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GIMBAL-ASSEMBLY SUBSYSTEM

NERVA Program

Contract SNP-1

December 1969

MASTER

NUCLEAR ROCKET OPERATIONS

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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RN-DR-0183

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GIMBAL-ASSEMBLY SUBSYSTEM

NERVA Program

Contract SNP-1

NUCLEAR ROCKET OPERATIONS

December 1969

CLASSIFICATION CATEGORY

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W. E. Stephens
CLASSIFYING OFFICER

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AEROJET-GENERAL CORPORATION
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I. PURPOSE

This document is one of a series of Departmental Reports which will document NERVA design and performance requirements at engine, subsystem, and component levels. These reports are intended to provide a single source for maintenance and documentation of design criteria and functional performance requirements, and may be used to display a continual assessment of overall design maturity. They also provide the basic data for component specification preparation, and will be used to document traceability of all design and performance criteria.

These reports will be revised and updated periodically to incorporate significant new design and/or performance requirements.

II. DESIGN REQUIREMENTS SHEETS

The Design Requirements Sheets in this document cover the

GIMBAL ASSEMBLY SUBSYSTEM

as described in the NERVA Engine Specification Tree, AGC Drawing 1137101, "E" Change. The sheets are organized into two principle categories: Section 1.0 provides design requirements criteria generated externally (e.g., environments) to the component; Sections 2.0 through 6.0 provide component functional performance requirements for steady state, startup, throttling, shutdown, and cooldown operations. Requirements are provided for both nominal and malfunction performance conditions.

DESIGN REQUIREMENTS SHEETS

Appended hereto are design criteria and functional performance requirements for the

GIMBAL ASSEMBLY SUBSYSTEM

EC-90244

The following data are included in this issue:

	<u>Sheet</u>	<u>Revision</u>
1.0 Design Criteria		
1.1 Reliability Allocation	1	0
1.2 Maintainability	2	0
1.3 Useful Life	3	0
1.4 Nuclear Environment	4	0
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1.6 Natural Environment	6	0
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1.8 Mechanical Interfaces	8	0
1.9 Electrical Interfaces	9	0
1.10 Functional Interfaces	10	0
1.11 Handling & Shipping	11	0
1.12 Test & Checkout	12	0
1.13 Static Loads	13	0
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1.15 Envelop Dimensions	15	0
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2.0 Steady State Functional Performance	18	0
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Date: 12-3-69

Rev: 0

Sheet: 1

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC-90244)

DATA SOURCE: Memorandum 7850:M0346, Mihanovich to Varga

1.1 Reliability Allocation

The probability that this component shall successfully fulfill its operating requirements shall be 0.999984 or greater.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC90244)

DATA SOURCE: Interpretation of NPRD-1 Revision 6 (draft) and engineering evaluation by Klacking/Shoemaker

1.2 Maintainability

The Gimbal assembly subsystem shall be designed to incorporate the maintainability requirements of the engine. (See, Sheet 2 of RN-DR-0187). The following time limitations shall be met: (a) Repair Time - the time required to repair shall not exceed (2.0) hours. (b) Active Maintenance Time - the maximum time required for preventive and corrective maintenance shall not exceed 0.1 man hours per hour during engine assembly and operations.

1.2.1 Maintenance and repair cycles.

1.2.1.1. Periodic maintenance shall not be required during storage.

1.2.1.2 Periodic maintenance or repair shall not be used to attain specified reliability or operating life requirements.

1.2.2 Service and access

1.2.2.1 The Gimbal assembly subsystem shall be designed so manual maintenance and repair, including parts replacement can be accomplished with standard hand tools.

1.2.2.2 Gimbal assembly subsystem shall be physically interchangeable without adjustment or modification of mating engine components.

Date: 12-3-69
Rev: 0
Sheet: 3

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC-90244)

DATA SOURCE: NPRD-1 Revision 6 (Draft)
Dept. 7810 Interpretation of NPRD-1
and Engineering Estimate - Froelich/Paavola. Engineering
estimate based on Apollo data by R. W. Thomas, Dept. 7770

1.3 Useful Life

The Gimbal Assembly Subsystem
shall be capable of satisfying the minimum useful life of the
NERVA Engine, allocated as follows:

1.3.1	Rated Operating Life	600 minutes
(maximum of 60 cycles)
1.3.2	Non-Rated Operating Life
(Transients and In-Flight Checkout)	72 days
1.3.3	Non-Operating Life	
1.3.3.1	Engine Assembly to Launch Pad
(Less Storage)	6 months
1.3.3.2	Launch Pad Environment	6 months
1.3.3.3	Space Storage Conditions	3 years
(Including Operational
Life)
1.3.4	Storage Life (Ground)	5 years
1.3.5	Cycle and Energize Life	

<u>Condition</u>	<u>Total Cycles</u>	<u>Total Energized Time, Hr.</u>
Prelaunch	100	5
In-Flight Checkout	100	5
In Flight Operating	300	10

- NOTE: 1) Cycles are accrued during energized time
2) In-Flight checkout includes both during and
between missions.

