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Design Summary - Reflector Drive System

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ABSTRACT

The design requirements, design description and expected performance of the reflector and drive control system are summarized.

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I INTRODUCTION

The conceptual design of the reflector and drive control system for the reactor of the 5 Kwe-TE Power System has been completed. This conceptual design is based on the completion of the studies described at the AEC/NASA Design Review in June, 1972 (Reference 1). This report summarizes the requirements, the design, and the performance of the selected conceptual system design.

II DESIGN REQUIREMENTS

The reflector and drive control system was designed to meet the following requirements which are specified in, or are compatible with the reactor subsystem specification (Reference 2).

Environmental - Ground Test

Temperature	50°F - 875°F
Pressure	Sea level ambient (low temperature operational checkout only) 10^{-5} Torr or less (high temperature operation)
Acceleration	1g gravity (toward the inlet end)
Shock and Vibration	Handling only
Irradiation	1×10^{20} nvt

Environmental-Launch (non Operating)

Temperature	50°F - 130°F
Pressure	Sea level ambient to 10^{-8} Torr or less

Acceleration	Any combination of 7.5g axial and 2.0 lateral or 1.0 g axial and 1.25 lateral, or 16.25g axial and .625g lateral
Shock and Vibration	To be determined (effects expected to be less than that of acceleration)
Environmental-Space Operation	
Temperature	50°F - 875°F
Pressure	10^{-8} Torr or less
Acceleration	.10g max in any direction
Irradiation	Same as for ground test
Operational	
Control Reflector Motion	~0.005"/step (1 electrical rev. of actuator phases)
Control Stepping Rate	1 step/sec or slower (alternate reflector sectors)
Reflector Backlash	< 0.005" axial and < 4.0° rotational
Flight Safety	
Launch	Control Section locked in shut- down (out) position
End of Life (EOL)	Reflector assemblies rotatable away from core vessel to achieve shutdown
Ground Test Safety	
Normal Scram	Simultaneous withdrawal of both reflector sectors at 5 steps per second rate

Backup Shutdown

EOL reflector assembly rotation
with stored energy. Reflector
assemblies repositionable for
restart

Control Sector

Counter Balance

Control sector weight counter
balanced to prevent inward
(downward) movement in the
event of actuator malfunction

III CONCEPTUAL DESIGN DESCRIPTION

A. Overall

The conceptual design of the reactor control reflector system is shown pictorially in Figure 1 and in details in Figures 2 and 3. Two half reflector assemblies are individually hinged to the core vessel structure near the coolant outlet, and held together at the opposite end by a retaining device. Each half reflector assembly is located laterally with respect to the core vessel by tongue and slot arrangement near the hinge end and radially by two locating pads near the coolant inlet end of the vessel. The retaining device incorporates a spring to take up the deflection between the two reflector halves caused by the thermal expansion of the core vessel and any differential expansions.

The reactor control reflector is essentially a 16 inch high, thick walled beryllium cylinder, with an ID of 10.720 and a minimum wall of 1.190 at one end, increasing uniformly at half cone angle of 8.5° . Each fixed half reflector has a 10 inch high window which subtends an angle of 117.5° , located at the thick end, to accommodate the moveable

control sector, whose configuration equals the material removed for the window. The fixed reflector and the lower support bracket form the basic structure of each half reflector assembly. The reflector hinges, locating and retention devices, and the moveable control sector and its guide and drive mechanisms are attached to this main structure. The fixed reflector and the control sectors are of nuclear grade beryllium with surfaces facing outward black anodized, and surfaces facing the reactor core vessel uncoated to control the beryllium temperatures.

The significant features of the conceptual design are listed below and described in detail in subsequent sections.

Reflector and Drive System Weight	160 lb
Control Sector Assembly Weight	26 lb
Reflector Material	Beryllium
Reflector Coating	Black anodizing
Linear Drive Mechanism	Ball Screw (Translating Nut)
Ball Screw Lead	.75 in. /rev
Drive Actuator	Modified S8DR
Actuator Step Size (4 pulse electrical revolution of the phases)	7.2° rotation
Actuator Output Gear Ratio	2.78 (50/18)
Overall Drive Ratio	0.0054 in. /7.2°
Drive System Bearings	Modified S8DR
Number of Bearings/Drive	3
Sector Backlash	None axially (spring loaded) 1.0° rotational
Sector Lock	Actuator Brake
Flight Shutdown	End of life only
Ground Test Shutdown	Normal scram } re- Backup shutdown } startable

Ground Test Backup Sector Lock

Anti-gravity springs

B. Control Sector Guide and Drive Mechanism

The reactor operation, from the safe shutdown thru startup and long term power operation, is controlled by the axial positioning of the two control sectors which adjusts width of the neutron escape windows in the reflector system. Based on the results of the extensive design studies, a simple translating ball screw mechanism was selected to both guide and drive the control sector. Basically, the control sector is supported by the translating nut and the guide bearing, both of which translate on the main drive screw. The drive screw, in turn, is located by bearings in the fixed reflector and the lower support bracket. All three of the guide bearings are of the self aligning monoball design (Figure 4) and are identical. The general configuration and the material combination of carbon graphite (Pure Carbon Co., grade P-5) ball within the alumina coated spherical socket, and rotating on an alumina coated shaft, are the same as the S8DR control drum bearings. The bearing motion and loading (radial only or radial and thrust) on the drive screw shaft bearings are, again, similar to the S8DR. The control sector guide bearing undergoes simultaneous rotation and translation under very light radial loads. While this type of bearing action was not present on the S8DR, pure translational carbon graphite bearings were successfully operated on the S8DR scram snubbers. The experimentally determined friction coefficient range of the bearing with the alumina-carbon graphite material combination is shown on Figure 5. By applying MoS_2 dry film lubricant to the alumina surface, the friction coefficient is expected to be more uniform, eliminating the higher values shown.

