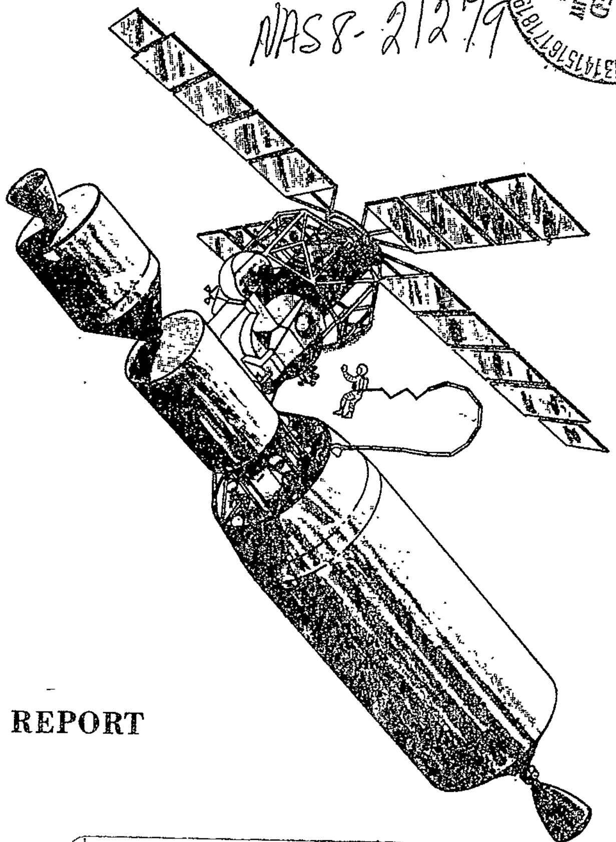
TOOLING CONCEPT FOR MANUFACTURING OPERATIONS IN SPACE

NAS8-21279



FINAL REPORT

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MARTIN MARIETTA CORPORATION

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STUDY OF TOOLING CONCEPTS FOR MANUFACTURING OPERATIONS IN SPACE

Final Report

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I. INTRODUCTION

This document constitutes Martin Marietta's final contract report for NASA Contract NAS8-21279, A Study of Tooling Concepts for Manufacturing Operations in Space (Serpentuator). The Serpentuator concept discussed in this report represents a unique approach to space mobility problems. The device consists of a number of powered links which can be actuated relative to each other, such that the Serpentuator tip can be placed anywhere within a spherical volume. This mechanical linkage can serve as a means of transport, guidance, stabilization, and rendezvous for space manufacturing operations. The device can be used either internally in the space cluster (Inserp) or externally (Exserp), and allows a flexibility not contained in other mobility devices.

During the course of this contract, five major areas of interest pertinent to the Serpentuator concept were investigated. These were: 1) application of Serpentuator to AAP related experiments, 2) application of Serpentuator to a large class of space EVA requirements, 3) conceptual design studies, 4) Serpentuator operational requirements, and 5) space qualification requirements. These specific areas of investigation depart somewhat from the original study plan. This was due to the fact that early results of this study and other MSFC efforts revealed certain areas of special interest. Consequently, direction was supplied by MSFC to concentrate in these areas (references 1 - 4).

Also, this report is organized to provide maximum continuity between the mission analysis sections, rather than to reflect the chronological order of reference 1 - 4. In general, Section III applies to reference 1, Section IV to reference 3, Section V to reference 2, Section VI to reference 3, and Section VII to reference 4. Section III discusses Serpentuator application to current AAP experiments and presents a brief review of the Compatibility Analysis of ATM Experiment Requirements for Serpentuator application. Section IV analyzes a large class of orbital EVA operations, comparing the Serpentuator with other mobility devices. In Section V the Inserp concept is studied for application to AAP Experiment M487. A conceptual design for a remote controlled Exserp, applicable to the dry launched orbital workshop is also presented. This application was studied for two specific tasks. Section VI discusses the operational requirements for Serpentuator system elements. Included in this analysis are structural considerations, detailed joint design considerations, controls requirements, and umbilical management. Section VII describes modifications to an existing Serpentuator System End Item Specification, presents an End Item Specification for the hinge elbow joint, and a Test Plan to space qualify a hinge elbow joint. Thus, this report presents the results of specifically assigned analysis tasks rather than a complete study of the entire system.

II. CONCLUSIONS/RECOMMENDATIONS

For the AAP program the best application of the Serpentuator would be on flight 4 for the film cassett removal and replacement. Although there are actually more EVA tasks on flight 2, the Serpentuator probably could not be spaceflight qualified in time for this application. However, since EVA operations for space programs in general can be anticipated and since the Serpentuator would provide a very satisfactory mode of transportation (especially from a safety standpoint) this concept should be pursued early in a space program. Several possibilities are available: 1) the Serpentuator could be included as a part of M-509 and evaluated simultaneously and competitively with other EVA devices, 2) it could be used in conjunction with M-508, 3) it could be included (as Inserp, however, the principle is the same) as an equipment transfer device for M-487, 4) it could be established as a separate experiment, and 5) it could be used for EVA flight 4 for film cassett removal. The issue is that the Serpentuator represents an attractive method for EVA transport and it should be given an opportunity for astronaut evaluation as soon as possible. This is especially true if extensive future EVA along the guidelines of Section IV is anticipated.