DATE: 12-3-69
REV: 0
SHEET: 4

DESIGN REQUIREMENT SHEET

Component: Gimbal Assembly Subsystem (EC-90244)

Data Source: Engineering judgement based on analyses of an idealist configuration -- Dept 7830 - E. Warman

1.4 Nuclear Environment

Description	Location(In) Station R		γ Kerma Rate Rads/Hr	γ Kerma Rate Rads (10 Hr Exp)	γ Heating Rate Btu/in ³ -sec	Thermal Neutron		Fast Neutron		Epi Thermal	
						Flux n/cm ² -sec	Nvt n/cm ²	Flux n/cm ² -sec	Nvt n/cm ²	Flux n/cm ² -sec	Nvt n/cm ²
	23.0	6.5	2.0+6	2.0+7	2.4-4	9.3+8	3.3+13	1.4+11	5.1+15	2.0+11	7.2+15
	23.0	0.0	2.0+6	2.0+7	2.4-4	9.5+8	3.4+13	1.4+11	5.2+15	2.0+11	7.0+15
	29.0	2.6	2.1+6	2.1+7	2.7-4	9.8+8	3.5+13	1.5+11	5.4+15	2.1+11	7.6+15
	16.8	3.3	1.8+6	1.8+7	2.3-4	8.6+8	3.1+13	1.3+11	4.8+15	1.8+11	6.5+15
				ETS-1							
	23.0	6.5	3.4+6		4.1-4			1.8+11			
	23.0	0.0	3.4+6		4.1-4			1.9+11			
	29.0	2.6	3.5+6		4.4-4			1.9+11			
	16.8	3.3	3.2+6		4.0-4			1.7+11			

DESIGN REQUIREMENT SHEET

COMPONENT: GIMBAL ASSEMBLY SUBSYSTEM (EC-90244)

DATA SOURCE: K. Sato, Dept. 7730

1.5 Thermal Environment

Data not available at this time

Date: 12-3-69
Rev: 0
Sheet: 6

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC-90244)

DATA SOURCE: NERVA Engine Natural Environment Report Data Item
S023-CP090194-F1 - S. A. Varga, Dept. 7810

1.6 Natural Environment

The natural environments to which the component will be exposed are as specified in Table 1.6-1. The tables and figures referenced within Table 1.6-1 are presented in the Reference Data Section of this document.

Table 1.6-1
NATURAL ENVIRONMENTS SUMMARY

Phase Environment	Space Operations	Flight Vehicle Boost	Vehicle Assembly and Checkout Prelaunch and Launch Operations
Altitude - Miles	262 to 210,000 N. miles	Sea Level to 262 N. miles	Sea Level
Atmospheric pressure, psia	2×10^{-12} at 262 N.M.	Pressure - Altitude profiles established by Figures 1 and 2	Min 14.4, max 15.0 $\Delta P = 0.04 \text{ lb/in}^2$ in 24 hr. $\Delta P_{\text{max}} = -.09 \text{ lb/in}^2$ in 1 hr
Atmospheric temperature (Kinetic) °R	2700°R at 262 N.M.	See Figure 3 for nominal profile	Min: 488 Max: 559 (NTR Values)
Atmospheric Density - lb/ft^3	1×10^{-13} at 262 N.M.	Density - Altitude profiles established by Figures 1 and 2	Min: 7.12×10^{-2} Max: 8.27×10^{-2}
Atmospheric composition	See Figure 4	As established from Figure 4 and Table 2.	See Table 2
Atmospheric humidity	Negligible	Max vapor concentration at launch: $11.8 \text{ gr H}_2\text{O/ft}^3$	Extreme: 100% rh @ 73°F for 6 hrs, 75% rh @ 82°F for 18 hrs, 15 day cycle
Solar radiation - $\text{Btu/ft}^2/\text{hr}$	442.4	N.A.	TBD
Rain	N.A.	N.A.	See Table 8
Snow	N.A.	N.A.	N.A.
Solar Radio Noise	N.A.	N.A.	N.A.

Table 1.6-2

2 of 2

Phase			
Environment	Space Operations	Flight Vehicle Boost	Vehicle Assembly and Checkout Prelaunch and Launch Operations
Wind, ft/sec	N.A.	N.A.	See Table 9
Sand and dust	N.A.	N.A.	See Table 3
Salt Spray	N.A.	N.A.	See Table 4
Fungi and bacteria	N.A.	TBD	TBD
Atmospheric electricity	N.A.	N.A.	See Table 5
Seismic environment	N.A.	N.A.	TBD
Magnetic field avg. total gauss, max	0.53	0.53	0.52
Meteoroids	See Figures 5 and 6. Meteoroid Mass density 0.5 gm/cm ³	N.A.	N.A.
Radiation - high energy particle	See Table 6	Negligible	N.A.
Radiation - trapped	See Figures 7 and 8	Negligible	N.A.
Radiation - ultraviolet and X-ray	See Table 7	Negligible	N.A.
Radiation - earth thermal avg., $\bar{E}$, Btu/ft ² /hr	$\bar{E} = 68.4 \left(\frac{3,963}{3,963 + \text{alt}} \right)^2$ alt = altitude location in miles	N.A.	N.A.
Radiation - earth albedo avg., $\bar{a}_E$, Btu/ft ² /hr	$\bar{a}_E = 173.4 \left(\frac{3,963}{3,963 + \text{alt}} \right)^2$	N.A.	N.A.
Ionosphere - ionized electron density - N/in. ³	N.A.	N.A.	N.A.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assy Subsystem (EC90244)

DATA SOURCE: Engineering evaluation by Klacking/Krivanec, Dept. 7840

1.7 Dimensional Interfaces

Detailed dimensional interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process.).

DATE: 12-3-69
REV: 0
SHEET: 8

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC90244)

DATA SOURCE: Engineering Evaluation by Klacking/Krivanec, Dept. 7840

1.8 Mechanical Interfaces

The gimbal assembly design shall provide for transmitting the interface structural loads over an engine gimbaling range of $\pm 3^\circ$ attachment to the UTS and MTS shall be of a bolted configuration. The gimbal center shall be on the engine center line and at engine station 23.0.

Detailed mechanical interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process).

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assy Subsystem (EC90244)

DATA SOURCE: Engineering evaluation by Section 7840 and Engineering estimate by E. H. Hill, Dept. 7770.

1.9 Electrical Interfaces:

Detailed electrical interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process).