The translating nut ball screw drive is selected as most applicable method of transforming the rotary output of the drive

actuator to the linear motion of the control sector within the space limitation. Although limited in numbers of applications, ball screws have been successfully operated under high temperatures without liquid lubrication, as indicated in Figure 6. The critical ball screw parameters (ball diameter, pitch diameter, and materials) of the conceptual design (Figure 7) were selected to provide large design margin under the expected operational conditions. The calculated life is 10^6 inches of travel under 350 lb load, compared to the maximum operational requirement of 1.8×10^3 inches of travel under 26 lb. The double ball circuit feature was selected to resist the overturning moment induced by the center of the gravity of the control sector being located off of the drive screw center line.

To allow for the thermal expansions over the wide operation temperature range, adequate physical clearances between moving parts of the drive system are designed in. The resulting axial backlash at the control sector is eliminated by spring loading the control sector in one direction. The total and net effective forces of the two anti-backlash springs located between the fixed reflector and the control sector are shown in Figure 8. The recesses in the control sector for these springs are sized to accommodate the anti-gravity springs for the ground test, discussed later.

C. Reflector Drive Actuator

A variable reluctance DC stepper actuator generates the motive torque for the reflector drive. This actuator, shown in Figure 9, is a configurational and dimensional modification of the successfully tested S8DR actuator design. The materials, electromagnetic design, and the coil fabrication techniques are identical to the S8DR. As with the S8DR, the actuator produces discrete steps of 1.8° of rotation when the successive phases are energized. The 2.78:1 ratio of the integral gear

box coupled with the .75 inch lead of the ball screw results in 0.0054 inch of control sector motion (0.5 ϕ of reactivity change) for each 7.2° rotation of the actuator. The 7.2° actuator rotation per control step, which represents a complete electrical revolution of the electromagnetic phases, was selected to simplify the controller requirements. Because the actuator always starts and stops at the same phase, the controller does not require any memory, such as was required for the S8DR where 3.6° per control step was used.

A built-in mechanical brake locks the actuator rotor in place except when stepping motion is required. Face gears on the mating brake discs provide positive braking with minimal braking force. Rotational backlash of the brake is eliminated by utilizing a torsionally rigid bellows to give the fixed brake disc axial flexibility for the engagement and disengagement. The brake is mechanically designed to hold the control sector in place during the spacecraft launch.

Both the actuator stator and the brake are designed to accommodate the "hard cable" wiring. The sheath of each single conductor cable is clamped at the terminal box and the conductor is welded to a cable junction which, in turn, is clamped at an insulated terminal strip. The termination design permits attachment of "jumper cables" to operate the actuator until the final installation and welding of the system cables.

The actuator assembly is attached to the lower reflector bracket and the output shaft of the gear box is attached to the shaft of the ball screw drive thru a bellows type flexible coupling. The axial and angular flexibility of the coupling separates the bearings and shaft of the actuator gear box and those of the ball screw drive to prevent any binding reaction between the two units.

D. Flight Safety

Two tapered lock pins on the lower reflector bracket engage the mating holes in the control sector when the sector is in the full out position. These pins not only act as mechanical full out stops, but also prevent rotation of the control sector during the launch. As shown in Figure 3, the normal anti-rotation device is unloaded at this sector position. In the normal reactor-up launch vehicle configuration, the full out stop function of these pins prevents axial sector motion induced by the spacecraft forward acceleration. In the reactor-down launch configuration, the control sector is locked (from the more reactive position) by the mechanical brake of the actuator thru the ball screw drive and the reduction gears.

An S8DR type limit switch signals that the control sector is in the full out position. By slight modification of the tapered pins and limit switch actuating lever, any intermediate full out position of the control sector may be selected.

The hinge mounting feature of each reflector half assembly is utilized to achieve the end of life shutdown. Torsional springs located at each hinge pin are designed to overcome the bending resistance of the hard cable to rotate the reflector assembly away from the core vessel when the retaining device is separated. The reflector retaining device will be an electrically actuated fusible link similar to that of the SNAP 10A system. Upon receipt of the shutdown signal, electrical energy is applied to a small heater located within the device, heating the housing until its strength falls below the applied load, causing rupture and separation. The thermal expansion spring at the reflector retaining device has sufficient force not only to overcome the torsional hinge springs, but also to resist the lateral launch acceleration on the reflector assemblies. The end of life spring force on the reflector

retaining link is adequate to cause rapid rupture when its temperature is increased by the heater.

E. Ground Test Safety

The normal scram requirement is achieved by the rapid withdrawal of both control sectors by the continuous operation of both actuators. In this operational mode, the actuator brake is disengaged by continuously energizing the brake solenoid, while the actuator is being stepped at 6 RPM rate until the full out limit switch is actuated. At the end of the scram, the brake solenoid is de-energized and the mechanical brake engaged to lock the control sector prior to deactivating the actuator phases.

The end of life shutdown capability of the reflector system is used to provide a backup shutdown feature for ground testing. As shown in Figure 10, the reflector system is modified slightly and reflector latching and reset mechanisms added. The reflector retaining device and its thermal expansion spring is removed from the reflector and a restart arm is attached to each reflector half assembly. This arm contains the armature of the scram magnet and the thermal expansion spring. A dual coil magnet acting on the armature, which, in turn, is spring mounted to the arm, holds each reflector half assembly against the core vessel during normal operation. When the backup shutdown signal is initiated, the power to both coils of the magnet is shut off, de-energizing the magnet, allowing the end of life shutdown torsion springs at the hinges to rotate each reflector half assembly away from the core. In the expected coolant inlet down orientation of the ground test, the center of gravity effect of each reflector half assists in the rotation away from the core. A snubber spring within the pneumatic reset cylinder cushions the reflector assembly at the end of the rotation. The thermal expansion spring, which mounts the magnet armature, acts as a secondary snubber.