It appears that the Serpentuator (Exserp): 1) should be about 60 ft long with pitch control at the base (although it may be more desirable to make Serpentuator longer and remove pitch control at base), 2) should be pre-programmed for selected points about the cluster, 3) be capable of automatic retrieval, with manual control of the tip only and possible manual vernier control of the main links, and 4) assuming the umbilical requirement remains, the umbilical should be attached along the Serpentuator. It may be desirable to include complete manual control as a backup mode in the event of automatic mode failure, however, the viewing and display requirements increase considerably. Another mode of control that would minimize computer requirements and operator training would be a master-slave arrangement where a model of the cluster with Serpentuator would be used to command the parent Serpentuator. Built in safety features could be easily incorporated in this type of control.

The Serpentuator link elements appear quite capable of space qualification; in fact, there are several designs already available for the elbow hinge joint. The rotary base joint requires further effort. Some suggested changes to space qualify this element are included in this report, however, questions remain with this approach and some initial testing should be conducted.

The ability of the Serpentuator to perform delicate operations remotely requires extensive further study. Conceptually, this appears feasible, but the ability of the tip adjustments to perform these tasks is not proven. There seems to be no great difficulty in placing the Serpentuator tip in the very near vicinity of the work station. There are several options to provide this capability.

The full capability of the Serpentuator, the accuracy of automated programming, the feasibility of automatic retrieval, the tip adjustments required, the requirement for telescoping tips, the delicacy of operations feasible, the manner of manual tip control, and the requirement for complete manual control, cannot be ascertained until the control accuracy and capability is established. This is largely dependent on the individual joint capability.

The future efforts required for the Serpentuator, prior to space qualification are:

Static Requirements

1. Definition of future requirements particularly relative to tip attachment hardware.

2. Definition of imposed forces on Serpentuator.

3. Establish restraint requirements and analyze imposed loads on Serpentuator for rigid attachment

4. Determine Serpentuator stiffness requirement.

5. Conduct trade-off study of weight and stiffness vs. ability to realign at work station.

Dynamic Requirements

1. Analyze ability to transport automatically.

    a. Conduct error analysis.
    b. Determine tip and element volumes of uncertainty.
    c. Determine whether manual tip motion alone can be used as fine adjustment.

2. Establish sensor requirements.

3. If tip control motion alone is not feasible, examine possibility of manual vernier control of individual links.

4. Determine effects on automatic retrieval.

5. Determine maximum velocity and overshoot characteristics as a function of stiffness.

6. Conduct complete dynamic analysis with hardware characteristics included.

Guidelines for the above will be greatly enhanced by the neutral buoyancy tests planned by MSFC. Some of these requirements which involve extensive analytic treatment may be answered as a result of the neutral buoyancy testing.

III. AAP MISSION ANALYSIS

A. Introduction

The effort discussed in this section was devoted to identifying Serpentuator applications for typical space operations related to the Apollo Applications Program (AAP). Since the Serpentuator was a rather new concept and would not have been considered in early experiment planning, it was anticipated that a number of experiments or operations could benefit from this system. In addition, this analysis would be used to define specific requirements for the Serpentuator elements. Thus, over 70 proposed AAP experiments were examined; of these 36 were considered current to the program. Three specific experiments were then selected and analyzed in detail to illustrate concrete Serpentuator applications and to provide a basis for general performance and design criteria. In addition since EVA represented the most general application of Exserp for AAP, this application was briefly analyzed. Also a brief review of a compatibility analysis of ATM experiments was conducted.

The overall results of this effort indicate that the Serpentuator could most effectively function as a versatile systems concept in support of a number of tasks rather than to support any particular experiment. This is due to the relative simplicity of most individual operations for AAP experiments on flights 1-4 and thus the great versatility of the Serpentuator is not required for individual experiments. More specific conclusions are presented at the end of this section. The results of this study also led to a comprehensive analysis of Serpentuator applications related to general EVA requirements. This additional analysis, directed by MSFC as revised Task C (Ref. 3), is discussed in Section IV.

B. Experiments Analysis

1. General

Over 70 proposed AAP experiments were reviewed for possible utilization of a Serpentuator system (AppendixA). This group of experiments includes those currently (effective 29 July 1968) scheduled for flights 1 through 4 (Table III-1), plus additional experiments which either have not been assigned to a specific flight or were originally scheduled, but have since been cancelled.