1. Gimbal Actuator/Engine Power Supply

<u>Voltage, Volts dc.</u>	<u>Current, amps</u>
28 ± 4	50

2. Gimbal Actuator/Stage Control System

<u>Voltage, Volts dc.</u>	<u>Current, amps</u>
0-10	0-200 MA

NOTE: Maximum power consumption $\leq$ 2000 watts under any condition.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assy Subsystem (EC90244)

DATA SOURCE: Engineering evaluation by Klacking/Krivanec, Section 7840

1.10 Functional Interfaces:

Detailed functional interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process).

The preliminary design criteria for the Gimbal Assembly Subsystem is presented in Section 2.0.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC90244)

DATA SOURCE: Packaging Plan, J. L. McClurkin, Section 7810

1.11 Handling & Shipping

1. This component is shipped installed in the Thrust Structure Module, as individual components and as part of the engine assembly.
2. It is anticipated that some type of lockout device will be required for pre-assembly handling.
3. The designer should consider the fact that the assembled engine will be transported in a horizontal attitude. A lockout device is suggested for use between the middle and upper thrust structures, however, loads in excess of the those defined for flight may be imposed by this mode of handling.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assy Subsystem (EC-90244)

DATA SOURCE: Memorandum 7810:1803M, R. A. Henderson to R. W. Froelich,
dated 11-21-69.

1.12 Test

Radiation hardness requirements for components within the engine test compartment will exceed the Flight Engine requirements due to secondary radiation.

For Ground Test requirements see Nuclear Environment Section.

Date: 11-26-69
Rev: 0
Sheet: 12-2

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assy Subsystem (EC-90244)

DATA SOURCE: J. L. McClurkin, Section 7810

1.12 Checkout

See information on DS 90251 Gimbal Actuator

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC90244)

DATA SOURCE: Preliminary Loads Analysis Based on Hot Bleed Port
 Configuration Weights, Unit Shear and Bending Moment Diagrams

1.13 Static Loads

Preliminary Design Only - Not to be used for design stress approval

Gimbal Assembly

(1) Launch Vehicle Operations (1. 0g lateral, 5.2g axial acceleration)

$$P_7 = \pm 256,000$$

$$P_8 = \pm 256,000$$

$$V_7 = \pm 36,000 \text{ lbs.}$$

$$V_8 = \pm 36,000$$

$$M_7 = \pm 204,000 \text{ in-lbs.}$$

$$M_8 = \pm 204,000 \text{ in-lbs.}$$

$$\text{Max. Compressive Load} = 75,000 \pm 2,000 = -77,000 \text{ lbs.}$$

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC90244)

DATA SOURCE: Saturn Vehicle Loads Report, G. S. Kaveney, Section 7730

1.14 Dynamic Loads

Load Condition: Launch Vehicle Operations

1. Max. longitudinal dynamic acceleration (3-35HZ Freq.Range) =
± 2.25 g's
2. Max. lateral dynamic acceleration (.1-15HZ Freq. Range) =
± 1.5 g's

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assy Subsystem (EC90244)

DATA SOURCE: Engineering Evaluation by Klacking/Krivanec, Section 7840

1.15 Envelop Dimensions

Detailed dimensional interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process), and Flight Engine - Full Flow concept AGC Drawing 1136390.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC90244)

DATA SOURCE: Drawings 1136332 and 1137099 were used for this estimate,
G. S. Kaveney, Section 7730

1.16 Weight Allocation - 600 lb

Gimbal Assembly Sub-system	600
Gimbal Bearing	300
Gimbal Actuator	150
Gimbal Actuator	150

Date: 12-3-69
Rev: 0
Sheet: 17

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem (EC-90244)

DATA SOURCE: NFRD-1 Revision 6 (Draft) Para. III.B.1.p
(As interpreted by Dept. 7810)

1.17 Safety

Maximum effort shall be placed on a design which eliminates single failures or credible combinations of errors and/or failures which endanger the safety of space and/or ground personnel.

Under degraded conditions component design shall provide for continuous engine operation at approximately 40% thrust and an I of not less than 500 seconds for a minimum of 1 hour at any time^{sp} during the engine's operating life.

OPERATION: 2.0 Steady State Functional Performance

SHEET: 18-1

[illegible]

COMPONENT: Gimbal Assembly Subsystem EC 90244

OPERATION: 2.0 Steady State Functional Performance

REV: 0

SHEET: 18-2

[illegible]

Figure 1-Time-domain performance specifications.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem

OPERATION: 3.0 Startup Transient Functional Performance

DATE: 12-3-69

REV: 0

SHEET: 19

[illegible]

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem

OPERATION: 4.0 Throttling Transient Functional Performance

DATE: 12-3-69

REV: 0

SHEET: 20

[illegible]

OPERATION: 5.0 Shutdown Transient Functional Performance

SHEET: 21

[illegible]

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Assembly Subsystem

OPERATION: 6.0 Cooldown Functional Performance

DATE: 12-3-69

REV: 0

SHEET: 22

[illegible]

DESIGN REQUIREMENTS SHEETS

Appended hereto are design criteria and functional performance requirements for the

GIMBAL ACTUATOR

DS-90251

The following data are included in this issue:

	<u>Sheet</u>	<u>Revision</u>
1.0 Design Criteria		
1.1 Reliability Allocation	1	0
1.2 Maintainability	2	0
1.3 Useful Life	3	0
1.4 Nuclear Environment	4	0
1.5 Thermal Environment	5	0
1.6 Natural Environment	6	0
1.7 Dimensional Interfaces	7	0
1.8 Mechanical Interfaces	8	0
1.9 Electrical Interfaces	9	0
1.10 Functional Interfaces	10	0
1.11 Handling & Shipping	11	0
1.12 Test & Checkout	12	0
1.13 Static Loads	13	0
1.14 Dynamic Loads	14	0
1.15 Envelop Dimensions	15	0
1.16 Weight Allocation	16	0
1.17 Safety	17	0
2.0 Steady State Functional Performance	18	0
3.0 Startup Transient Functional Performance	19	0
4.0 Throttling Transient Functional Performance	20	0
5.0 Shutdown Transient Functional Performance	21	0
6.0 Cooldown Functional Performance	22	0

