting flange, which is suitable for retaining liquid nitrogen for low temperature, and with a wrap-around flange heating element just below the LN₂ collar for high-temperature conditioning.

During the temperature torque cycling tests, continuous recordings were made of the actuator command signal and feedback voltages, of the Inland torque motor command signal voltage, and of the eight thermocouples that were positioned as follows: two were on the actuator base and one each was on the actuator gear motor, actuator potentiometer base, Inland torque motor base, Inland torque motor top, heat exchanger, and helium gas inlet fitting. An additional thermocouple was used as a high-temperature controller input signal. In addition, the actuator inlet pressure, the dummy TPCV body pressure, and the torque motor enclosure pressure were continuously observed.

The test system electrical setup is shown in the schematic diagram Figure 2.

C. SEQUENCE OF OPERATIONS

Following the installation of the actuator in the torque motor stand, testing was performed as follows:

1. Amplifier Gain Test
2. Performance Reference Test
 - a. Step Response Test
 - b. Frequency Response Test
 - c. Threshold Test
3. Temperature Torque Cycling Test
4. Performance Reference Test (Repeat (2) above)
5. Amplifier Gain Test

D. PROCEDURES AND RESULTS

1. Amplifier Gain Test

a. Procedure

With the actuator installed into the test stand but with the shaft spline coupling disconnected (i.e., no load), and no gaseous He supply to the gear motor, amplifier output current was measured for various known input voltages.

b. Results

A curve of amplifier gain in milliamps/millivolt before and after the temperature-torque cycling test is shown in Figure 6. The curves indicate that the gain is virtually linear in the range tested, and no change in gain occurred during the temperature torque cycling test.

2. Step Response Test

a. Procedure

With the unit installed as noted in Section III.D.1.a but with actuator helium supply pressure at 215 psia, the actuator was positioned to 45° nominal (5 volts on the recorder command trace). By means of the function generator, a 0.33 cps $\pm$ 1° square wave was superimposed on the nominal position signal.

b. Results

The following data show the response values before and after the temperature torque cycling test:

Figure 6 - Amplifier Gain Tests Before and After Temperature-Torque Cycling

	<u>Before</u>	<u>After</u>
Rise time, sec	0.025	0.015
Overshoot, %	16.0	19.0
Settling time, sec	0.088	0.19

3. Frequency Response Test

a. Procedure

With the actuator installed as indicated in Section III.D.2.a and by the use of a function generator, a $\pm 1^\circ$ sine wave was superimposed on the nominal position signal at frequencies of .01, 0.1, 0.5, 0.8, 1, 2, 4, 6, 8, 10, 12, 16, 20, 25, and 30 cps. A Weston, Boonshaft, and Fuchs Transfer Function Analyzer, Model No. DA-410A, S/N 6001, was used in the test to provide a digital readout of the phase angle and amplitude ratio, from which Bode plots were obtained.

b. Results

Figures 7 and 8 are plots of amplitude and phase angle-vs-frequency, respectively, resulting from the tests made before and after the temperature torque cycling test. Figure 9 is a plot of the amplitude ratios before and after, and Figure 10 shows both phase lags for comparative purposes.

The before and after figures show that the differences in gain and phase plots are not significant and can be attributed to normal system nonlinearities and accuracy of measurements; i.e., these data indicated no appreciable change in performance resulting from the test.

The crossover frequency (where the phase lag is 90°) is 20.5 and 21.8 cps for the before and after testing, respectively. The specification requires that the crossover frequency will be greater than 8 cps.

Figure 7 - Gain and Phase Lag vs Frequency Before TPCV
Temperature-Torque Cycling Test

Figure 8 - Gain and Phase Lag vs Frequency After TPCV
Temperature-Torque Cycling Test

Figure 9 - Amplitude Ratios Before and After Temperature-Torque Cycling Test

Figure 10 - Phase Angle Before and After Temperature-Torque Cycling Test

4. Threshold Test

a. Procedure

The initial test conditions were identical to those of Section III.D.3.a, and the sine-wave frequency was 0.1 cps. The amplitude of the sine wave was increased then decreased as required to indicate the presence of, then the lack of response to the command until the threshold of the response was determined.

b. Results

The threshold before and after the temperature torque-cycling test was $\pm 0.075^\circ$.

5. Temperature Torque Cycling Test

a. Procedure

The test unit (still mounted on the stand) was connected to the test stand torque motor by means of the splined coupling. The electrical portion of the test setup was in accordance with Figures 2, 3, 4, and 5.

With the test specimen electrically energized and the command potentiometers set at a nominal position of 45° (5 volts), a pressure of 215 psia was applied to the actuator inlet. The test stand helium pressure was then increased to 100 psi with a continuous slow bleed off through the hand vent valve (Figure 1).

The test stand Inland torque motor command potentiometer was energized and adjusted to null relative to the test stand feedback potentiometer. Then the torque motor was energized.

Again, by means of the function generator, a 0.3 cps sine wave was superimposed onto the 45° command position signal with sufficient amplitude to generate ± 240 lb-in. of torque at the peak, (by driving the test stand torque motor off its setpoint). The test specimen nominal command signal was then adjusted so that the peak torque in the TPCV opening direction was 400 lb-in. while the peak was 80 lb-in. in the closing direction. This mode of torque cycling was continued throughout the 5-hour duration of the test, while the actuator interface flange temperature was first cooled to -265°F, then heated to +600°F in accordance with the temperature-time profile shown in Figure 11. Also as shown in Figure 10 the output shaft dynamic seal pressure was set at 100 psia initially, raised to 200 psia during the warm up period, then to 300 psia during the heat soak period, and finally reduced to atmosphere, at which point heating was terminated.

c. Results

During the temperature torque cycling test, no changes in actuator performance were evident as indicated by the values of actuator current and feedback voltage, the Inland torque motor preamp voltage input, and feedback signals. Figures 12, 13, 14, and 15 show actual traces of the indicated parameters taken (1) at the beginning of the test, (2) during the low temperature phase, (3) during the high temperature phase, and (4) at the end of the test.