The experiments listed in Table III-1 are listed in order of priority for each flight. Appendix A presents a summary of all the AAP related experiments studied except for the three experiments selected for detailed analysis and discussed in this section. The experiments in Appendix A are grouped into three categories according to potential Serpentuator applications; experiments involving positioning or deployment, experiments requiring EVA, and experiments with no Serpentuator applications.

Table III-1

AAP Experiment Listing

(July 29, 1969)

Flight Number	Experiment Number	Experiment Title
AAP-1		
	M052	Bone and Muscle Changes
	M056	Specimen Mass Measurement
	S015	Zero-g Single Human Cell
	S027	X-Ray Astronomy
	M415	Thermal Control Coatings
	T018	Precision Optical Tracking
	D008	Radiation in Spacecraft
AAP-2		
	M402	Orbital Workshop
	M487	Habitability/Crew Quarters
	M051	Cardiovascular Function Assessment
	M050	Metabolic Activity
	M052	Bone and Muscle Changes
	M056	Specimen Mass Measurement
	M058	Human Mass Measurement Device
	M053	Human Vestibular Function
	M018	Vectorcardiogram
	M055	Time and Motion Study
	D019	Suit Donning and Sleep Station Evaluation
	D020	Alternate Restraints Evaluation
	T025	Coronagraph Contamination Evaluation
	S018	Micrometeorite Collection
	T027	ATM Contamination Measurement
	M509	Astronaut Maneuvering Equipment
	M508	EVA Hardware Evaluation
	T020	Jet Shoes
	D021	Expandable Airlock Technology
	S065	Multiband Terrain Photography
	T003	In-Flight Nephelometer
	M479	Zero-g Flammability
	T013	Crew-Vehicle Disturbance
	T018	Precision Optical Tracking
	S009	Nuclear Emulsion
	T004	Frog Otolith Function
	T023	Surface Adsorbed Materials
	T021	Meteoroid Velocity
	T017	Meteoroid Impact and Erosion
	D022	Expandable Re-entry Structures
	D017	Carbon Dioxide Reduction
	S019	UV Stellar Astronomy
	S020	UV/X-Ray Solar Photography
	M489	Heat Exchanger Service
	M493	Electron Beam Welding
	M492	Tube Joining Assemblies

Table III-1 (Cont'd)

Flight Number	Experiment Number	Experiment Title
AAP-3A		
	M402R	Orbital Workshop
	M487R	Crew Quarters
	M051R	Cardiovascular Function
	M050R	Metabolic Cost of Tasks
	M052	Bone and Muscle Changes
	M056R	Specimen Mass Measurement
	M058	Body Mass Measurement
	M053R	Vestibular Function
	M018R	Vectorcardiogram
	M055R	Time and Motion Study
	M509R	Astronaut Maneuvering Equipment
	M479R	Zero-g Flammability
	M493R	Electron Beam Welding
	S027	X-Ray Astronomy
	T018	Precision Optical Tracking
	S018	Micrometeorite Collection
	S065R	Multiband Terrain Photography
	S073	Gegenschein/Zodiacal Light
	S072	Circadian Rhythm - Vinegar Fly
	S019R	UV Stellar Astronomy
	S020R	UV/X-Ray Solar Photography
	S063	UV Airglow Horizon Photography
	S028	Dim Light Photography
AAP-3		
	M402R	Orbital Workshop
	M487R	Crew Quarters
	M051R	Cardiovascular Function
	M050R	Metabolic Cost of Tasks
	M052R	Bone and Muscle Changes
	M056R	Specimen Mass Measurement
	M058R	Body Mass Measurement
	M053R	Vestibular Function
	M018R	Vectorcardiogram
	M055R	Time and Motion Study
	S061	Potato Respiration
	T018	Precision Optical Tracking
AAP-4		
	S055A	XUV Spectroheliometer
	S082A	XUV Spectroheliograph
	S083B	XUV Spectrograph
	S052	White Light Coronagraph
	S054	X-Ray Spectrographic Telescope
	S056	X-Ray Telescope
	H - α #1	HCO H - α Telescope/Camera
	H - α #2	ATM H - α Telescope
	T018	Precision Optical Tracking

(R - Resupply or Reactivate)

Of all the experiments studied, nineteen presented possible application to aid or replace astronaut EVA, and ten had, presumably, potential application to aid in transport and positioning of experiment equipment. The remainder had no potential Serpentuator application.

The experiments with positioning and deployment requirements are included in Table III-2.