To reset the reflector assembly for the reactor restart, each pneumatic reset cylinder is pressurized with inert gas to rotate the reflector half against the core vessel. Slight additional force compresses the expansion spring to permit contact between the magnet armature and the magnet face, establishing the magnetic latching. A limit switch is actuated when the reflector half is in the reset position. Upon depressurization of the pneumatic cylinder, the return spring within the cylinder repositions the piston to the ready-to-snub location. An indicator switch on the cylinder indicates when this piston position is reestablished. This signal is necessary, prior to reactor startup, to assure that each reflector assembly is capable of another backup shutdown operation.

The backup shutdown holding magnets are designed similar to the brake solenoid of the drive actuator, using the same materials and coil winding techniques. Each coil of the dual coil is designed to hold the reflector with adequate force margin. The reflector reset limit switch is identical to the control sector full out switch. The pneumatic cylinder is of commercial design, modified for the test environment. The snubber and return spring are designed for this application. The piston return switch is of the reed design. The magnets and the reset cylinders are mounted on the upper half of the ground test reactor support structure.

In the coolant inlet down orientation of the reactor during the ground test, the gravitational effect on the control sector is toward the more reactive direction. Normally, the actuator brake holds the control sector at its position except during stepping. The torque generated at the actuator rotor during stepping is adequate to raise or lower the sector against the gravitational pull. If, however, one or more actuator phase is inactive, and the stepping is initiated, the gravitational pull on the sector may cause it to move downward until

the stepping is completed and the brake is, again, mechanically applied. Such a failure of the actuator phase could be caused by the following malfunctions: open circuit in both coils of a phase, failure in the electrical cables between the controller and the actuator terminals, or malfunction of the controller. To preclude this possible incident, the weight of the control sector is counterbalanced. The normal flight anti-backlash springs between the fixed reflector and the sector are replaced with heavier anti-gravity springs. The force of these springs and the resulting net force on the sector are shown in Figure 11. As will be described in the next section, the counterbalancing action of these springs is sufficient to prevent inadvertent uncontrolled downward (inward) motion of the control sector in the event of actuator malfunction.

IV EXPECTED PERFORMANCE

A. Overall

The conceptual reflector system is designed to structurally withstand the launch environment and, subsequently operate for five years in space environment. Additionally, the system is capable of operation in the ground test environment of 10^{-5} Torr or less pressure and 1g gravity.

During reactor startup the actuators are stepped to move alternate sectors at selected rate(s) not exceeding one 7.2° step ($\sim 5\phi$) per second. Once the power operation is established, an actuator is stepped periodically only to maintain the power level or to change power level. This periodic actuator motion will continue until both sectors are moved to the full in position or the shutdown

signal is given.

In addition to the startup and periodic stepping, reactor scram (5¢/sec) by the rapid rotation of the actuator may be required during the ground test. The system design is capable of 50 such scrams and subsequent restart during the five year lifetime. The number of shut-downs employing the backup shutdown system is expected to be very limited. The possible limitation to the number of this type of shut-downs may be the flexing endurance of the electrical cables. This endurance has not been established, although tests are planned.

B. Control Sector Driving and Braking Torques

The torque required at the actuator rotor to position the control sector under the normal control mode is dependent on the net effective weight of the sector, bearing loads, the friction coefficient of the bearings, and the efficiencies of the ball screw and gear drives. As discussed previously, the friction coefficient of the bearings may vary over a wide range. An expected value of .35 was selected for performance predictions with .10 and .60 as the possible lower and upper limits. The expected torque requirements under the ground test and flight conditions are shown in Figures 12 and 13. The torque values for friction coefficients of .35 and .60 were based on the lowest expected ball screw efficiency of .70, while the highest expected efficiency of .90 was used with the friction coefficient of .10. The gear efficiency was maintained at 90% for all cases.

Control sector scram, during ground test only, will require movement toward the full out position. As noted in Figure 11, the maximum torque required to move the sector in this direction is approximately 66% of the maximum torque required to move the sector to full in. The expected torque output of S8DR type actuator at the scram speed of 6 RPM is approximately 70% of slow speed stepping

torque output. Thus, an actuator designed to meet the torque requirement to step the sector to full in has adequate torque capability for the scram requirement. The actuator torque requirements of 100 oz-in, during stepping and 70 oz-in, during scram were selected to allow approximately 33% margin over the maximum expected drive requirements.

As previously discussed, the actuator brake torque under the flight or ground test operation need only be sufficient to hold the control sector against acceleration or gravity effect on it between actuator stepping. During normal launch, the mechanical full out stops restrain the sector against the reaction to forward acceleration. However, in the inverted (reactor-down) launch, the actuator brake must lock the control sector against the launch acceleration generated forces. This torque was calculated using the minimum friction coefficient of 0.10, maximum drive screw efficiency of 0.90 and gear efficiency of 0.90. The stated 16.25 launch acceleration includes 25% margin. The actuator brake torque requirement of 180 oz-in. was selected to provide approximately 33% margin over the maximum expected requirements.

C. Control Sector Locking During Ground Test

As mentioned earlier, for ground testing the control sector anti-backlash springs are replaced with heavier anti-gravity springs. The drive torque requirement curves of Figure 12 show that positive actuator torque is required to drive the control sector in either direction if the coefficient of friction is .35 or .60. If the friction coefficient drops to .10, positive actuator torques are still required to move the sector in. When the sector is more than 50% in, the loss of any actuator braking will cause the sector to move outward to approximately the midpoint of travel. Thus, for this system, the control sector should not move

toward the more reactive position in the event of the postulated malfunction of the actuator, electrical cables, or controller. In fact, under normal conditions, the sector should remain at its position at the time of failure.

V REFERENCES

1. AI-AEC-72-16 AEC/NASA Review Reactor-Shield Subsystem, June 26-28, 1972
2. SS652N200001 Reactor Subsystem Specification - 5 Kwe Reactor-TE System, 6-2-72.