Date: 12-3-69

Rev: 0

Sheet: 1

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Memorandum 7850:M0346, Mihanovich to Varga

1.1 Reliability Allocation

The probability that this component shall successfully fulfill its operating requirements shall be 0.999988 or greater.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS 90251)

DATA SOURCE: Interpretation of NPRD-1, Revision 6 (Draft) and Engineering Evaluation by Klacking/Shoemaker

1.2 Maintainability

The Gimbal Actuators shall be designed to incorporate the maintainability requirements of the Engine. (See Sheet 2 of RN-DR-0187) The following time limitations shall be met: (a) Repair Time - the time required to repair shall not exceed 1.0 hours; (b) Active Maintenance Time - The maximum time required for preventive and corrective maintenance shall not exceed 0.1 man hours per hour during engine assembly and operations.

1.2.1 Maintenance and Repair Cycles

1.2.1.1 Periodic maintenance shall not be required during storage.

1.2.1.2 Periodic maintenance or repair shall not be used to attain specified reliability or operating life requirements.

1.2.2 Service and Access

1.2.2.1 Capability for remote malfunction detection and fault isolation will be provided.

1.2.2.2 Capability for remote and manual replacement of the Gimbal Actuators shall be provided for both ground test engines and space operations.

1.2.2.3 The Gimbal Actuators shall be designed so manual maintenance and repair, including parts replacement, can be accomplished with standard hand tools.

1.2.2.4 Gimbal Actuators shall be physically interchangeable without adjustment or modification of mating engine components.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: NPRD-1 Revision 6 (Draft)
Dept. 7810 Interpretation of NPRD-1
and Engineering Estimate - Froelich/Paavola. Engineering
estimate based on Apollo data by R. W. Thomas, Dept. 7770

1.3 Useful Life

The Gimbal Actuators
shall be capable of satisfying the minimum useful life of the
NERVA Engine, allocated as follows:

- 1.3.1 Rated Operating Life 600 minutes
(maximum of 60 cycles)
- 1.3.2 Non-Rated Operating Life 72 days
(Transients and In-Flight Checkout)
- 1.3.3 Non-Operating Life
- 1.3.3.1 Engine Assembly to Launch Pad 6 months
(Less Storage)
- 1.3.3.2 Launch Pad Environment 6 months
- 1.3.3.3 Space Storage Conditions 3 years
(Including Operational Life)
- 1.3.4 Storage Life (Ground) 5 years
- 1.3.5 Cycle and Energized Life

<u>Condition</u>	<u>Total Cycles</u>	<u>Total Energized Time, Hr</u>
Prelaunch	100	5
In-Flight Checkout	100	5
In Flight Operating	300	10

- NOTE: 1) Cycles are accrued during energized time
2) In-Flight checkout includes both during and
between missions.

DATE: 11-25-69
REV: 0
SHEET: 4

DESIGN REQUIREMENT SHEET

Component: Gimbal Actuators (DS-90251)

Data Source: Engineering Judgment Based on Analyses of an Idealist Configuration - Dept 7830/E. Warman

1.4 Nuclear Environment

Description	Location(In) Station R		γ Kerma Rate Rads/Hr	γ Kerma Rate Rads (10 Hr Exp)	γ Heating Rate Btu/in ³ -sec	Thermal Neutron		Fast Neutron		Epi Thermal	
						Flux n/cm ² -sec	Nvt n/cm ²	Flux n/cm ² -sec	Nvt n/cm ²	Flux n/cm ² -sec	Nvt n/cm ²
Aft Point	30.6	41.0	2.2+6	2.2+7	2.7-4	2.7+9	9.7+13	1.1+11	3.8+15	2.4+11	8.6+15
Mid Point	22.5	41.0	2.0+6	2.0+7	2.4-4	2.6+9	9.2+13	9.9+10	3.5+15	2.3+11	8.1+15
Fwd Point	12.0	41.0	1.7+6	1.7+7	2.1-4	2.3+9	8.1+13	9.0+10	3.2+15	2.0+11	7.0+15
ETS-1											
Aft Point	30.6	41.0	3.6+6		4.4-4			1.5+11			
Mid Point	22.5	41.0	3.4+6		4.1-4			1.4+11			
Fwd Point	12.0	41.0	3.1+6		3.8-4			1.3+11			

DATE: 12-1-69
REV: 0
SHEET: 5

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: K. Sato, Dept. 7730

1.5 Thermal Environment

Data not available at this time.

Date: 12-3-69
Rev: 0
Sheet: 6

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: NERVA Engine Natural Environment Report Data Item
S023-CP090194-F1 - S. A. Varga, Dept. 7810

1.6 Natural Environment

The natural environments to which the component will be exposed are as specified in Table 1.6-1. The tables and figures referenced within Table 1.6-1 are presented in the Reference Data Section of this document.

1 of 2

Table 1.6-1
NATURAL ENVIRONMENTS SUMMARY

Phase Environment	Space Operations	Flight Vehicle Boost	Vehicle Assembly and Checkout Prelaunch and Launch Operations
Altitude - Miles	262 to 210,000 N. miles	Sea Level to 262 N. miles	Sea Level
Atmospheric pressure, psia	2×10^{-12} at 262 N.M.	Pressure - Altitude profiles established by Figures 1 and 2	Min 14.4, max 15.0 $\Delta P = 0.04 \text{ lb/in}^2$ in 24 hr. $\Delta P_{\text{max}} = -.09 \text{ lb/in}^2$ in 1 hr
Atmospheric temperature (Kinetic) °R	2700°R at 262 N.M.	See Figure 3 for nominal profile	Min: 488 Max: 559 (ETR Values)
Atmospheric Density - lb/ft^3	1×10^{-13} at 262 N.M.	Density - Altitude profiles established by Figures 1 and 2	Min: 7.12×10^{-2} Max: 8.27×10^{-2}
Atmospheric composition	See Figure 4	As established from Figure 4 and Table 2.	See Table 2
Atmospheric humidity	Negligible	Max vapor concentration at launch: $11.8 \text{ gr H}_2\text{O/ft}^3$	Extreme: 100% rh @ 73°F for 6 hrs, 75% rh @ 82°F for 18 hrs, 15 day cycle
Solar radiation - $\text{Btu/ft}^2/\text{hr}$	442.4	N.A.	TED
Rain	N.A.	N.A.	See Table 8
Snow	N.A.	N.A.	N.A.
Solar Radio Noise	N.A.	N.A.	N.A.