Table III - 2

Equipment Positioning and Deployment Applications

S019	UV Stellar Astronomy
S063	UV Airglow Horizon Photography
S065	Multiband Terrain Photography
S022	Low Z Cosmic Ray
S023	High Z Cosmic Ray
S049	IR Interferometer Spectrometer
S067	Gamma-Ray and X-Ray Spectroscopy
D020	Alternate Restraints Evaluation
M487	Habitability of Crew Quarters
M508	Astronaut EVA Hardware Evaluation

The first three of these experiments would require Serpentuator installation within the Multiple Docking Adapter (MDA) where limited maneuvering space makes the Serpentuator impractical. Experiments S022 and S023 involve equipment deployment on a boom throughout the entire mission, and would require a separate Serpentuator system. A simple extendable boom should suffice for this function. Experiments S049 and S067 include sensor deployment and pointing maneuvers that require reorientation of the entire spacecraft. Although a Serpentuator could easily perform these tasks, the two experiments were not scheduled for a specific AAP flight; consequently, further analysis was discontinued. Experiment D020 is essentially the same as M508, with different work restraints. Experiments M487 and M508 are discussed later in this section.

Of the 19 experiments requiring EVA, the following five from Table III-1 (considered current for AAP) represent reasonably firm EVA requirements for Flight 2:

D021	Expandable Airlock Technology
D022	Expandable Re-entry Structures
T017	Meteroid Impact and Erosions
T021	Meteroid Velocity
T023	Surface Absorbed Materials

The only other current EVA requirement for AAP is ATM film cassette removal on Flight 4. The above five experiments as well as the film cassette removal on Flight 4 are considered in subsection B. Thus, from the above it is apparent that the main application of Serpentuator relative to AAP missions is associated with EVA. The three experiments M487, M508 and M469 were deemed most applicable for Serpentuator applications for AAP and were selected for detailed analysis to establish specific Serpentuator task requirements. All three experiments were originally scheduled for AAP Flight 2, but M469 has since been cancelled. Presumably a new experiment with similar maintenance and repair tasks will involve comparable Serpentuator applications. M487 was selected because it afforded an opportunity to utilize and evaluate the Serpentuator directly. Also, the "fireman's pole" concept now scheduled for use in this experiment has become increasingly complex. Since most of the Serpentuator applications related to AAP were EVA associated, M508 presented a possibility of evaluating the Serpentuator for EVA support. M469 was selected as representative of a class of Serpentuator applications where Exserp would be used directly.

2. Experiment M487 Habitability of Crew Quarters

The purpose of this experiment is to evaluate the living quarters of the S-IVB compared with the cubage and crew appointments of previous spacecraft. After passivation and activation of the Orbital Work Shop (OWS), astronauts will transfer experiment packages from the MDA, stow them in the OWS, and install the crew compartments and related equipment. As part of M487, crew members will also transfer and stow equipment packages for the 13 experiments listed in Table III-3.

Table III-3

Experiments Transferred to OWS

M018	In-Flight Vectrocardiogram
M050	Metabolic Cost of In-Flight Tasks
M051	Cardiovascular Function
M052	Bone and Muscle Change
M053	Human Vestibular Function
M055	Time and Motion Study
M056	Specimen Mass Measurement
M058	Body Mass Measurement
T013	Crew-Vehicle Disturbance
M508	Astronaut EVA Hardware Evaluation
M509	Astronaut Maneuvering Equipment
D019	Suit Donning and Sleep Station Evaluation
D020	Alternate Restraints Evaluation

A total of 53 packages, totaling approximately 1600 pounds, will be transported. Individual packages range from 1 to 135 lb in weight and 20 in^3 to 10 ft^3 in volume. Completion of this experiment requires 44 man-hours.

A Serpentuator installed in the forward compartment of the OWS could transport these packages from the MDA to the OWS. Two modes of operation are available. The first mode would require the Serpentuator to travel along a programmed trajectory between the two vehicles. One crew member would attach packages to the Serpentuator inside the MDA. The Serpentuator would then move out through the Airlock Module (AM) to the OWS forward compartment and into the crew quarters area. A second crew member would remove and store the packages in the desired location. This operation involves only planar motion and would be repeated as many times as necessary.

In the second mode of operation, an astronaut would manually control the Serpentuator to transfer and position equipment for storage in the OWS forward compartment. The Serpentuator could function either as an IVA aid, with the astronaut carrying the package and controlling motion from the tip, or as an equipment positioning aid, with the astronaut controlling motion from the base. The type of operations would depend on the complexity of the operation required at the tip.

The equipment packages to be transported in this experiment are listed sequentially in Table III-4. Dimensions weights, and intended OWS location are given where available. Details of the necessary Serpentuator motion are discussed in Section V.