REACTOR ASSEMBLY

5 kwe TE SYSTEM

Figure 1

- NOTES: UNLESS OTHERWISE SPECIFIED ON THIS DRAWING
1. DWG INTERPRETATION PER ST015NAD019.
  2. MATERIAL CERTIFICATION REQUIRED.
  3. MACHINING PER ST010SNAD007 (WARD).
  4. ROUGH MACHINE THEN HEAT TREAT PER LACH11-DIS EXCEPT AS FOLLOWS:
A. SOLUTION TREAT AT 2100°F ± 25°F FOR 2 TO 4 HRS.
AIR COOL TO 400°F OR LOWER.
B. AGE AT 1550°F ± 25°F FOR 22 TO 24 HRS. AIR COOL TO 400°F OR LOWER.
C. AGE AT 1300°F ± 25°F FOR 18 TO 22 HRS. AIR COOL.
D. FINISH MACHINE.
E. STRESS RELIEVE AT 1300°F ± 25°F FOR 1 HR ± 5 MIN IN AIR.
  5. ULTRASONIC CLEAN PER AAD110-000 PRIOR TO COATING.
  6. COAT PER NAD116-016, TYPE II AL₂O₃.
  7. FINISH THE COATED SURFACE PER NAD121-001.
  8. TO REFINISH MACHINE AFTER APPLICATION OF COATING TO SPHERICAL SURFACE.
  9. DIAMETER TOLERANCE INCLUDES MISMATCH BETWEEN SOCKET HALVES.
  10. VAPOR DEGREASS, VAPOR ONLY, PER ST010NAD010 AFTER FABRICATION.
  11. RETAIN 1/16" MATCHED SET AND FURNISH ONLY AS A MATCHED SET.
  12. HAND BURNISH BALL WITH MoS₂ TREATED NON-LINTING CLOTH TO OBTAIN 100% COVERAGE OF ALL SURFACES WITH MoS₂. REMOVE EXCESS POWDER BY BLOWING WITH CLEAN DRY AIR.
  13. AFTER COATING OF THE BALL PER NOTE 12 THE MEASURED DIAMETRAL CLEARANCE BETWEEN THE BALL AND SOCKET (MEASURED TO THE AXIS OF SOCKET HO) SHALL BE WITHIN .0015" - .0024".
  14. ALL LUBRICATION, ASSEMBLY & IDENTIFICATION OPERATIONS TO BE CONDUCTED IN A CLEAN AREA WITH NON-LINTING GLOVES.
  15. IDENTIFY BY ELECTROCHEMICAL ETCHING PER NAD104-001.
  16. IDENTIFY PART NO. AND SERIAL NO. BY TAGG110.
  17. SERIALIZE FOR LIMITED TRACEABILITY PER NAD104-003.
  18. PACKAGE PARTS OR ASSY'S FOR SHIPMENT OR STORAGE PER NAD116-001, UNIT PROTECTION METHOD 1A-8.
  19. FABRICATE PER

QTY	REQD	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL	DATA SPECIFICATIONS, SIZES, NOTES, VENDORS	LINE NO.
1		D3-250	DRIFTEL PIN		MoS ₂ POWDER	MIL-881-7866 (1/1)	010
1		05	BALL		303 CRES.	PRECISION BALL BEARING	011
1		04	SOCKET HALF		INCOCEL X-750 BAR	AMS 5667	012
1		03	SOCKET HALF		INCOCEL X-750 BAR	AMS 5667	013
1		02	SOCKET SUBASSY				014
1		01	ASSY				015

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES.