As already indicated, according to the results of the before and after performance reference tests, apparently no significant changes in actuator performance occurred as a result of the test. Bode plots of the frequency data for both the before and after performance reference tests are shown in Figures 7 through 10 for purposes of comparison as indicated in Section III.D.3.b. L

Figure 11 - Time-Temperature Profile, TPCV Actuator
Temperature-Torque Cycling Test, 14 June 1967

Figure 12 - Beginning of Temperature Torque Cycling Test

Figure 13 - Low-Temperature Portion of Temperature-Torque Cycling Test

Figure 14 - High-Temperature Portion of Temperature-Torque Cycling Test

Figure 15 - End of Temperature-Torque Cycling

Following the endurance test and during a subsequent torque calibration test, a limit cycling of the actuator was encountered at one specific actuator position (in the vicinity of the 45° set point used during the test). This condition prompted a search to determine if the actuator could be made to limit cycle at other positions as well. The search revealed that the actuator was prone to limit cycling at approximately 1.3° intervals of actuator position throughout its entire 90° operating range, at a frequency and amplitude of approximately 25 cps and 0.3° peak-to-peak, respectively. (Note also that from the results of the amplifier gain test, the actuator servo amplifier gain had not changed during the test).

In view of the preceding circumstances, it was concluded that some change may have occurred within the actuator during (or after) the temperature torque cycling test, and an investigation of the irregular performance was made.

Examination of the actuator when it was removed from the endurance test stand revealed that discoloration was visible on the actuator output shaft and the actuator mounting flange (Figure 16). Also the output shaft coupling appeared to have been subjected to severe heating.

Subsequent disassembly of the actuator revealed the following:

1. Discoloration of the output shaft had progressed to the inside face of the shaft, leaving that area a gold color.
2. The actuator bearings were somewhat rough running, particularly those at the actuator output end.

Figure 16 - Actuator Output Shaft After Temperature-Torque
Cycling Test

3. The actuator transmission gear teeth appeared to have been fretted or galled, a condition that was most evident at or near the ends of the teeth. In addition, some of the teeth appeared to have been shaved down the face, with the shaving (in each case) deposited near the root of the tooth (Figures 17, 18, and 19). This shaving condition appeared to be the most severe on the driven gear. The condition was more severe on the side resisting the 400 lb-in. torque load, which was applied during the temperature torque cycling test.

4. Manual rotation of the gear motor required an irregular application of torque (with respect to position). Subsequent measurement of torque provided the following data:

- a. Running torque; 18 to 25 in.-grams, clockwise;
20 to 30 in.-grams, counterclockwise.
- b. Breakaway torque: 29 in.-grams, clockwise;
32 in.-grams, counterclockwise (maximum).

5. On disassembly of the gear motor, the face of the gear teeth had some discontinuity of the molybdenum disulfide coating. However, this condition was only visible under high magnification, and probably had no adverse effect on gear motor operation.

6. The gear motor body had a small groove running around the inlet side of one of the driving gear cavities. Apparently a particle had been lodged between the tip of a tooth and the body during a portion of the gear's rotation (Figure 20).

7. A test of the two potentiometers was conducted to determine if they had been subject to adverse effects during the temperature torque cycling test.

Figure 17 - Transmission Gear Teeth After Temperature-Torque Test, High Torque (400-in.-lb) Side

Figure 18 - Transmission Gear Teeth After Temperature-Torque
Test, Low Torque (80-in.-lb) Side

Figure 19 - Closeup of Gear Teeth After Temperature-Torque Test

Figure 20 - Gear Motor Body Showing Posttest Scratch

The test consisted of a standard linearity check described schematically in Figures 21 and 22.

The results of these tests are also shown in these figures. The data are typical for potentiometers of this type and are within specification limits.

6. Posttest Evaluation

a. Test Temperature

As already indicated, due to the degree of discoloration of the actuator input shaft, compared with that of the input flange (which was instrumented), it was suspected that the shaft reached higher temperatures during the endurance test than those recorded at the flange. To make an approximate determination of the shaft temperature, a series of Inconel samples were subjected to 2-hour helium atmosphere soaks, at temperatures ranging from 600°F to 1500°F in increments of 100°. The helium was taken directly from the supply system used for the endurance test. Discoloration of the samples resulted in a color spectrum (Figure 23) and various parts of the actuator were compared with this spectrum. The comparison indicated that the input shaft temperature reached approximately 900° to 1000°F (conservatively). Figure 23 shows areas on the output shaft together with the corresponding sample.

b. Transmission Gear Tooth Wear

Because of the uneven transmission gear tooth wear, and the loss of or change in gear tooth surface that was detected following the endurance test, the transmission design was reviewed as a possible causal factor.

Figure 21. Potentiometer Posttest Schematic and Results
(Terminals 1, 2, and 3)

Figure 22. Potentiometer Posttest Schematic and Results
(Terminals 16, 17, and 18)

POST-TEST VIEW SHOWING MATCHING PORTION
OF OUTPUT SHAFT FLANGE

700°F - NO COLOR CHANGE

800°F - SLIGHT GOLD
TINGE SHOWING

900°F - DEFINITE GOLD
COLOR WITH TRACES OF
PURPLE

1000°F - DEEP BLUE AND
PURPLE

1100°F - PREDOMINANTLY
BLUE

1200°F - BLUE TO GREEN

1400°F - LIGHT GREEN TO
BLACK

1500°F - DEEPER GREEN -
BLACK

COMPARISON OF COLOR CHANGES WITH
EXPOSURE OF INCONEL SPECIMENS IN
A HELIUM ATMOSPHERE

CLOSE UP OF 900°F COLOR SAMPLE AND
CORRESPONDING OUTPUT SHAFT COLOR

CLOSE UP OF 1000°F COLOR SAMPLE AND
CORRESPONDING OUTPUT SHAFT COLOR

Figure 23 - Posttest Views of Input Shaft Flange and
Corresponding Temperature Samples

Although it was apparent that the initial choice of base materials and heat treatment of the gear teeth left room for improvement, spectrographic analysis of the shavings found near the root of the teeth indicated the shavings did not contain iron, i.e., no 17-4 PH steel base material. Rather, the shavings were composed mainly of silver, with traces of molybdenum and silicon, which are constituents of the gear tooth coating only, (a silver plate with baked-on molydisulfide coating). The basic gear material, therefore, must be considered adequate, despite the merits of the initial choice.

c. Gear Tooth Configuration

Relative to gear tooth configuration, a preliminary 10x-size layout of the teeth in mesh indicated that due to a difference in the pressure angle of the output and input gears, the sharp corners of gear tooth tips were contacting the mating teeth and causing scuffing or shaving down of the faces.