Table III-4

Experiment M487 - Equipment to be Moved from MDA to OWS

Description	Size (Inches)	Weight (Pounds)	Location: Forward Compartment	Location: Crew Quarters
Intercom Stations and Connectors	12x12x24	40.0	X	X
Fecal Dryer	24x15x30	20.0		X
Vacuum Valve Tool	1x2x10	1.0		X
Fecal Collector	24x20x30	47.0		X
M052 Equipment	12x15x18	18.0		X
M056 Equipment	6x9x9	14.0		X
Waste Management Storage Container	20x30x12	15.0		X
Personal Hygiene Containers for WMA	11x11x33	30.0		X
Personal Hygiene Containers for FMA	11x11x33	30.0		X
Shower	32x32x14	30.0		X
Tissue Dispenser for WMA	5x7x5	3.0		X
Vacuum	8x10x12	8.0		X

Table III-4 (Cont'd)

Description	Size (Inches)	Weight (Pounds)	Location Forward Compartment	Location Crew Quarters
Food Preparation Module		35.0		X
Food Preparation Water Tanks(2)	18x13Dia.	18.0		X
Shower Water Tank	18x13Dia.	9.0		X
Food Serving Trays	22.16.3	3.0		X
Nominal Food Module		10.0		X
Experimental Food Module		10.0		X
Experimental Food Module		10.0		X
Experimental Food Module		10.0		X
Nominal Food Module		10.0		X
Nominal Food Module		10.0		X
Nominal Food Module		10.0		X
Nominal Food Module		10.0		X
Nominal Food Module		10.0		X
Nominal Food Module		10.0		X
M056 Equipment	6x9x9	14.0		X
Stools (2)		5.0		X
Personal Equipment Stowage, Sleep restraints, medical kits	24x38x20	60.0		X
Entertainment Equipment		7.0		X
Suit Donning/Drying/Stowage Rack		15.0		X
D019 Equipment	12x20x22	25.0		X
D019 Equipment	20x24x38	45.0		X
Entertainment Equipment		7.0		X
M050 Equipment	12x12x24	48.0		X
M050 Equipment	12x12x30	30.0		X
M050 Equipment	10x18x24	8.0		X
Experiment Support System	31x15x20	100.0		X
M053 Equipment	16x22x22	68.0		X
M053 Equipment	10x22x26	50.0		X
M053 Equipment	11x16x25	28.0		X
M051-M018-M050 Equipment	20x24x30	38.0		X
M058 Equipment	22x24x28	38.0		X
Film Repository	24x22x5		X	
D020 Equipment	20x24x36	55.0	X	
D020 Equipment	18x24x28	42.0	X	
M509 Equipment	14x28x34	115.0	X	
M509 Equipment	12x12x38	135.0	X	
M509 Equipment	8x13x18	24.0	X	
M508 Equipment			X	
M508 Equipment			X	
Trash Disposal Containers and Crew Quarters Soft Hatch Cover	12x18x18	27.0		X
T013 Equipment	20x20x40	85.0	X	

3. Experiment M508 Astronaut EVA Hardware Evaluation

This experiment is a series of simulated EVA tasks to test EVA hardware within the safe confines of the OWS forward compartment. Various tools, restraint systems, and crew/equipment transfer devices will be evaluated as EVA aids. All tasks will be performed in both the Apollo Block II suit and Litton Hard Suit to determine the effect of suit mobility on EVA performance. Two astronauts are required for this experiment, one serving as the test subject while the other assists, observes, and records data. Each set of tasks requires approximately one hour to prepare, two hours to perform, and one hour to stow. Eight test sessions are planned, totalling 64 man-hours.

The following equipment will be tested in experiment M508:

1. Crew/Equipment Transfer Devices:

a. Extravehicular Crew Transfer Device (EVCTD): A manually-operated, extendable boom (similar to the Gemini antenna) capable of transferring astronauts or equipment to distances of 50 ft.

b. Wire Gun: A hand-held unit that dispenses a piece of wire as far as 100 feet with a hand-hold at the end to rescue a stranded astronaut.

2. Universal Tool Kit:

a. Power Tool: A hand-held, reactionless, battery-operated drill that will produce a maximum torque of 45 ft-lb. Battery will be rechargeable. Maximum operating time per battery will be eight to ten minutes.

b. Manual Tools: Various tools for wrenching and torquing, which will be used to evaluate effectiveness of conventional tools versus reactionless power tools.

3. Restraints and Tether Systems:

a. Variable Flexible Restraint: A restraint system with variable flexibility-rigidity, under operator control for use as a crew restraint to permit effective work.

b. Tubular Restraint: A restraint system which extends or retracts like a telescope to form a rigid two-point attachment system. The booms are mounted on the sides of a waist belt, with attachment points on the free end of the boom.

c. Capsular Adhesive System: A dispensing unit which is either attached to the end of a restrains system or carried as a separate unit. By a selection lever on the dispenser, an adhesive pad is positioned for activation. When pressure is applied to the pad, the capsule ruptures and allows intimate contact between pad and adherent, thus providing a restraint attachment point.

d. Nylon Web Restraint: A flexible restraint with a large hook at the free end for attachment to various tether rings. Restraint system will be similar to that used during Gemini XII EVA.

e. Foot Restraint: Molded foot restraints similar to those used in the Adapter section during Gemini XII EVA. Pilot evaluation indicated that these restraints permit duplication of one-g task proficiency.

f. Tension Reel Tether: This system is designed so that the EVA astronaut can control the length of his tether line. During the Gemini missions, tether control was performed by the Command Pilot. However, an EVA astronaut should be able to control his own tether, especially when out of sight of another astronaut.