DECIMALS: ANGLES: FRACTIONS:
 .001 = .001   .005 = .005   .010 = .010   .015 = .015   .020 = .020   .025 = .025   .030 = .030   .035 = .035   .040 = .040   .045 = .045   .050 = .050   .055 = .055   .060 = .060   .065 = .065   .070 = .070   .075 = .075   .080 = .080   .085 = .085   .090 = .090   .095 = .095   .100 = .100   .105 = .105   .110 = .110   .115 = .115   .120 = .120   .125 = .125   .130 = .130   .135 = .135   .140 = .140   .145 = .145   .150 = .150   .155 = .155   .160 = .160   .165 = .165   .170 = .170   .175 = .175   .180 = .180   .185 = .185   .190 = .190   .195 = .195   .200 = .200   .205 = .205   .210 = .210   .215 = .215   .220 = .220   .225 = .225   .230 = .230   .235 = .235   .240 = .240   .245 = .245   .250 = .250   .255 = .255   .260 = .260   .265 = .265   .270 = .270   .275 = .275   .280 = .280   .285 = .285   .290 = .290   .295 = .295   .300 = .300   .305 = .305   .310 = .310   .315 = .315   .320 = .320   .325 = .325   .330 = .330   .335 = .335   .340 = .340   .345 = .345   .350 = .350   .355 = .355   .360 = .360   .365 = .365   .370 = .370   .375 = .375   .380 = .380   .385 = .385   .390 = .390   .395 = .395   .400 = .400   .405 = .405   .410 = .410   .415 = .415   .420 = .420   .425 = .425   .430 = .430   .435 = .435   .440 = .440   .445 = .445   .450 = .450   .455 = .455   .460 = .460   .465 = .465   .470 = .470   .475 = .475   .480 = .480   .485 = .485   .490 = .490   .495 = .495   .500 = .500   .505 = .505   .510 = .510   .515 = .515   .520 = .520   .525 = .525   .530 = .530   .535 = .535   .540 = .540   .545 = .545   .550 = .550   .555 = .555   .560 = .560   .565 = .565   .570 = .570   .575 = .575   .580 = .580   .585 = .585   .590 = .590   .595 = .595   .600 = .600   .605 = .605   .610 = .610   .615 = .615   .620 = .620   .625 = .625   .630 = .630   .635 = .635   .640 = .640   .645 = .645   .650 = .650   .655 = .655   .660 = .660   .665 = .665   .670 = .670   .675 = .675   .680 = .680   .685 = .685   .690 = .690   .695 = .695   .700 = .700   .705 = .705   .710 = .710   .715 = .715   .720 = .720   .725 = .725   .730 = .730   .735 = .735   .740 = .740   .745 = .745   .750 = .750   .755 = .755   .760 = .760   .765 = .765   .770 = .770   .775 = .775   .780 = .780   .785 = .785   .790 = .790   .795 = .795   .800 = .800   .805 = .805   .810 = .810   .815 = .815   .820 = .820   .825 = .825   .830 = .830   .835 = .835   .840 = .840   .845 = .845   .850 = .850   .855 = .855   .860 = .860   .865 = .865   .870 = .870   .875 = .875   .880 = .880   .885 = .885   .890 = .890   .895 = .895   .900 = .900   .905 = .905   .910 = .910   .915 = .915   .920 = .920   .925 = .925   .930 = .930   .935 = .935   .940 = .940   .945 = .945   .950 = .950   .955 = .955   .960 = .960   .965 = .965   .970 = .970   .975 = .975   .980 = .980   .985 = .985   .990 = .990   .995 = .995   1.000 = 1.000   1.005 = 1.005   1.010 = 1.010   1.015 = 1.015   1.020 = 1.020   1.025 = 1.025   1.030 = 1.030   1.035 = 1.035   1.040 = 1.040   1.045 = 1.045   1.050 = 1.050   1.055 = 1.055   1.060 = 1.060   1.065 = 1.065   1.070 = 1.070   1.075 = 1.075   1.080 = 1.080   1.085 = 1.085   1.090 = 1.090   1.095 = 1.095   1.100 = 1.100   1.105 = 1.105   1.110 = 1.110   1.115 = 1.115   1.120 = 1.120   1.125 = 1.125   1.130 = 1.130   1.135 = 1.135   1.140 = 1.140   1.145 = 1.145   1.150 = 1.150   1.155 = 1.155   1.160 = 1.160   1.165 = 1.165   1.170 = 1.170   1.175 = 1.175   1.180 = 1.180   1.185 = 1.185   1.190 = 1.190   1.195 = 1.195   1.200 = 1.200   1.205 = 1.205   1.210 = 1.210   1.215 = 1.215   1.220 = 1.220   1.225 = 1.225   1.230 = 1.230   1.235 = 1.235   1.240 = 1.240   1.245 = 1.245   1.250 = 1.250   1.255 = 1.255   1.260 = 1.260   1.265 = 1.265   1.270 = 1.270   1.275 = 1.275   1.280 = 1.280   1.285 = 1.285   1.290 = 1.290   1.295 = 1.295   1.300 = 1.300   1.305 = 1.305   1.310 = 1.310   1.315 = 1.315   1.320 = 1.320   1.325 = 1.325   1.330 = 1.330   1.335 = 1.335   1.340 = 1.340   1.345 = 1.345   1.350 = 1.350   1.355 = 1.355   1.360 = 1.360   1.365 = 1.365   1.370 = 1.370   1.375 = 1.375   1.380 = 1.380   1.385 = 1.385   1.390 = 1.390   1.395 = 1.395   1.400 = 1.400   1.405 = 1.405   1.410 = 1.410   1.415 = 1.415   1.420 = 1.420   1.425 = 1.425   1.430 = 1.430   1.435 = 1.435   1.440 = 1.440   1.445 = 1.445   1.450 = 1.450   1.455 = 1.455   1.460 = 1.460   1.465 = 1.465   1.470 = 1.470   1.475 = 1.475   1.480 = 1.480   1.485 = 1.485   1.490 = 1.490   1.495 = 1.495   1.500 = 1.500   1.505 = 1.505   1.510 = 1.510   1.515 = 1.515   1.520 = 1.520   1.525 = 1.525   1.530 = 1.530   1.535 = 1.535   1.540 = 1.540   1.545 = 1.545   1.550 = 1.550   1.555 = 1.555   1.560 = 1.560   1.565 = 1.565   1.570 = 1.570   1.575 = 1.575   1.580 = 1.580   1.585 = 1.585   1.590 = 1.590   1.595 = 1.595   1.600 = 1.600   1.605 = 1.605   1.610 = 1.610   1.615 = 1.615   1.620 = 1.620   1.625 = 1.625   1.630 = 1.630   1.635 = 1.635   1.640 = 1.640   1.645 = 1.645   1.650 = 1.650   1.655 = 1.655   1.660 = 1.660   1.665 = 1.665   1.670 = 1.670   1.675 = 1.675   1.680 = 1.680   1.685 = 1.685   1.690 = 1.690   1.695 = 1.695   1.700 = 1.700   1.705 = 1.705   1.710 = 1.710   1.715 = 1.715   1.720 = 1.720   1.725 = 1.725   1.730 = 1.730   1.735 = 1.735   1.740 = 1.740   1.745 = 1.745   1.750 = 1.750   1.755 = 1.755   1.760 = 1.760   1.765 = 1.765   1.770 = 1.770   1.775 = 1.775   1.780 = 1.780   1.785 = 1.785   1.790 = 1.790   1.795 = 1.795   1.800 = 1.800   1.805 = 1.805   1.810 = 1.810   1.815 = 1.815   1.820 = 1.820   1.825 = 1.825   1.830 = 1.830   1.835 = 1.835   1.840 = 1.840   1.845 = 1.845   1.850 = 1.850   1.855 = 1.855   1.860 = 1.860   1.865 = 1.865   1.870 = 1.870   1.875 = 1.875   1.880 = 1.880   1.885 = 1.885   1.890 = 1.890   1.895 = 1.895   1.900 = 1.900   1.905 = 1.905   1.910 = 1.910   1.915 = 1.915   1.920 = 1.920   1.925 = 1.925   1.930 = 1.930   1.935 = 1.935   1.940 = 1.940   1.945 = 1.945   1.950 = 1.950   1.955 = 1.955   1.960 = 1.960   1.965 = 1.965   1.970 = 1.970   1.975 = 1.975   1.980 = 