Phase			Vehicle Assembly and Checkout Prelaunch and Launch Operations
Environment	Space Operations	Flight Vehicle Boost	
Wind, ft/sec	N.A.	N.A.	See Table 9
Sand and dust	N.A.	N.A.	See Table 3
Salt Spray	N.A.	N.A.	See Table 4
Fungi and bacteria	N.A.	TBD	TBD
Atmospheric electricity	N.A.	N.A.	See Table 5
Seismic environment	N.A.	N.A.	TBD
Magnetic field avg. total gauss, max	0.53	0.53	0.52
Meteoroids	See Figures 5 and 6. Meteoroid Mass density 0.5 gm/cm ³	N.A.	N.A.
Radiation - high energy particle	See Table 6	Negligible	N.A.
Radiation - trapped	See Figures 7 and 8	Negligible	N.A.
Radiation - ultraviolet and X-ray	See Table 7	Negligible	N.A.
Radiation - earth thermal avg., $\bar{E}$, Btu/ft ² /hr	$\bar{E} = 68.4 \left(\frac{3,963}{3,963 + \text{alt}} \right)^2$ alt = altitude location in miles	N.A.	N.A.
Radiation - earth albedo avg., $\bar{a}_E$, Btu/ft ² /hr	$\bar{a}_E = 173.4 \left(\frac{3,963}{3,963 + \text{alt}} \right)^2$	N.A.	N.A.
Ionosphere - ionized electron density - N/in. ³	N.A.	N.A.	N.A.

DATE: 12-3-69
REV: 0
SHEET: 7

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Engineering Evaluation by Klacking/Krivanec, Dept. 7840

1.7 Dimensional Interfaces

Detailed dimensional interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process).

DATE: 11-25-69

REV: 0

SHEET: 8

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Engineering Evaluation by Klacking/Krivanec, Dept. 7840

1.8 Mechanical Interfaces

The actuators shall be located on the engine pitch and yaw axis and shall be secured to the UTS with gimbal actuation take out points on the MTS. The actuators shall be capable of transmitting the structural loads at the interface over the engine gimbal range of $\pm 3^\circ$.

Detailed mechanical interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process).

DATE: 12-3-69
REV: 0
SHEET: 9

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Engineering Evaluation by Klacking/Krivanec, Dept. 7840 and
Engineering estimate by E. H. Hill, Dept. 7770.

1.9 Electrical Interfaces:

Detailed electrical interface characteristics will be presented
in the 75K NERVA FFE Component Interface Control Drawing 1136408
(in process).

1. Gimbal Actuator/Engine Power Supply

<u>Voltage, Volts dc</u>	<u>Current, amps</u>
28 $\pm$ 4	50

2. Gimbal Actuator/Stage Control System

<u>Voltage, volts dc</u>	<u>Current, amps</u>
0-10	0-200 MA

NOTE: Maximum power consumption - 2000 watts under any condition.

DATE: 12-3-69
REV: 0
SHEET: 10

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Engineering Evaluation by Klacking/Krivanec, Dept. 7840

1.10 Functional Interfaces:

Detailed functional interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process).

The preliminary design criteria for the Gimbal Actuators are presented in Section 2.0

DATE: 11-25-69
REV: 0
SHEET: 11

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Packaging Plan, J. L. McClurkin, Dept. 7810

1.11 Handling and Shipping

This component is shipped installed in the Thrust Structure Module, as individual components and as part of the engine assembly.

No peculiar handling requirements are anticipated prior to or during factory assembly.

DATE: 12-3-69
REV: 0
SHEET: 12-1

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Memorandum 7810:1803M, R. A. Henderson to R. W. Froelich,
dated 11-21-69

1.12 Test

Radiation hardness requirements for components within the engine test compartment will exceed the Flight Engine requirements due to secondary radiation.

For Ground Test requirements see Nuclear Environment Section.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: XE Experience, J. L. McClurkin, Dept. 7810

1.12 Checkout

Checks to be Performed:

- A. Insulation dielectric measurements
- B. Electrical Circuit measurements
- C. Functional/Operating tests

Checkout Details:

A. Insulation Dielectric Measurements

1. Connect all actuator electrical connections to the electrical test set.
2. Measure each actuator wire, instrumentation wire, and shield to verify that the insulation resistance is above 500 megohms at 10 VDC. NOTE: Test current shall not exceed 10 ma.
3. Disconnect connections and replace protective covers.

B. Electrical Circuit Measurements

1. Connect all actuator electrical connectors to the electrical test set.
2. Measure the circuit impedance to verify that the components, or their circuits, are within a prescribed tolerance, with respect to resistance, impedance and capacitance.
3. Verify that there are no opens, shorts, or grounds, unless specifically designated to be so, between any two wires, shields and valve grounds.
4. Verify position potentiometer and limit switch settings with respect to actuator position.
5. Disconnect test set and replace protective covers.