4. Space Suits:

a. Litton Hard Suit
b. Flight suit or backup flight suit.

A Serpentuator (Inserp) installed in the OWS forward compartment could be evaluated as an EVA mobility aid in conjunction with this experiment. The Serpentuator could replace the Unidirectional Extra-vehicular Crew Transfer Device and the wire gun for astronaut retrieval. The Serpentuator could also be evaluated as a work restraint or platform. In this manner, the transporting and positioning capabilities of the Serpentuator, as well as the effects of task performance on the Serpentuator, could be evaluated. Effectively, this application involves the use of the Serpentuator as experiment equipment, with the objective of evaluation of the Serpentuator, whereas the previous application (Experiment M487), involves the use of the Serpentuator as operational hardware. Conceivably, the qualification requirements could be reduced for this application since a Serpentuator failure would not jeopardize completion of the mission.

4. Experiment M469 - ST-124 Removal and Disassembly

The purpose of this experiment is to gain experience in orbital assembly, disassembly, maintenance, and repair operations. In addition to testing reactionless space tools and conventional hand tools, maintenance and repair techniques will be evaluated by performing actual tasks. Tool analysis will provide relative efficiency comparisons and detect possible performance degradation during operation. Component removal from the ST-124 will involve removal of bolts, fluid couplings, electrical cables and modules, as well as manipulation of a medium-size mass.

An astronaut carrying tool kits, lights, and camera will leave the airlock on an umbilical and traverse to the ST-124 location at the Instrument Unit (IU) of the S-IVB. After installing the camera and lights on a truss over the ST-124, he will electrically de-energize the unit, bleed off pressure, disconnect water-methanol lines on the outer cover, and finally remove the cover, wedging balsa blocks in place to prevent movement. He will then remove one gyro from the platform and transport it, along with camera, lights, and tools, back to the airlock. Successful completion of this task will verify astronaut capability for the majority of maintenance tasks.

A Serpentuator mounted external to the spacecraft (Exserp) would be a significant aid in this type of operation. The Exserp would transfer the astronaut to the ST-124 location and position him to perform the necessary tasks. It could also carry the tools, lights, and camera, as well as a case for the parts to be returned. A restraint would be required at the worksite to prevent the astronaut from exerting large forces that would move the Serpentuator away from the site.

The possible use of Serpentuator to eliminate EVA in this experiment was also investigated. In this mode of operation, the Serpentuator would be controlled by an astronaut from within the spacecraft. A TV camera and lights mounted on the tip would monitor and record the activity. The last link in the Serpentuator would have three degrees of freedom to permit the necessary motion. Five controllable working arms attached to the Serpentuator would contain:

1. A wrench adjustable from 9/16 to 11/16 inches;
2. Clamp shell-type to hold or move objects and remove quick-disconnect lines;
3. Sock head screwdriver;
4. Diagonal cutters;
5. Adjustable Allen hex driver.

These working arms would be mounted in a rotating drum at the end of the Serpentuator. Each arm would extend or retract for operating in confined spaces. Individual drive motors would rotate and open or close the arms. An astronaut would position the Serpentuator tip at the ST-124 area from within the spacecraft, and remove the various items by selecting the proper working arm.

A number of unknown factors are associated with use of the Serpentuator in this manner. Actuator accuracy, repeatability, control system capability, attachment design, and astronaut training time are a few of the areas that need further study. A significant effort would be required to justify this complex mode of operation.

C. EVA Requirements for AAP Missions

1. General

The current trend in AAP operations planning is to avoid experiments that require extensive astronaut EVA, since it is not only time-consuming but also involves many unknown safety factors. The EVA presently scheduled is limited to AAP flights 2 and 4, essentially for data retrieval. Maintenance and repair requirements have not yet been established.

A previous Martin Marietta study, <u>Crew Safety Analysis for Cluster AAP Flight 2</u> (Ref.6), discussed the hazards associated with certain experiments and manned EVA in general. Reviewing this study, no Serpentuator applications for alleviating specific experiment hazards were found. However, the entire group of experiments involving EVA present common hazards that could be significantly reduced by using the Serpentuator as the prime mode of EVA transport. This application is discussed more completely in section IV.

2. Exserp Integration Requirement

From the preliminary studies of the 70 experiments certain guidelines were established concerning Serpentuator location and integration with the spacecraft to support the EVA requirements for AAP missions 2 and 4. In general, three major criteria for the Exserp system must be considered: 1) It must cover as much surface area of the CSM and S-IV-B as possible; 2) It must be compactly stored during launch; and 3) The eight-link system must be easily deployed in orbit.

Four of the five experiments involving EVA on AAP flight - 2 (D021, D022, T017, T021),require activity on the AM structures near the hatch. The fifth experiment (T023) is performed in the vicinity of the IU on the S-IVB. EVA on flight 4 is limited to film retrieval from the ATM. To accomplish the film retrieval alone the Exserp could be mounted on the side of the ATM. From this location it could easily transport an astronaut from the AM hatch to worksites on the ATM. However, this would permit Serpentuator operation on flight 4 only, since the ATM is not launched until flight 4.