1.980   1.985 = 1.985   1.990 = 1.990   1.995 = 1.995   2.000 = 2.000   2.005 = 2.005   2.010 = 2.010   2.015 = 2.015   2.020 = 2.020   2.025 = 2.025   2.030 = 2.030   2.035 = 2.035   2.040 = 2.040   2.045 = 2.045   2.050 = 2.050   2.055 = 2.055   2.060 = 2.060   2.065 = 2.065   2.070 = 2.070   2.075 = 2.075   2.080 = 2.080   2.085 = 2.085   2.090 = 2.090   2.095 = 2.095   2.100 = 2.100   2.105 = 2.105   2.110 = 2.110   2.115 = 2.115   2.120 = 2.120   2.125 = 2.125   2.130 = 2.130   2.135 = 2.135   2.140 = 2.140   2.145 = 2.145   2.150 = 2.150   2.155 = 2.155   2.160 = 2.160   2.165 = 2.165   2.170 = 2.170   2.175 = 2.175   2.180 = 2.180   2.185 = 2.185   2.190 = 2.190   2.195 = 2.195   2.200 = 2.200   2.205 = 2.205   2.210 = 2.210   2.215 = 2.215   2.220 = 2.220   2.225 = 2.225   2.230 = 2.230   2.235 = 2.235   2.240 = 2.240   2.245 = 2.245   2.250 = 2.250   2.255 = 2.255   2.260 = 2.260   2.265 = 2.265   2.270 = 2.270   2.275 = 2.275   2.280 = 2.280   2.285 = 2.285   2.290 = 2.290   2.295 = 2.295   2.300 = 2.300   2.305 = 2.305   2.310 = 2.310   2.315 = 2.315   2.320 = 2.320   2.325 = 2.325   2.330 = 2.330   2.335 = 2.335   2.340 = 2.340   2.345 = 2.345   2.350 = 2.350   2.355 = 2.355   2.360 = 2.360   2.365 = 2.365   2.370 = 2.370   2.375 = 2.375   2.380 = 2.380   2.385 = 2.385   2.390 = 2.390   2.395 = 2.395   2.400 = 2.400   2.405 = 2.405   2.410 = 2.410   2.415 = 2.415   2.420 = 2.420   2.425 = 2.425   2.430 = 2.430   2.435 = 2.435   2.440 = 2.440   2.445 = 2.445   2.450 = 2.450   2.455 = 2.455   2.460 = 2.460   2.465 = 2.465   2.470 = 2.470   2.475 = 2.475   2.480 = 2.480   2.485 = 2.485   2.490 = 2.490   2.495 = 2.495   2.500 = 2.500   2.505 = 2.505   2.510 = 2.510   2.515 = 2.515   2.520 = 2.520   2.525 = 2.525   2.530 = 2.530   2.535 = 2.535   2.540 = 2.540   2.545 = 2.545   2.550 = 2.550   2.555 = 2.555   2.560 = 2.560   2.565 = 2.565   2.570 = 2.570   2.575 = 2.575   2.580 = 2.580   2.585 = 2.585   2.590 = 2.590   2.595 = 2.595   2.600 = 2.600   2.605 = 2.605   2.610 = 2.610   2.615 = 2.615   2.620 = 2.620   2.625 = 2.625   2.630 = 2.630   2.635 = 2.635   2.640 = 2.640   2.645 = 2.645   2.650 = 2.650   2.655 = 2.655   2.660 = 2.660   2.665 = 2.665   2.670 = 2.670   2.675 = 2.675   2.680 = 2.680   2.685 = 2.685   2.690 = 2.690   2.695 = 2.695   2.700 = 2.700   2.705 = 2.705   2.710 = 2.710   2.715 = 2.715   2.720 = 2.720   2.725 = 2.725   2.730 = 2.730   2.735 = 2.735   2.740 = 2.740   2.745 = 2.745   2.750 = 2.750   2.755 = 2.755   2.760 = 2.760   2.765 = 2.765   2.770 = 2.770   2.775 = 2.775   2.780 = 2.780   2.785 = 2.785   2.790 = 2.790   2.795 = 2.795   2.800 = 2.800   2.805 = 2.805   2.810 = 2.810   2.815 = 2.815   2.820 = 2.820   2.825 = 2.825   2.830 = 2.830   2.835 = 2.835   2.840 = 2.840   2.845 = 2.845   2.850 = 2.850   2.855 = 2.855   2.860 = 2.860   2.865 = 2.865   2.870 = 2.870   2.875 = 2.875   2.880 = 2.880   2.885 = 2.885   2.890 = 2.890   2.895 = 2.895   2.900 = 2.900   2.905 = 2.905   2.910 = 2.910   2.915 = 2.915   2.920 = 2.920   2.925 = 2.925   2.930 = 2.930   2.935 = 2.935   2.940 = 2.940   2.945 = 2.945   2.950 = 2.950   2.955 = 2.955   2.960 = 2.960   2.965 = 2.965   2.970 = 2.970   2.975 = 2.975   2.980 = 2.980   2.985 = 2.985   2.990 = 2.990   2.995 = 2.995   3.000 = 3.000   3.005 = 3.005   3.010 = 3.010   3.015 = 3.015   3.020 = 3.020   3.025 = 3.025   3.030 = 3.030   3.035 = 3.035   3.040 = 3.040   3.045 = 3.045   3.050 = 3.050   3.055 = 3.055   3.060 = 3.060   3.065 = 3.065   3.070 = 3.070   3.075 = 3.075   3.080 = 3.080   3.085 = 3.085   3.090 = 3.090   3.095 = 3.095   3.100 = 3.100   3.105 = 3.105   3.110 = 3.110   3.115 = 3.115   3.120 = 3.120   3.125 = 3.125   3.130 = 3.130   3.135 = 3.135   3.140 = 3.140   3.145 = 3.145   3.150 = 3.150   3.155 = 3.155   3.160 = 3.160   3.165 = 3.165   3.170 = 3.170   3.175 = 3.175   3.180 = 3.180   3.185 = 3.185   3.190 = 3.190   3.195 = 3.195   3.200 = 3.200   3.205 = 3.205   3.210 = 3.210   3.215 = 3.215   3.220 = 3.220   3.225 = 3.225   3.230 = 3.230   3.235 = 3.235   3.240 = 3.240   3.245 = 3.245   3.250 = 3.250   3.255 = 3.255   3.260 = 3.260   3.265 = 3.265   3.270 = 3.270   3.275 = 3.275   3.280 = 3.280   3.285 = 3.285   3.290 = 3.290   3.295 = 3.295   3.300 = 3.300   3.305 = 3.305   3.310 = 3.310   3.315 = 3.315   3.320 = 3.320   3.325 = 3.325   3.330 = 3.330   3.335 = 3.335   3.340 = 3.340   3.345 = 3.345   3.350 = 3.350   3.355 = 3.355   3.360 = 3.360   3.365 = 3.365   3.370 = 3.370   3.375 = 3.375   3.380 = 3.380   3.385 = 3.385   3.390 = 3.390   3.395 = 3.395   3.400 = 3.400   3.405 = 3.405   3.410 = 3.410   3.415 = 3.415   3.420 = 3.420   3.425 = 3.425   3.430 = 3.430   3.435 = 3.435   3.440 = 3.440   3.445 = 3.445   3.450 = 3.450   3.455 = 3.455   3.460 = 3.460   3.465 = 3.465   3.470 = 3.470   3.475 = 3.475   3.480 = 3.480   3.485 = 3.485   3.490 = 3.490   3.495 = 3.495   3.500 = 3.500   3.505 = 3.505   3.510 = 3.510   3.515 = 3.515   3.520 = 3.520   3.525 = 3.525   3.530 = 3.530   3.535 = 3.535   3.540 = 3.540   3.545 = 3.545   3.550 = 3.550   3.555 = 3.555   3.560 = 3.560   3.565 = 3.565   3.570 = 3.570   3.575 = 3.575   3.580 = 3.580   3.585 = 3.585   3.590 = 3.590   3.595 = 3.595   3.600 = 3.600   3.605 = 3.605   3.610 = 3.610   3.615 = 3.615   3.620 = 3.620   3.625 = 3.625   3.630 = 3.630   3.635 = 3.635   3.640 = 3.640   3.645 = 3.645   3.650 = 3.650   3.655 = 3.655   3.660 = 3.660   3.665 = 3.665   3.670 = 3.670   3.675 = 3.675   3.680 = 3.680   3.685 = 3.685   3.690 = 3.690   3.695 = 3.695   3.700 = 3.700   3.705 = 3.705   3.710 = 3.710   3.715 = 3.715   3.720 = 3.720   3.725 = 3.725   3.730 = 3.730   3.735 = 3.735   3.740 = 3.740   3.745 = 3.745   3.750 = 3.750   3.755 = 3.755   3.760 = 3.760   3.765 = 3.765   3.770 = 3.770   3.775 = 3.775   3.780 = 3.780   3.785 = 3.785   3.790 = 3.790   3.795 = 3.795   3.800 = 3.800   3.805 = 3.805   3.810 = 3.810   3.815 = 3.815   3.820 = 3.820   3.825 = 3.825   3.830 = 3.830   3.835 = 3.835   3.840 = 3.840   3.845 = 3.845