A subsequent extensive investigation of this possibility was accomplished at Bendix, the results of which substantially verified preliminary findings by Aerojet. A complete report of this Bendix study is contained in Bendix Research Laboratories Report No. CA-23105, "Failure Analysis of the Nutator Transmission of Turbine Power Control Valve Actuator Model NT-D1, Serial No. 17," which is included in this report as Appendix A.

d. Seal

Of interest in the actuator post-endurance test evaluation was the condition of the seal.

Microscopic examination of the seal showed it to be in good condition. Some buildups were present, which appeared to be carbon or outgassed carbon binder material due to the high-temperature environment. The seal surface was a 4 microin. finish with a 6 microin. circumferential scratch, which probably did not affect the sealing function.

7. Conclusions

a. The results of the endurance testing described in this report, together with the extensive operating time the test actuator S/N 17 was subjected to before the start of the Endurance Test, verify that the units useful life is significantly longer than will be required for the XE testing application. In addition the high-temperature environmental conditions to which the actuator was subjected during the temperature torque cycling test were much more severe than had been originally intended.

b. Despite the preceding conclusion, the tests helped to reveal inadequacies in the actuator transmission gear design, which led to corresponding improvement of future hardware. Specifically the nutating gear has been redesigned with (1) a larger pressure angle, (2) a decreased addendum, and (3) radii at the tips and a decreased root radius, all of which are intended to eliminate the shaving action. Appendix A shows the details of these changes.

The changes will be effective on the Model NT-D2 actuators that are shortly to be delivered. Therefore, it is recommended that the endurance test described in this report be repeated using the new design. Also, the test equipment is to be modified so that the input shaft temperature will be used for control in place of the valve-actuator interface flange, in order to eliminate overheating.

APPENDIX

BENDIX FAILURE ANALYSIS OF THE
NUTATOR TRANSMISSION OF TURBINE
POWER CONTROL VALVE ACTUATOR MODEL
NT-D1, SERIAL NUMBER 17

ATTACHMENT

FAILURE ANALYSIS OF THE NUTATOR TRANSMISSION OF TURBINE POWER CONTROL VALVE ACTUATOR MODEL NT-D1, SERIAL NUMBER 17

INTRODUCTION

After completing one life cycle in the life test, TPCV actuator, Model NT-D1, Serial No. 17 was found to limit-cycle. The rotation of the output shaft was checked and found to be running rough. Aerojet-General personnel carefully disassembled the actuator and examined the transmission. Metal chips were discovered at the bottom of the gear teeth of the output gear, and the gear teeth faces appeared as though they were abnormally worn over about one-third of their area.

Bendix personnel visited Aerojet-General to examine the actuator parts, particularly the transmission gears, and to review the history of the actuator.

This attachment presents the detailed failure analysis of the transmission of actuator Serial No. 17. Included in the following sections are a description of the failed gears, a history of actuator No. 17, a history of the nutator transmission for TPCV actuators, an analysis of the gear teeth geometry, a review of gear materials, and conclusions and recommendations.

1 DESCRIPTION OF NUTATOR GEARS OF TRANSMISSION UNDER ANALYSIS

A sketch of the transmission (Part No. 2775033) used in the Model NT-D1 TPCV actuators is shown in Figure 1-1. In this sketch the output gear (Part No. 2775728) and the nutating gear (Part No. 2775815) under analysis are indicated. Noted in the sketch is vertex of the pitch cones of the two gears which is also the theoretical point about which the nutating gear nutates. The plus and minus direction of rotation are indicated.

1.1 Output Gear (Part No. 2775728)

Of the two gears, the output gear showed the most significant signs of wear. There was tooth contact throughout the entire length of the teeth, but the areas at the outer and inner portions of the tooth face showed signs of aggravated wear or scuffing. (See Figure 1-2.) On almost every tooth face that would be in contact when moving against the 400 in-lb load, there was an area at the outer portion of the tooth face that showed signs of scuffing with a metal chip at the bottom of tooth face. This area had the most significant signs of wear. It is not known at this time whether the chips at the bottom of the teeth are chips of the base metal of the gear or of the plating applied in the lubrication process. The metal chips can be seen in the photograph of the gear in Figure 1-3. There were also indications of scuffing on the inner portion of the tooth faces but they were not nearly so severe as those at the outer portion.

On the faces in contact when opposing the 80 in-lb load, there were signs of scuffing and metal chips on the inner portion of almost every tooth face. (See Figure 1-4.) Although there were metal chips in nearly every tooth, the wear was not so severe as on the outer portion of the opposite face. There were also signs of scuffing at the outer portion of the tooth face and metal chips in occasional teeth.

1.2 Nutating Gear (Part No. 2775815)

The nutating gear showed less signs of aggravated wear than the output gear. There was tooth contact along the entire length of tooth, but there were signs of scuffing at the inner and outer ends of the tooth face. (See Figure 1-5.) There were metal chips at the bottom of a few of the teeth, but these instances were relatively minor in comparison to the output gear. (See Figures 1-6 and 1-7.)

Figure 1-1 - Transmission Assembly (Part No. 2775033)

Figure 1-2 - Output Gear (Part No. 2775728)

P-5236

Figure 1-3 - Chips at Bottom of 400 in-lb Face of Output Gear

Figure 1-4 - Chips at Bottom of 80 in-lb Face of Output Gear

Figure 1-5 - Nutating Gear (Part No. 2775815)

Figure 1-6 - Nutating Gear, Showing Wear

Figure 1-7 - Nutating Gear, Showing Wear

2 HISTORY OF ACTUATOR S/N 17

Prior to the life tests of actuator S/N 17, the actuator was subjected to and used in a number of tests. The operating time in these tests totaled 61 hours. The tests included vibration, frequency response, stall torque, and checkout tests of the actuator and the use of the actuator in engine simulation, test-stand checkout, and hot-valve tests. The life test was initiated without the refurbishment of the actuator.