C. Functional/Operating Tests

1. Remove protective covers and connect the electrical test set to the Gimbal Actuator.

2. Apply 10 VDC to the position potentiometer.
3. Apply 28 VDC (current limited) to the limit switches.
4. Supply actuator position commands monitoring the following parameters through the entire operating cycle:
 - a. Actuator current vs position and time
 - b. Voltage across the actuator
 - c. Limit switch operation vs time
 - d. Comparison of all position monitoring sensors
 - e. Actuator position and command signal vs time (response)
 - f. Actuator overshoot at command position
5. Supply the actuator with sine wave and square wave position commands and monitor Items a through f, Paragraph 4 above. Supply the sine wave commands and the square wave commands at the following frequencies: (TBD)
6. Perform the tests indicated in Paragraphs 4 and 5 at the high and low voltage extremes, and verify the ability of the actuator to meet its operating characteristics.
7. Disconnect the test set and replace the protective covers.

D. Documentation

During all of the above testing, test records shall be maintained to a detail that will allow a trend analysis to be performed on the actuator and its subassemblies. Data log sheets, print-outs, X-Y Plotter Charts, and strip chart recordings shall support the test records as applicable.

DATE: 11-26-69
REV: 0
SHEET: 13

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Preliminary Loads Analysis Based on Hot Bleed Port Configuration
Weights, Unit Shear and Bending Moments Diagrams, G. S. Kaveney,
Dept. 7730

1.13 Static Loads

(1) Launch Vehicle Operations (1.0 g lateral, 5.2 g axial acceleration)

$$P_{\text{Max}} = \pm 69,000 \text{ lbs.}$$

$$M = 0 \quad S = 0$$

Preliminary Design Only - Not to be Used for Design Stress Approval

DATE: 11-26-69
REV: 0
SHEET: 14

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Saturn Vehicle Loads Report - G. S. Kaveney, Dept. 7730

1.14 Dynamic Loads

Load Condition: Launch Vehicle Operations

1. Maximum longitudinal dynamic acceleration (3-35 Hz Freq. Range) =
± 2.25 g's
2. Maximum lateral dynamic acceleration (.1-15 Hz Freq. Range) = ± 1.5 g's

DATE: 12-3-69
REV: 0
SHEET: 15

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: Engineering Evaluation by Klacking/Kriivanec, Dept. 7840

1.15 Envelop Dimensions

Detailed dimensional interface characteristics will be presented in the 75K NERVA FFE Component Interface Control Drawing 1136408 (in process), and flight engine full flow concept, AGC Dwg 1136390.

DATE: 11-26-69
REV: 0
SHEET: 16

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: AGC Drawing 1136332 - G. S. Kaveney, Dept. 7730

1.16 Weight Allocation - 150 pounds each

NOTE: This weight is based on the named drawing plus an assumed weight for the actuator and brake which are unknown at this time.

Date: 11-26-69
Rev: 0
Sheet: 17

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators (DS-90251)

DATA SOURCE: NPRD-1 Revision 6 (Draft) Para. III.B.1.p
(As interpreted by Dept. 7810)

1.17 Safety

Maximum effort shall be placed on a design which eliminates single failures or credible combinations of errors and/or failures which endanger the safety of space and/or ground personnel.

Under degraded conditions component design shall provide for continuous engine operation at approximately 40% thrust and an I_{sp} of not less than 500 seconds for a minimum of 1 hour at any time during the engine's operating life.

OPERATION: 2.0 Steady State Functional Performance

DATE: 12-3-69

REV: 0

SHEET: 18-1

[illegible]

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuator DS 90251

OPERATION: 2.0 Steady State Functional Performance

DATE: 12-15-69

REV: 0

SHEET: 18-2

OPERATIONAL PARAMETERS	NOMINAL PERFORMANCE			MALFUNCTION PERFORMANCE *		
	REQUIREMENT	TOLERANCE	DATA SOURCE	REQUIREMENT	TOLERANCE	DATA SOURCE
2.14 Design Rated Output Force, lbs.	12,000		Preliminary Transform- ation of Gimbal Assy Subsystem requirements			
2.15 Design Rated Stroke, in. min.	± 2.14		by R.W.Thomas Dept. 7770			
2.16 Maximum Stroke, in.	± 2.86					
2.17 Design Rate, in/ces. min max	.54 .71					
2.18 Design Acceleration, in/sec ² , min. max ²	.36 .53					
2.19 Final Valve Error, in.	.070					
2.20 Threshold, in.	.035					
2.21 Snubbing, in., min.	± 2.68					
2.22 Position transducer accuracy, % DRS	1.0					
2.23 Rate transducer accuracy, % full range	1.0

Fig 1

Figure 1-Time-domain performance specifications.

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators

OPERATION: 3.0 Startup Transient Functional Performance

DATE: 12-3-69

REV: 0

SHEET: 19

OPERATIONAL PARAMETERS

NOMINAL PERFORMANCE

MALFUNCTION PERFORMANCE *

REQUIREMENT

TOLERANCE

DATA SOURCE

REQUIREMENT

TOLERANCE

DATA SOURCE

Refer to Section 2.0

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators

OPERATION: 4.0 Throttling Transient Functional Performance

DATE: 12-3-69

REV: 0

SHEET: 20

OPERATIONAL PARAMETERS

NOMINAL PERFORMANCE

MALFUNCTION PERFORMANCE *

REQUIREMENT

TOLERANCE

DATA SOURCE

REQUIREMENT

TOLERANCE

DATA SOURCE

Refer to Section 2.0

OPERATION: 5.0 Shutdown Transient Functional Performance

SHEET: 21

[illegible]

DESIGN REQUIREMENT SHEET

COMPONENT: Gimbal Actuators

OPERATION: 6.0 Cooldown Functional Performance

DATE: 12-3-69

REV: 0

SHEET: 22

[illegible]

III. REFERENCE DATA

This section contains reference data common to two or more of the components described in Section II. The following reference data is provided as of the date of issue of this report.