To support EVA requirements on both flights 2 and 4 one alternative is to locate the Exserp base on the MDA between the docking devices and the S-IVB interface, at a point where the limbs will not interfere with the ATM. This position would allow coverage of most of the desired surface area. For launch, the Serpentuator could be wrapped around (and rigidly attached to) the circumference of the MDA and would be protected by the shroud during ascent. In orbit, the attachment could be released automatically, making the system available for immediate use.

As the Serpentuator is presently designed, the base link has two degrees of freedom - yaw and roll. If the Exserp is located as described above, potential surface coverage will be a function of ATM position. Much of the surface over 150° on either side of the base will not be covered. If the base is within 90° of the ATM docked position, surface areas on the other side of the docking collar will not be accessible. Figure III-2 illustrates the locus of attainable points.

Much greater surface coverage is possible if the Serpentuator is relocated and the base link is given freedom of motion in the pitch plane. This would place the base on the MDA directly behind the ATM docking adapter. With pitch freedom the Serpentuator now has complete motion symmetry on either side of the spacecraft and covers a maximum area, as shown in FigureIII-2.The main advantage of this mounting location, combined with pitch freedom, is that a single Exserp could satisfy all the ATM EVA requirements as well as those on the main body of the spacecraft.

To illustrate these advantages, let the Serpentuator base be mounted as shown in FigureIII-2. If the base link has yaw and roll freedom only, it would be impossible to locate the Serpentuator tip at Point A and avoid the ATM structure. However, with pitch motion added to the base the Serpentuator tip could easily reach point A while avoiding the ATM structures. Similarly, Point B, which is 180° from point A on the CSM, is accessible by the tip only if pitch freedom is allowed at the base, otherwise the CSM structure blocks the plane of motion.

Now consider the Serpentuator located as shown in Figure III-2. Point A in that figure is accessible but Point B is not. In the latter case the MDA and CSM obstruct the links. With pitch motion at the base, Point B would be attainable. Points C and D (top view) are inaccessible because the Serpentuator is not long enough to reach the top of the ATM. A base with pitch motion mounted as shown in Figure III-2 would allow the Serpentuator tip to reach both C and D.

3. ATM Time Line Study

A Martin Marietta report, Compatability Analysis of ATM Experiments Requirements, was reviewed to determine if the Serpentuator system could reduce overall mission time. This analysis was essentially a time line study to determine whether total mission time could be reduced by performing certain experiments simultaneously. The ability to operate these experiments simultaneously, however, is determined by the pointing requirements for each experiment, and not by any particular astronaut duties. The astronauts participation is limited to swtiching knobs monitoring meters, etc.

The most effective Serpentuator application in these experiments would be to aid or eliminate astronaut EVA for film retrieval and replacement. The four-day period now allotted for this task could be significantly reduced, especially with a remote-controlled Serpentuator to eliminate EVA entirely. One of the major drawbacks of astronaut EVA arises from the acclimation time necessary to change from a nitrogen-oxygen to pure oxygen atmosphere (about 3 hours) and back again. Even if the astronaut were attached to the tip of the Serpentuator, a significant problem of umbilical management could possibly be avoided by attaching the umbilical along the Serpentuator.

IV. EVA ANALYSIS

A. Introduction

In addition to the AAP experiments analyses, EVA requirements for a large class of experiments were evaluated for Serpentuator application. The Serpentuator was then compared to other EVA translational devices for these applications. This effort was performed as revised Task C, as directed by MSFC (Ref 3).

There are many disadvantages associated with the present EVA technique utilized on AAP, both from an operational and safety standpoint. Significant problems have been encountered with the management of the umbilicals to prevent them from becoming entangled with spacecraft structures and the present method does not permit quick or convenient rescue of a stranded astronaut. The astronaut is attached to the spacecraft only by a tether or umbilical, neither of which is suitable for rescue except at very close ranges. Thus, retrieval must be conducted by a second astronaut.

Essentially there are three major problem areas related to EVA. These are: 1) the time intervals required for EVA preparation, pressurization and depressurization, 2) umbilical management, and 3) rescue. The Serpentuator concept cannot solve the first problem but it can assist in umbilical management and rescue operations. It can also eliminate some of the EVA requirements. Two significant advantages of the Serpentuator for rescue operations are: a) in the event of transportation equipment failure, the Serpentuator could still be used as a handrail; and b) in the event of life support system failure or astronaut incapacitation automatic retrieval is possible.