In the life test, the actuator was mounted on a turbine power control valve that has been made part of the test fixture. The butterfly shaft was coupled to an Inland torquemotor to allow torque loads to be accurately programed and applied. To simulate temperature the turbine power control valve body was heated using a Calrod heater. Cryogenic temperatures were produced by cooling the valve body and actuator with liquid nitrogen. During the life tests the torque load was 400 in-lbs in a CCW and 80 in-lbs in CW direction. The input command to the actuator was a 0.3-cps sine wave with 6-degree peak-to-peak amplitude. The actuator position was 45 degrees. The time-temperature profile of the life cycle is shown in Figure 2-1. Also indicated in the figure is the output shaft dynamic seal pressure. The temperature indicated in the Figure was that measured by a thermocouple attached to the actuator at a dynamic-seal mounting screw. A life cycle was approximately five hours. Actuator performance was evaluated before and after the life cycle. After the cycle was completed, it was found that the actuator would limit-cycle and that the rotation of the output shaft without pneumatic power was rough. The actuator was carefully disassembled. The transmission gears of the actuator were found to be as described in Section 1. The total operating time of the actuator was approximately 70 hours.

Figure 2-1 - Temperature Profile in Life-Test Cycle

3 HISTORY OF TRANSMISSION DESIGN

The nutator transmission has been used in all Turbine Power Control Valve Actuators since the initiation of the B series of TPCV actuators. The transmission of the B-series actuators was designed to meet the requirements of BRL actuator specification DS-563. The actuator load as function of valve position was defined. The maximum valve load torque was 248 in-lbs; the friction load was 60 in-lbs; and the inertia load of the valve was considered negligible. The duty cycle of the actuator was not defined. The transmission designed had a ratio 82:1 and was capable of handling a 10 in-lb input torque. The gears of the transmission were made of 17-4PH. This material was selected for its high fatigue and yield strength combined with its excellent retention of ductility at cryogenic temperatures. The gear geometry, cone angle, pressure angle, and pitch selected for this initial transmission and the material selected have been used in all subsequent nutator transmissions built for TPCV actuator. Transmission Part No. 2151312 was used in the Models NT-B2 and NT-B3 actuators. Two transmissions of this design were life tested. The first transmission was run under maximum load at constant speed for four hours and three minutes. At the completion of the testing of this transmission, the gears showed significant signs of wear. A number of minor changes, including the increasing of the face width of the gears, were made in the second transmission. The second transmission was subjected to tests of temperature shock, constant-load endurance, and low-temperature cyclic load endurance in which a peak load of 383 in-lbs was applied. Tests of this transmission were concluded after 7.33 hours. While there were indications of wear at the conclusion of the tests of the second transmission, they were not considered excessive. The details of the testing of the transmission are presented in report number BPAD 863-4-15122R.

The NT-B4 actuator used transmission Part No. 2775005. This transmission was essentially the same transmission as Part No. 2151312 except that the single double-row angular-contact bearing was replaced with a pair of angular-contact bearings.

In the Model NT-C actuators, some refinements were made in transmission design. The face width of gears was increased but the gear geometry remained unchanged.

The Model NT-D1 actuators were designed to AGC specification NDC-51A. In this specification, a maximum output torque of 600 in-lbs and life of 20 hours were specified. No duty cycle was specified. The transmission was redesigned but gear geometry and material were retained.

The transmission of the Model NT-D2 actuator is essentially the same as that of Model NT-D1 actuator. In the specification for the Model NT-D2 actuator, AGC 90080, maximum torque is 600 in-lb; the actuator load as function of position is defined; a life of 100 hours is specified; no duty cycle is indicated.

4 ANALYSIS OF GEAR GEOMETRY

4.1 Description of Gear Mesh

A schematic diagram of the gear teeth is shown in Figure 4-1. The pitch lines of the gears are described by cones whose vertices are coincident when the gears are properly mated. The pitch-cone angle of the nutating gear is larger than the pitch cone angle of the rotating gear. When the transmission is assembled, the center lines of the gears are displayed by an angle equal to the difference in the pitch-cone angles. The gears, then, are meshed at the pitch line on one side of the gear but are not meshed on the diametrically opposite side of the gear. A sectional view taken perpendicular to the pitch line of the meshed gear describes the specified pressure angle. In operation, the center line of the nutating gear describes a cone with the vertex at the pitch-cone vertex. As the gear nutates, it becomes disengaged from the output gear at one point and becomes meshed at another point. There is a one-tooth difference between the nutating and output gears, and for each nutation cycle, the output gear is advanced $1/N$ of a revolution (where N is the number of teeth on the output gear).

4.2 Gear Geometry as Presented on Drawings 2775815 and 2775728

The nutating gear and the output gear are manufactured according to drawings 2775815 and 2775728, respectively. In order to obtain proper operation of the gear set, the pitch-cone and pressure angles of the gear teeth must be accurately machined and the proper tooth configuration must be generated. The gear teeth and spaces can be considered truncated pyramids as illustrated in Figures 4-2 and 4-3. The tooth spaces (and thus the teeth) may be generated using a form tool (mill cutter or grinding wheel). The vertex of the form-tool angle (Figure 4-4) moves along the line AC of Figure 4-3. It is to be noted that the line AC is at a different angle from the pitch line. The cutting-tool angle is therefore defined when viewing the tooth space along the line AC, and must be different from the pressure angle which is defined by viewing the space along the pitch line. On drawings 2775815 and 2775728, then, the tooth space angles are given as 19 degrees, 28 minutes, 46 seconds, and 20 degrees, 35 minutes, 15 seconds, and should be used for gear manufacturing only. If the gears are cut with these angles along the proper angle for the line AC (Figure 4-3), the proper pressure angle should be obtained when the gears are mated.

4.3 Analysis of Gear Geometry

An analysis of the present gear geometry was performed to determine if the dimensional information given on drawings 2775815 and 2775728 was correct. The equations to obtain the pressure angle from the given dimensions were derived using the sketches shown in Figures 4-5 and 4-6. Refer to Figure 4-5; the following equations were derived for the nutating gear (Part No. 2775815):

Figure 4-1 - Schematic Diagram of Transmission Gear Mesh

Figure 4-2 - Typical Gear Tooth

Figure 4-3 - Typical Tooth Space

Figure 4-4 - Sketch of Gear-Cutting Tool

Figure 4-5 - Schematic Diagram of Geometry for Nutating Gear (Part No. 2775815) (83 Teeth)

Figure 4-6 - Schematic Diagram of Geometry for Output Gear (Part No. 2775728) (82 Teeth)

$$\tan \theta = \frac{d}{l_1} \quad (1)$$

$$\tan \theta_2 = \frac{d}{l_4} \quad (2)$$

$$l_1 = r \tan (\phi - \phi_1) \quad (3)$$

$$l_4 = r \sin (\phi - \phi_1) \quad (4)$$

where

ϕ = pitch cone angle

ϕ_1 = angle of line AC (Figure 4-3)

θ = pressure angle

θ_2 = cutting tool angle

Other dimensions are as shown on the sketches.