CARBON-GRAPHITE vs ALUMINA FRICTION (DYNAMIC)

Figure 15

72JU7-2-67

HIGH TEMP BALL SCREW EXPERIENCE

<u>TEST</u>	<u>DESIGN</u>	<u>EXPERIENCE</u>
NASA LITHIUM VALVE LOOP (G.E.)	17-4 PH NUT. HIPERCUT SCREW WC-6Co BALL 3/8 DIA X 1/8 LEAD NO LUBE	5,000 HR AT $\sim 800^{\circ}\text{F}$ IN 10^{-7} TORR 500-1000 HR DWELL UNDER ~ 1000 AXIAL LOAD. 95 CYCLES (3 TURNS) ON 1 UNIT 600 CYCLES (1-3 TURNS) ON 1 UNIT
NASA Nb-IZr CORROSION LOOP (G.E.)	SAME AS ABOVE	2 UNIT USED TO CONTROL THROTTLE VALVE DURING 10K HR TEST $> 500^{\circ}\text{F}$, 10^{-7} TORR
CONCORDE JET SILENCER DR. (AIR-RESEARCH)	Ni PLATED H-11 NUT & SCREW WC-6Co BALL 3/4 DIA X 1/16 LEAD X-15 DRY LUBE	4000 CYCLES (~ 48 TURNS) UNDER 1700 LB. LOAD (~ 90 HR) 450F IN AIR. EFF $\sim 93\%$ (INIT) - 88% (FINAL)
FFTF IVHM DRIVE (LMEC)	INCONEL-718 NUT & SCREW. STELLITE STAR-J BALL 2-7/8 DIA X .66 LEAD	SOAKED IN 1100F SODIUM AND OPERATED AT 450F UNDER 1450 LB & HIGHER LOADS

Figure 6

72-JU21-2-207

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
	EO 57965		

NOTES: UNLESS OTHERWISE SPECIFIED ON THIS DRAWING

1. DREW. INTERPRETATION PER STOISNA0019.
1. COAT WITH Al_2O_3 PER NBO115-016, TYPE II, AFTER FINAL STRESS RELIEF. FINISH PER NAO121-001 TO FINAL REQUIREMENTS.
2. SPUTTER COAT $4,000 \pm 400$ ANGSTROM MOS_2 PER VARIAN ASSOCIATE SPEC 12472 DEN, OR EQUIV, TO ALL CONTACTING SURFACES. APPLY BONDED MOS_2 PER NAO112-008, TYPE I, OR EQUIV, TO NUT I.D. & SCREW O.D. ASSEMBLE BALL SCREW & OPERATE OVER FULL TRAVEL TO WEAR IN " DRY LUBRICANT. REMOVE ALL LOOSE LUBRICANT.
4. PACKAGE PER NAO116-001, METHOD IIB, OR EQUIV.
5. DO NOT ULTRASONIC CLEAN AFTER Al_2O_3 COATING.