A. Natural Environment

The following figures and tables provide data which may be used to establish the natural environment that the NERVA Engine will be exposed to during prelaunch, launch and boost, and space operations. Table 1 provides an engine-level summary of these environments, and the balance of the tables and figures are used to establish environments as a function of mission operation and/or geographic location. Design Requirement Sheet 6, (Design Criteria 1.6, Natural Environment,) includes, for each component, a component-level Table 1 defining the specific natural environments affecting that particular component.

Table 1
NATURAL ENVIRONMENTS SUMMARY

Phase Environment	Space Operations	Flight Vehicle Boost	Vehicle Assembly and Checkout Prelaunch and Launch Operations
Altitude - Miles	262 to 210,000 N. miles	Sea Level to 262 N. miles	Sea Level
Atmospheric pressure, psia	2×10^{-12} at 262 N.M.	Pressure - Altitude profiles established by Figures 1 and 2	Min 14.4, max 15.0 $\Delta P = 0.04 \text{ lb/in}^2$ in 24 hr. $\Delta P_{\text{max}} = -.09 \text{ lb/in}^2$ in 1 hr
Atmospheric temperature (Kinetic) °R	2700°R at 262 N.M.	See Figure 3 for nominal profile	Min: 488 Max: 559 (FTR Values)
Atmospheric Density - lb/ft ³	1×10^{-13} at 262 N.M.	Density - Altitude profiles established by Figures 1 and 2	Min: 7.12×10^{-2} Max: 8.27×10^{-2}
Atmospheric composition	See Figure 4	As established from Figure 4 and Table 2.	See Table 2
Atmospheric humidity	Negligible	Max vapor concentration at launch: $11.8 \text{ gr H}_2\text{O/Rt}^3$	Extreme: 100% rh @ 73°F for 6 hrs, 75% rh @ 82°F for 18 hrs, 15 day cycle
Solar radiation - Btu/ft ² /hr	442.4	N.A.	TED
Rain	N.A.	N.A.	See Table 8
Snow	N.A.	N.A.	N.A.
Solar Radio Noise	See Table 10	See Table 10	See Table 10

Phase			Vehicle Assembly and Checkout Prelaunch and Launch Operations
Environment	Space Operations	Flight Vehicle Boost	
Wind, ft/sec	N.A.	N.A.	See Table 9
Sand and dust	N.A.	N.A.	See Table 3
Salt Spray	N.A.	N.A.	See Table 4
Fungi and bacteria	N.A.	TBD	TBD
Atmospheric electricity	N.A.	N.A.	See Table 5
Seismic environment	N.A.	N.A.	TBD
Magnetic field avg. total gauss, max	0.53	0.53	0.52
Meteoroids	See Figures 5 and 6. Meteoroid Mass density 0.5 gm/cm ³	N.A.	N.A.
Radiation - high energy particle	See Table 6	Negligible	N.A.
Radiation - trapped	See Figures 7 and 8	Negligible	N.A.
Radiation - ultraviolet and X-ray	See Table 7	Negligible	N.A.
Radiation - earth thermal avg., $\bar{E}$, Btu/ft ² /hr	$\bar{E} = 68.4 \left(\frac{3,963}{3,963 + \text{alt}} \right)^2$ alt = altitude location in miles	N.A.	N.A.
Radiation - earth albedo avg., $\bar{a}_E$, Btu/ft ² /hr	$\bar{a}_E = 173.4 \left(\frac{3,963}{3,963 + \text{alt}} \right)^2$	N.A.	N.A.
Ionosphere - ionized electron density - N/in. ³	N.A.	N.A.	N.A.

TABLE 2
NORMAL ATMOSPHERIC COMPOSITION FOR CLEAN,
DRY AIR AT ALL LOCATIONS
(VALID TO 55.9 MILES GEOMETRIC ALTITUDE)

<u>Gas</u>	<u>Percent by Volume</u>	<u>Percent by Weight</u>
Nitrogen (N ₂)	78.084	75.520
Oxygen (O ₂)	20.9476	23.142
Argon (Ar)	0.934	1.288
Carbon dioxide (CO ₂)	0.0314	0.048
Neon (Ne)	1.818×10^{-3}	1.27×10^{-3}
Helium (He)	5.24×10^{-4}	7.24×10^{-5}
Krypton (Kr)	1.14×10^{-4}	3.30×10^{-4}
Xenon (Xe)	8.7×10^{-6}	3.9×10^{-5}
Hydrogen (H ₂)	5×10^{-5}	3×10^{-6}
Methane (CH ₄)	2×10^{-4}	1×10^{-4}
Nitrous oxide (N ₂ O)	5×10^{-5}	8×10^{-5}
Ozone (O ₃) summer	0 to 7×10^{-6}	0 to 1.1×10^{-5}
winter	0 to 2×10^{-6}	0 to 3×10^{-6}
Sulfur dioxide (SO ₂)	0 to 1×10^{-4}	0 to 2×10^{-4}
Nitrogen dioxide (NO ₂)	0 to 2×10^{-6}	0 to 3×10^{-6}
Ammonia (NH ₃)	0 to trace	0 to trace
Carbon monoxide (CO)	0 to trace	0 to trace
Iodine (I ₂)	0 to 1×10^{-6}	0 to 9×10^{-6}

TABLE 3
SAND AND DUST

	<u>Sand</u>	<u>Dust</u>
Size of Particles	0.0031 to 0.039	3.9×10^{-6} to 3.1×10^{-3}
Diameter, in.	90% between 0.0031 and 0.012	90% between 3.9×10^{-6} and 7.9×10^{-6}
Hardness and Shape	>50% of particles composed of angular quartz or harder, 7 to 8 on MOH's scale	
Number, Distribution and Associated Conditions	1.2 lb/ft ³ during sand storm 10% between 0.079 and 3.3 ft above ground 90% below 0.079 ft	3.7×10^{-7} lb/ft ³ uniform distribution

Relative humidity 30% or less wind
velocity 32.8 ft/sec at 10 ft altitude

TABLE 4
SALT SPRAY

Salt Spray Exposure	TBD
Salt Accumulation (Extremes)	3.94×10^{-6} to 7.87×10^{-4}
Particle Size, inches	98% of total greater than 3.15×10^{-5}
Accumulation (Fallout)	10.2×10^{-7}
lb/ft ² /day, Max	During Rain Storm
Min	5.12×10^{-8} Unevenly Distributed.