Substituting equations (2), (3), and (4) into equation (1) results in

$$\tan \theta = \frac{r \sin (\phi - \phi_1) \tan \theta_2}{r \tan (\phi - \phi_1)} \quad (5)$$

which can be simplified to

$$\tan \theta = \cos (\phi - \phi_1) \tan \theta_2 \quad (6)$$

Equation (6), then, relates the pressure angle to the pitch-cone angle, the cutting-tool angle and the angle along which the form tool is moved while cutting the tooth space. Similar relations can be obtained for the output gear using Figure 4-6. The final equation for the pressure angle of the gear is

$$\tan \theta' = \cos (\phi_1' - \phi') \tan \theta_2' \quad (7)$$

where the angles are as defined above. (Primed quantities refer to output gear.)

The data given for manufacturing the two gears is as follows:

Nutating Gear

$$\phi = 30 \text{ deg}$$

$$\phi_1 = 27.3486 \text{ deg}$$

$$\theta_2 = 19.4794 \text{ deg}$$

Output Gear

$$\phi = 31.175 \text{ deg}$$

$$\phi_1' = 33.6806 \text{ deg}$$

$$\theta_2' = 20.5875 \text{ deg}$$

Calculated pressure angles for the nutating and output gears are 19.4588 degrees and 20.5655 degrees, respectively. It is seen, therefore, that the manufacturing dimensions given on the drawings do not result in a pressure angle of exactly 20 degrees as specified. The gears will not properly mesh at the pitch line when assembled in the transmission.

In order to obtain a clearer picture of how the gears mesh, the gear geometry was calculated at $r = 1.25$ inches and $r = 1.62$ inches (inner and outer radii of the gear teeth measured along the pitch line). Typical gear mesh for the two radii are shown in Figures 4-7 and 4-8, which are drawn several times size. It is seen from these figures that, due to the improper angles, the gears do not mesh along the pitch line. It is also seen how the rotating gear can be "shaved" by the nutating gear as the two come into mesh. Additionally, Figure 4-7 indicates that the teeth of the gears can bottom on the radius of the spaces at the smaller values of radius r . This correlates with the wear pattern of the faces of the teeth of both gears.

The transmission gears can be reworked to obtain the same pressure angle by reworking the nutator gear only. The teeth can be

Figure 4-7 - Typical Gear Mesh at $r = 1.25$ inches

Figure 4-8 - Typical Gear Mesh at $r = 1.62$ inches

machined at a slightly larger angle than the 19 degrees, 28 minutes, 46 seconds specified on drawing 2775815. The addendum of the teeth will also have to be decreased to prevent interference at the bottom of the rotating gear space. At the same time, the corners of the teeth should be broken with a slight radius to help alleviate any "shaving" action. It may also be desirable to deepen the nutating gear space by decreasing the root radius. With these modifications, the nutating gear will require shimming at assembly to assure coincidence of the pitch-cone vertices.

5 GEAR MATERIALS

The physical properties of a group of stainless steels that warrant consideration for this application, including the 17-4PH stainless steel presently being used, are presented in Table 5-1. All materials presented in this table have sufficient physical strength and ductility.

It has been indicated that the galling characteristics of the gear material may have an effect on the short life achieved by the failed parts. The 17-4PH stainless steel is considered to have relatively good wear characteristics; thus is recommended for the making of gears. The Armco Steel Corporation has conducted galling tests on various stainless steels in which loads causing galling were determined. The results of these tests are included in Table 5-1. The data indicates that the 410- or 416-series of stainless steels have greater resistance to galling than 17-4PH. The report also indicates that improved galling characteristics, approaching that of the 410 and 416 steels, could be achieved with 17-4PH by using mating parts with differing hardnesses.

In the TPCV actuator application, the mating parts are lubricated with a dry-film lubricant, and environmental and load conditions differ considerably from those of the galling tests. Therefore, it is difficult to evaluate with any degree of certainty the effect of the galling characteristics of the materials on the life they achieve. This is not to say that in future designs it would not be advisable to change the material from 17-4PH to either a series 410 or 416 stainless steel.

Table 5-1 - Material Review for Nutator Gears

		Material									
Characteristic		17-4 PH				410		416		431	
Tempering Temperature		900	925	1025*	1150	1000	300	1000	300	500	900
Tensile Strength	Room Temp. -320°F	190,000 263,000	170,000	155,000	135,000	145,000	195,000	137,000	176,000	193,000	200,000
Yield Strength	Room Temp. -320°F	170,000 243,000	155,000	145,000	105,000	115,000	150,000	110,000	138,000	148,000	156,000
% Elongation in Two Inches	Room Temp. -320°F	4-10 7	10 >7	12 >7	16 >7	20	15 7	15 10	9.5	17	18
IZOD Impact (ft-lb)	Room Temp. -320°F	**20	5	15-35	30-50	20	35	25	20	52	42
Hardness	BHN	388/488	375/438	331/401	277/352	300	390	285	363	388	415
	Rockwell C	40/47	38/45	35/42	28/32	32	41	30	38	41	44
Galling Load (psi)***			6000	6000	5000		20,000	30,000			

* Temperature of 17-4 PH used in present gears

** Minimum impact properties for 17-4 PH in position 900 are not acceptable.

*** "Stainless Steel Galling Characteristics," H. Tanczyn, Armco Steel Corporation, April 20, 1955 issue of "Steel" Magazine.

6 CONCLUSIONS AND RECOMMENDATIONS

It was concluded from the failure analysis that scuffing of the gear teeth and the resulting metal chip at the bottom of gear teeth was due to the difference in the pressure angle of the nutating and output gears and the sharp corners on the gear tooth tips. The chips found at the bottom of the teeth are probably chips of the plating material from Magnaplate process used to lubricate the gear teeth. The conclusion that the chips are from the plating process is drawn because it is not probable that the base material of gears would generate a chip, since both gears are of the same hardness. The plating material is soft in comparison to the base material and therefore a gear tooth with a sharp corner could shave the softer material.