DESIGN REQUIREMENTS

1. GEOMETRY:

BALL CIRCLE DIA	.750
BALL DIA	.187 MIN
BALL GROOVE	CIRCULAR ARC
NO. OF GROOVES	2
GROOVE LEAD	.750 R.H.
NO. OF BALL CIRCUITS	2
URNS PER CIRCUIT	1.5 TO 1.8

2. MATERIALS:

NUT & SCREW	INCONEL-718 (HYPERCUT-ALTERNATE)
BALL	WC-6MO (STELLITE-ALTERNATE)
RETURN TUBE	CORROSION & HEAT RESISTANT ALLOY
② LUBRICANT	SPUTTERED MOS. (BONDED MOS.-ALTERNATE)

FOR INFORMATION
WILL NOT BE REPLACED AND MAY
BE CHANGED WITHOUT NOTICE

ENVELOPE CONTROL DRAWING

					005
					004
					003
					002
	EX-N65220031-01	BALLSCREW ASSY			001
QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	DATA: SPECIFICATIONS SIZES, NOTES, VENDORS	LINE NO.

PARTS LIST

			UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES			PARTS LIST		
			TOLERANCES ON DECIMALS ANGLES FRACTIONS JGX = ± .03 JGX = ± .010 ± 30° ± 32			Aerospace International North American Division P. O. Box 107 / Group Park, California 95020		
			DO NOT SCALE PRINT			DR BY <u>R HORTON</u> <u>6-10-72</u>		
			HOLES NOTED "DRILL"			CHK BY <u>W/ [signature]</u>		
			.013 THRU .040 + .001 - .001					
			.041 THRU .130 + .002 - .001					
			.131 THRU .229 + .003 - .001					
			.230 THRU .500 + .004 - .001					
			.501 THRU .750 + .005 - .001					
			.751 THRU 1.000 + .005 - .001					
			1.001 THRU 2.000 + .010 - .001					
DASH NO.			NEXT USING DWG.			M & P <u>W.H. Zinke</u> <u>7/7/72</u>		
MODEL			APPLICATION			STRESS		
						SIZE CODE IDENT NO. DRAWING NO. <u>D</u> <u>09974</u> <u>EX-N652220031</u>		
						SCALE SHEET		

DESIGN REQUIREMENTS (CONTD)

3. STATIC (LAUNCH) PERFORMANCE

TEMPERATURE	40F TO 250F
ENVIRONMENT	AIR (80% R.H.) TO 10 ⁻³ TORR
LIFE	3 MINUTES
AXIAL LOAD	500 LB
OVER TURNING LOAD	550 IN-LB
SCREW ROTATION	STATIONARY (LOCKED)

4. DYNAMIC PERFORMANCE

TEMPERATURE	40F TO 800F
ENVIRONMENT	$\leq 10^{-5}$ TORR (AIR)
LIFE	44,000 HOURS
AXIAL LOAD	30 LB
OVER TURNING LOAD	30 IN-LB
SCREW ROTATION	200 CYCLES OF 16 TURNS
EFFICIENCY	80% MIN

VIEW A
NO SCALE

VIEW B
NO SCALE

AXIAL SPRING FORCE ON CONTROL SECTOR (FLIGHT)

Figure 8

Figure 9

Figure 10

REV	DATE	BY	CHKD	APP'D
1	10/1/65	J. J. J.	J. J. J.	J. J. J.
2	10/1/65	J. J. J.	J. J. J.	J. J. J.
3	10/1/65	J. J. J.	J. J. J.	J. J. J.
4	10/1/65	J. J. J.	J. J. J.	J. J. J.
5	10/1/65	J. J. J.	J. J. J.	J. J. J.
6	10/1/65	J. J. J.	J. J. J.	J. J. J.
7	10/1/65	J. J. J.	J. J. J.	J. J. J.
8	10/1/65	J. J. J.	J. J. J.	J. J. J.
9	10/1/65	J. J. J.	J. J. J.	J. J. J.
10	10/1/65	J. J. J.	J. J. J.	J. J. J.
11	10/1/65	J. J. J.	J. J. J.	J. J. J.
12	10/1/65	J. J. J.	J. J. J.	J. J. J.
13	10/1/65	J. J. J.	J. J. J.	J. J. J.
14	10/1/65	J. J. J.	J. J. J.	J. J. J.
15	10/1/65	J. J. J.	J. J. J.	J. J. J.
16	10/1/65	J. J. J.	J. J. J.	J. J. J.
17	10/1/65	J. J. J.	J. J. J.	J. J. J.
18	10/1/65	J. J. J.	J. J. J.	J. J. J.
19	10/1/65	J. J. J.	J. J. J.	J. J. J.
20	10/1/65	J. J. J.	J. J. J.	J. J. J.
21	10/1/65	J. J. J.	J. J. J.	J. J. J.
22	10/1/65	J. J. J.	J. J. J.	J. J. J.
23	10/1/65	J. J. J.	J. J. J.	J. J. J.
24	10/1/65	J. J. J.	J. J. J.	J. J. J.

AXIAL FORCES ON CONTROL SECTOR (GND TEST)

CONTROL SECTOR DRIVE TORQUE (GND TEST)

Figure 12

REFLECTOR DRIVE TORQUE

FLIGHT $g = +1.0$

Figure 13

TORQUE TO HOLD CONTROL SECTOR

Figure 14