TABLE 5
CHARACTERISTICS OF LIGHTNING STROKES

	Average	Maximum
Peak Current, Amps	10,000	Not greater than 100,000 90% of time.
Time interval, micro seconds	6	10
Start of stroke to peak current		
Fall from peak current to 1/2 of peak value	24	20
Total stroke charge (Coulombs)	25	100
Transmitted to earth (90% of Current Flow)		

TABLE 6
SOLAR HIGH ENERGY PARTICLE RADIATION AT 1 AU

Particle Energy, MEV	>30	>100
Integrated Yearly Particle Flux Protons/in. ²		
Near solar min	7.75×10^7	1.55×10^7
Near solar max	1.24×10^9	9.3×10^7
Composition	Predominantly H ⁺ and He ⁺⁺	
Flux variation with Distance from Sun	$\left[\frac{1 \text{ AU}}{X \text{ AU}} \right]^2$	

TABLE 7

ULTRAVIOLET AND X-RAY RADIATION CHARACTERISTICS

UltravioletPrincipal Line Emission Fluxes (watts/ft²)Lyman Alpha H⁺I (1216Å) 5×10^{-4}

He II (303.8Å)

 2.4×10^{-4} H⁺I (1026Å) 5.6×10^{-6}

CIII (977Å)

 4.7×10^{-6} X-Ray Flux (watts/ft²)2-8Å8-20Å20-200ÅSunspot min
(quiet sun) 2.8×10^{-10} 3.8×10^{-8} 1.2×10^{-5} Sunspot max
(quiet sun) 1.9×10^{-9} 2.2×10^{-6} 9.5×10^{-5} Upper Limit
During Flare
Activity 2.1×10^{-5} 4.2×10^{-5} 8.6×10^{-4}

TABLE 8

DESIGN RAINFALL RATES FOR EASTERN TEST RANGE, MICHOU, MISSISSIPPI TEST FACILITY, GULF TRANSPORTATION, TRANSPORTATION LARGE TO MICHOU, AND TRANSPORTATION SACRAMENTO TO MICHOU

<u>Time Period</u>	<u>1 min</u>	<u>1 hour</u>	<u>24 hours</u>	<u>Year</u>
Total Amount, in.	0.5	4	20	To be determined
Rate, in./hr	30.0	4.0	0.8	
Average Drop Diameter, in.	0.16	0.11	0.07	
Average Rate of Fall, ft/sec	28.8	24.9	20.0	
Peak Wind Speed, ft/sec	98.4	65.6	65.6	
Average Wind Speed, ft/sec	55	19.6	14.7	

TABLE 9

SURFACE WIND SPEED ENVELOPE DURING STRONGEST WIND MONTH FOR ALL LOCATIONS
WINDS BETWEEN SURFACE AND 492 FOOT HEIGHT

Height Above Ground (ft)	Quasi-Steady-State* Wind (ft/sec)			Peak Wind** (ft/sec)		
	99.9 Percentile	99 Percentile	95 Percentile	99.9 Percentile	99 Percentile	95 Percentile
9.84	43.9	40.6	31.8	61.6	56.7	44.2
29.5	54.7	50.5	39.3	76.7	70.8	55.4
59.0	62.9	58.0	45.2	88.5	81.3	63.6
100	69.8	64.6	50.1	97.7	90.2	70.5
200	80.0	74.1	57.7	112.2	103.6	80.7
300	86.9	80.3	62.6	121.7	112.5	87.6
400	92.1	84.9	66.2	128.9	119.1	92.8
500	96.4	88.9	69.2	134.8	124.6	97.1

*Two minute average.

**Two minute average (1.4 times Quasi-Steady-State Wind)

TABLE 10
SOLAR RADIO NOISE

Quiet Sun Noise Power
watts/ft²/cps

Varies from 10^{-20} at 0.4 in.
wavelength to 10^{-23} at 160 inch
wavelength

Solar Storm Noise Power Increase
(orders of magnitude)

1 to 8

Variation with Sunspot Between
2.5 and 80 inch wavelength
Orders of Magnitude

Up to 4

Figure 1A

FIGURE 1b

ALTITUDE VS TIME FOR MISSION A

TOTALS FOR 3 YEAR LIFE

1. LUNAR ORBIT 360 DAYS
2. IN FLIGHT 70 DAYS
3. EARTH ORBIT 665 DAYS

FIGURE 2a

ATMOSPHERIC PRESSURE-HEIGHT EXTREMES FOR ALL AREAS
OF CONCERN AND DENSITY-HEIGHT EXTREMES FOR THE
EASTERN TEST RANGE

FIGURE 2b

ATMOSPHERIC PRESSURE AND DENSITY VERSUS ALTITUDE
(ABOVE 300,000 FEET)

FIGURE 3

TEMPERATURE VERSUS ALTITUDE
(EASTERN TEST RANGE REFERENCE ATMOSPHERE)

Figure 4

ESTIMATED MEAN CONCENTRATIONS OF
PRINCIPAL ATMOSPHERIC CONSTITUENTS
ABOVE 37.9 STATUTE MILES

FIGURE 5

ATMOSPHERIC ENTRY VELOCITY DISTRIBUTION
FOR SPORADIC METEOROIDS

Figure 6

FIGURE 7 PROTON OMNIDIRECTIONAL FLUX
AT THE GEOMAGNETIC EQUATOR

FIGURE 8

ELECTRON MAP OMNIDIRECTIONAL FLUX
(ELECTRONS/IN.² - SEC) AT THE GEOMAGNETIC EQUATOR