In support of the foregoing conclusion, it is also concluded that it is unlikely that the galling characteristics of the base material contributed significantly to the failure. The gear teeth of the transmission are lubricated with a dry-film lubricant that actually prevents the contact of the base materials and lowers the coefficient of friction between the contacting faces of the gear teeth. Once the dry-film lubricant has deteriorated to the point where the base materials of the two gears come into contact, the transmission efficiency should decrease and the wear of the gear teeth increase. It is questionable to what extent that galling characteristics of the base material would limit the life of a transmission after the base materials come into contact. A review of materials indicated that the 416-series stainless steel did have better resistance to galling and could be substituted for the 17-4PH material presently being used.

It was noted in reviewing the history of the transmission design that the actuator duty cycle, loads, and environments as a function of time, have never been defined or specified. Therefore, it is not possible to establish the adequacy of the transmission for this application.

It is recommended that gear teeth of the nutating gear be changed to have the same pressure angle as the output gear and that the corners on the tips of the gear teeth be broken. It is not possible to predict to what extent the life of the transmission will be improved by correcting the pressure angles and breaking the sharp corners of the gear teeth. This can be established only through testing of the transmission. It is also recommended that the required duty cycle of the actuator be established and be made part of the actuator specification to allow adequacy of the transmission to be determined.

APPENDIX I

NDC-51A NERVA DESIGN CRITERIA, ACTUATOR, ELECTRO-PNEUMATIC,
ROTARY, FOR TURBOPUMP POWER CONTROL VALVE

NDC-51A
6 March 1964
Superseding
NDC-51
24 September 1962

NERVA DESIGN CRITERIA

ACTUATOR, ELECTRO-PNEUMATIC, ROTARY,
FOR TURBOPUMP POWER CONTROL VALVE

NDC-51A
6 March 1964
Superseding
NDC-51
24 September 1962

CODE IDENT NO. 70143

NERVA DESIGN CRITERIA

(A) ACTUATOR, ELECTRO-PNEUMATIC, ROTARY,
FOR TURBOPUMP POWER CONTROL VALVE

1. SCOPE

(A) 1.1 This design criteria establishes the requirements for a rotary, electro-pneumatic actuator for the turbopump power control valve, to be used with the NERVA Hot-Bleed Engine.

(A) 2. APPLICABLE DOCUMENTS

2.1 Department of Defense documents. - Unless otherwise specified, the following documents, listed in the latest issue of the Department of Defense Index of Specifications and Standards, shall form a part of this design criteria to the extent specified herein.

SPECIFICATIONS

Military

MIL-W-3947	Weight and Balance Control Data for Guided Missiles
MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment, General Specification for

STANDARDS

Military

MIL-STD-129	Packaging for Shipment and Storage
MIL-STD-130	Identification Marking of U. S. Military Property
MIL-STD-176	Weight and Balance Data Reporting Forms for Guided Missiles
MS33540	Safety Wiring, General Practices for
MS33586	Metals, Definition of Dissimilar

(Copies of documents required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards.)

Mar. 1964:746:RB:sjp

2.2 Other documents. - Unless otherwise specified, the following documents, of the latest issue in effect, shall form a part of this design criteria to the extent specified herein.

PUBLICATIONS

National Aeronautics and Space Administration

Marshall Space Flight Center (MSFC)

MSFC Index of Specifications, Standards and Procedures
Engineering Standards Manual (4 volumes)

(Copies of MSFC publications may be obtained from the Propulsion and Vehicle Engineering Division, Bldg. 4610, George C. Marshall Space Flight Center, Huntsville, Alabama.)

2.3 Aerojet-General Corporation documents. - Unless otherwise specified, the following documents, of the latest issue in effect, shall form a part of this design criteria to the extent specified herein.

SPECIFICATION

AGC-14097 Interference Control Requirements, NERVA
Engine

DRAWING

094232 Interface Control DWG-TPC Valve & Actuator
w/Crowned Splines

PUBLICATION

REON Report

No. 2487 REON Reliability and Quality Assurance Program
Plan

3. REQUIREMENTS

(A) 3.1 Materials. - Materials used in the manufacture of the actuator shall be of high quality, suitable for the purpose intended, and selected in accordance with applicable documents as established by the MSFC index of specifications, standards and procedures (see 2.2).

3.1.1 Standard parts. - Wherever practicable, standard parts shall be selected from the MSFC Engineering Standards Manual (see 2.2) and identified by their standard part number.

3.1.2 Metals.- The use of metals such as cobalt which, when irradiated, yield radioactive isotopes having a long half-life shall be held to a minimum. Metals having a total elongation (measure of ductility by tensile testing) of less than three percent at the cryogenic temperatures specified in 3.2.3.2 combined with the radiation environment of 3.5.2, or in either environment separately, shall not be used. The widest practical use shall be made of stainless steels, aluminum alloys, and titanium alloys.

3.1.2.1 Dissimilar metals.- Unless suitably protected against electrolytic corrosion, dissimilar metals as defined in MS33586 shall not be used.

3.1.3 Nonmetals.- Nonmetals such as rubber, plastics, or other organic materials having a short life expectancy in the radiation environment of 3.5.2, shall not be used.

3.1.4 Protective treatment.- Materials which will deteriorate when exposed to the environmental and operational conditions herein shall be protected against such deterioration in a manner that will assure the actuator complying with the performance requirements of 3.3. The use of any protective coating that will crack, chip, or scale with age or extremes of environmental and operating conditions shall not be used.

3.2 Design and construction.-

3.2.1 Description.- Unless otherwise specified, the actuator shall consist of the following principal component parts:

- (a) Magnetic drive amplifier with housing*
- (b) Torque motor
- (c) Servo valve
- (d) Gear motor
- (e) Speed reducing transmission with splined output shaft
- (f) Potentiometers for servo feedback and position indication
- (g) Seals, dynamic shaft
- (h) Connector assembly, remote handling
- (i) Switches, indication

*The magnetic amplifier with housing shall be provided as a separate unit. The other component parts shall be integral with the actuator.

(A)

3.2.1.1 Dimensions.- The envelope and mounting dimensions shall be in accordance with the applicable drawings. Interface dimensions for the TPCV and the actuator shall be in accordance with Aerojet Drawing 094232 (see 2.3).

3.2.1.2 Weight.- The maximum weight of the actuator and drive amplifier shall be 18 lb.

3.2.1.2.1 Weight and balance control data.- Weight and balance control data as specified in Military Specification MIL-W-3947 (see 2.1) shall be supplied in accordance with the form requirements of MIL-STD-176.

(A) 3.2.1.3 Connector assembly.- The connector for electrical power and signals and for actuating fluid supply and exhaust shall be as shown in the applicable drawing.

3.2.2 Maintainability.- The actuator shall be designed and constructed to provide ready accessibility for overhaul and maintenance. The need for specially designed tools and equipment for actuator maintenance shall be avoided wherever possible.

(A) 3.2.3 Actuating fluid.- The actuating fluid shall be gaseous hydrogen (GH_2).

3.2.3.1 Fluid cleanliness.- The concentration of contaminants in the actuating fluid shall not exceed 6 milligrams of contaminants per pound of GH_2 . Contaminant particles shall not exceed 10 microns in their longest dimensions.

3.2.3.2 Ratings.- The actuator shall be designed for the following ratings:

	Actuating Fluid	Coolant, (GH_2)
(a) Temperature, inlet, °R	200 to 570	<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;">↑</div> <div style="text-align: center;">To be specified</div> <div style="margin-left: 10px;">↓</div> </div>
(b) Working pressure, inlet, psia	215 ± 10	
(c) Exhaust back pressure, outlet, psia	55 ± 5	
(d) Proof pressure, psia	245 ± 10	
(e) Burst pressure, psia	307 ± 10	
(f) Leakage, helium, 50 psi, cc/sec	10 ⁻²	
(g) Flow rate, max, lb/sec	0.025	

3.2.4 Servo-valve electrical system.-

3.2.4.1 Electrical requirements.- The electrical requirements of the components of the servo-valve system shall be as shown in table I.

Table I: Electrical Requirements for Servo-Valve

Component	Volts Nom.	Operation watts, max.	
		No-Load	Load
Amplifier	115 ac (400 cps, sp)	2.5	4
Potentiometer	10 dc	0.1	0.1
Indicating switches	28 dc	0	3

3.2.4.2 Input command signal.- The input command signal to the amplifier shall range from 0 to 10 volts.

3.2.4.3 Amplifier impedance.- The input impedance of the amplifier circuit shall be greater than 1000 ohms at all times of null. Output impedance shall be 20 ohms maximum.

3.2.4.4 Servo-valve control.- The position of the servo-valve shall be controlled by an electrical signal from the amplifier.

(A)

3.2.5 Indexing.- The actuator output shaft shall be indexed as shown on the applicable drawing, which will assure matching of actuator and load zero positions within $\pm 1^\circ$.

3.2.6 Sealing.- The actuator internal seals and any seals required at the inlet and outlet ports shall be provided with the actuator.

3.2.6.1 Leakage.- Fluid leakage of dynamic shaft seals and connector seals shall not exceed 5 cc/sec per inch of diameter, measured with 50 psi helium at ambient temperature.

3.2.7 Lubrication.- All internal moving parts of the actuator shall be lubricated and sealed at time of assembly. The actuator shall then be capable of functional operation in accordance with 3.9, without requiring additional lubrication.

3.2.8 Safety wiring.- Safety wiring, where used, shall conform to MS33540.

3.2.9 Rotation.- When viewed from the shaft end, the output shaft of the actuator shall rotate clockwise during the opening or increasing valve angle stroke.

3.3 Performance and product characteristics.-

3.3.1 Torque.- The actuator, when coupled with the turbine power control valve, shall provide the output torque to meet the following load characteristics:

- (a) Breakout, running, and dynamic torque, as shown in figure 1.
- (b) Moment of inertia about rotary axis of the actuator will be negligible.

3.3.2 Angular displacement.- The actuator output shaft shall be capable of the following:

- (a) Full angular displacement, degrees, nominal 90
- (b) Slew velocity, deg/sec, min. 360

3.3.3 Linearity.- On command signal the position of the actuator shall be linear to within ± 2 percent of full angular displacement.

(A) 3.3.4 Resolution dead zone.- The resolution of the actuator shall be $\pm 0.5^\circ$ with a sawtooth input signal of $\pm 2^\circ$ in amplitude and a 0.10 cycle per second frequency. This requirement is effective in the 5° to 90° actuator shaft position range.

(A) 3.3.5 Frequency response.- The response of the actuator to a sinusoidal input signal of $\pm 2^\circ$ amplitude shall approximate a second order system with a break point at a nominal 8 cps with a 0.5 damping ratio minimum.

3.3.6 Transient response.- The response of the actuator to an input step amplitude equal to 45° angular stroke from any point greater than 5° shall be such that 62 percent of the corresponding output level shall be achieved within 0.12 second.

(A) 3.3.6.1 Overshoot.- The overshoot, following a transient disturbance to the actuator input, shall not be greater than 15 percent of the ordered output level.

3.3.7 Repeatability.- The commanded position of the actuator shall be repeatable within ± 1.5 percent of the full stroke (see 3.3.2(a)).

(A) 3.3.8 Random drift.- The inaccuracy of commanded position due to random servo drift shall be less than $\pm 0.3^\circ$.

3.3.9 Settling time.- Following a transient disturbance, the output position shall be restrained to within 5 percent of the ordered position within 0.3 second.

3.4 Components.-

3.4.1 Potentiometers.- Potentiometers shall be provided for servo feedback and position indication. Potentiometers shall have the following characteristics:

(a)	Resistance, ohms	500 $\pm$ 50
(b)	Resolution, percent of full range	0.01
(c)	Independent linearity, percent	± 0.5
(d)	Insulation resistance	20 megohms at 1500 vdc for one minute

3.4.1.1 Null adjustment.- An electrical null adjustment of the potentiometer with respect to the mechanical null of the actuator output shaft shall be provided.

3.5 Environmental and load factors.-

3.5.1 Nonoperating.- The actuator shall be capable of withstanding the environments and load factors singly or in combinations that may occur while nonoperating, as shown in table II, without deterioration of any nature which would prevent the actuator from meeting the performance requirements of 3.3 and 3.9.

(A) Table II: Environmental Conditions, Nonoperating

Environment	Condition	Duration, max
Temperature, °F		
(a) Shipping and storage	-65 to +160	See 3.8
(b) Installed	-260 to +160	See 3.9
Acceleration, sustained, max, g*		
(a) Parallel to actuator longitudinal axis		
(1) Forward	6	10 min
(2) Aft	1.2	10 min
(b) Normal to actuator longitudinal axis	1	10 min
Vibration*	See table III	10 min
Noise*	See figure 2	10 min
Shock, along axis shown, half sine wave, g's max.		
(a) Packaged for shipment, any axis	6	0.01 sec. max
(b) Boost phase*		
(1) Parallel to actuator longitudinal axis	10	0.01 sec. max
(2) Normal to actuator longitudinal axis	3	0.01 sec. max
Rain	Procedure II, MIL-E-5272	**
Sand and dust	Procedure I, MIL-E-5272	**
Salt spray	Procedure I, MIL-E-5272	**
Fungus	Procedure I, MIL-E-5272	**
Humidity	Procedure I, MIL-E-5272	**

* Installed and nonoperating

** See applicable procedure, MIL-E-5272

A

Table III: Vibration Levels*

	Axis	Frequency (cps $\pm$ 1%)	Amplitude ($\pm$ 10%) Ref: MSFC Memo M-P & VE-SD-501-62
SINUSOIDAL SWEEP LEVELS Note: Sweep rate shall be 3 minutes per octave up and back.	Longitudinal (parallel to engine longitu- dinal axis)	5 to 45 45 to 87 87 to 2000	1.33g, zero to peak 0.013 inch DA 5.0g, zero to peak
	Lateral (per- pendicular to engine longitu- dinal axis)	5 to 12 12 to 500	0.135 inch DA 1.0g, zero to peak
SINUSOIDAL DWELL LEVELS Note: Dwell time at each major reso- nance is 6 minutes.	Longitudinal (parallel to engine longitu- dinal axis)	5 to 45 45 to 87 87 to 2000	0.67g, zero to peak 0.0065 inch DA 2.5g, zero to peak
	Lateral (per- pendicular to engine longitu- dinal axis)	5 to 2000 12 to 500	0.067 inch DA 0.5g, zero to peak
GAUSSIAN RANDOM This vibration requirement concerns a flat spectral density of $0.045g^2/cps$ over a frequency range of 5 to 3500 cps for 16 minutes along three mutually perpendicular axes.			

*The values in this table are for the assembled engine. However, the actuator shall be designed and mounted such that the vibration amplification factor from the thrust chamber dome to the actuator shall not be greater than three (3).

(A)

3.5.2 Operating.-- The actuator shall be capable of withstanding the environments and load factors, singly or in combinations, that may occur when energized, as shown in table IV, without deterioration of any nature which would prevent the actuator from meeting the performance requirements of 3.3 and 3.9.

Table IV: Environmental Conditions, Operating

Environment	Condition	Duration, max
Temperature, °F	-260 to +540	See 3.9
Altitude	30,000 ft. and higher	-----
Attitude	Any	-----
Noise and Vibration	To be specified	-----
Shock, any axis, max, g	1	0.01 sec.
Acceleration, sustained, max, g		-----
(a) Parallel to actuator longitudinal axis		
(1) Forward	2	
(2) Aft	1.2	
(b) Normal to actuator longitudinal axis	1	
Radiation, estimated		See 3.9
(a) Neutron flux ($E > 0.01$ mev) neutron/cm ² - sec	2×10^{11}	
(b) Gamma flux, mev/cm ² - sec	6×10^{12}	

(A)

3.6 Reliability.-- Reliability of the actuator and its components shall be commensurate with requirements and all service environments. The level of reliability for the actuator shall be assigned when available.

3.7 Identification.-- The actuator shall be identified in accordance with MIL-STD-130.

3.8 Storage life.-- The actuator shall be capable of being stored for 5 years under the storage temperature range specified in table II, requiring only light maintenance, such as lubrication, and shall thereafter meet the performance requirements of 3.3 and 3.9.

3.9 Service life.- The actuator shall be capable of the performance called for in this design criteria for a minimum life of 2 hours without failure or malfunction. After the 2-hour function and minimum amount of rework involving minor parts, the actuator shall be capable of operating up to 20 hours. .

3.10 Electrical interference.- The actuator shall not cause electrical interference beyond the limits stipulated in Aerojet-General Corporation Specification AGC-14097 (see 2.3) under all operational conditions of this design criteria.

(A) 3.11 Quality assurance provisions.- These provisions shall be in accordance with the specific and applicable portions of REON Report No. 2487 (see 2.3) as specified in the contract or order.

(A) 3.12 Workmanship.- The workmanship shall be of sufficiently high grade to insure satisfactory operation, reliability, and durability consistent with the service life of the actuator and the requirements of this design criteria. Particular attention shall be given to the neatness and thoroughness of marking of parts, welding, and freedom of parts from burrs and sharp edges. The finished actuator and all integral parts shall be clean and free of oils and all materials which might adversely affect the operation of the actuator.

Authorized for Release:

H. S. McQueen, Department Manager
Engineering Specifications
Rocket Engine Operations, Nuclear
Azusa
sjp

TO BE FURNISHED

(stall torque, 600 in-lb minimum)

A

LAUNCH CONDITION EXTERNAL NOISE LEVEL SPECTRUM FOR NERVA ENGINE

Figure 2

DOCUMENT APPROVAL
SIGNATURE SHEET

NERVA DESIGN CRITERIA

NDC-51A

Type of Document

Document Number

Title of Document ACTUATOR, ELECTRO-PNEUMATIC, ROTARY,
FOR TURBOPUMP POWER CONTROL VALVE

Document Prepared by R.H. Benedict

Document Checked by S.J. Powell

APPROVAL SIGNATURE

DEPT.

DATE

N. L. Irvine

732

3/17/64

N. L. Irvine, Senior Department Manager
REON Instrumentation and Controls

W. F. Funnell

739

3/12/64

W. F. Funnell, Department Manager
NERVA Controls Systems

Bruno F. Darin

736

3/13/64

B. F. Darin, Technical Assistant
Product Assurance Division

RECEIVED
1968 FEB 28 AM 11:11
O-C
CLEVELAND, OHIO