B. NAR Study Summary and Preliminary EVA Analysis

A major reference source for this effort was a study by North American Rockwell Corporation (NAR), Extravehicular Engineering Activities Program Requirements Study (Ref 8). This comprehensive study covers a broad spectrum of experiments in order to define the EVA necessary to support earth-orbital scientific and technical programs from 1968 to 1980, with emphasis on the 1971-1974 period. Over half (746) of the 1212 experiments examined in the study require EVA to some extent. In the above studies sixteen experiments were selected by NAR as representative of the entire spectrum of EVA requirements for the early manned missions (1971-1974) including the first flights of the dry workshop. Of the 1212 experiments, 70% are possible candidates for this period, including 77% of the 746 experiments requiring EVA support. Therefore the 16 experiments represent a majority of the entire group of experiments studied.

These 16 representative experiments were examined in detail to establish EVA requirements in terms of task attributes, translational distances, mass and time requirements, etc.

For these experiments 74 separate EVA excursions, involving 93 EVA tasks are required. Of these, 49 tasks are identified as firm requirements, while 44 are potential requirements. The translational distances necessary to accomplish these tasks are shown in Table IV-1.

Table IV-1 EVA Translation Distances

	Firm		Potential		Total	
Distance	Number	Percentage	Number	Percentage	Number	Percentage
0 - 20 ft.	22	45%	10	23%	32	34%
20 - 40 ft.	16	33%	19	43%	35	38%
40 - 60 ft.	6	12%	9	20%	15	16%
60 - 80 ft.	1	2%	3	7%	4	4%
80 - 100 ft.	3	6%	3	7%	6	7%
Over 100 ft.	1	2%	0	0%	1	1%

The time durations involved in the 74 EVA excursions are given in Table IV-2. In addition to astronaut transfer, 82 of the 93 tasks require equipment transport. In most cases this equipment is transported along with the astronaut and is either used at the worksite or retrieved from the worksite. These equipment masses are listed in Table IV-3.

From Table IV-1 and IV-3 a 60-ft Serpentuator, capable of transporting a 60-lb mass in addition to the astronaut, would satisfy approximately 90% of the EVA requirements. If the range were reduced to 40-ft from the point of egress, the Serpentuator could still support 70% of these tasks.

Table IV-2 EVA Time Durations

Time Duration	Requirements Number	Percentage
1 - 2 hours	7	9%
2 - 3 hours	35	47%
3 - 4 hours	30	41%
Over 4 hours	2	3%

Table IV-3 Mass Transfer Requirements

Mass	Transfer Requirements Number	Percentage
0 - 20 lbm	47	57%
20 - 40 lbm	17	21%
40 - 60 lbm	7	9%
60 - 80 lbm	4	5%
80 - 100 lbm	4	5%
Over 100 lbm	3	3%

C. Serpentuator Versus Other EVA Mobility Devices

The 16 representative experiments were further analyzed in a trade-off study to establish specific areas where a Serpentuator would be superior to other EVA mobility devices, such as hand-rails, extendable booms, and powered maneuvering units. Tasks performed both by EVA and remote control were considered. As directed, the mobility devices were evaluated on the basis of the following performance parameters:

a. EVA task categories versus range distance;
b. EVA task categories versus number of sorties;
c. EVA task categories versus 1) man required, 2) man or remote control, 3) remote control only;

d. Cargo mass and volume versus positional accuracy;
e. Task performance time versus total sortie time;
f. Propellant or power consumption versus total sortie time;
g. Time to store/service versus total sortie time;
h. Crew safety versus mobility device reliability.

Initial analysis indicated that 11 of the 16 representative experiments were suitable for Serpentuator application. These 11 experiments are conducted in conjunction with the OWS cluster or dry workshop configuration. Of the remaining 5 experiments, 2 are operated in synchronous orbit with the CSM only, and 2 experiments are operated as separate subsatellites in the vicinity of the workshop. These latter 2 experiments are launched with the CSM. After orbit is attained, the CSM is used to deploy the experiment subsatellite in a separate orbit near the workshop. The CSM then docks with the MDA. The experiment package is not docked to the workshop at any time. The fifth experiment involves deployment of a large structure. This experiment is docked to the CSM, near the workshop. Thus, these five experiments do not appear appropriate to this study and were eliminated.

For the purpose of comparing the mobility aids with the Serpentuator system, EVA functions were grouped into four general task categories:

a. Equipment operation (including deployment and installati of experiment equipment);
b. Observation and inspection;
c. Data retrieval;
d. Maintenance and repair.

The 11 experiments analyzed involve 59 different tasks in these four categories, requiring a total of 53 EVA excursions.

Figure IV-1 illustrates the translational distances required for each task category. As previously discussed, approximately 90% of these tasks involve distances less than 60 ft. Manual translation is currently planned for all but one of these tasks.

The number of EVA excursions required in each task category is illustrated in Figure IV-2. The majority of excursions are concerned with either equipment operation or maintenance and repair.

Six of the 59 tasks could be performed remotely by Serpentuator, eliminating the need for EVA. Five of these involve observation and inspection while the sixth requires operation of small sensors.

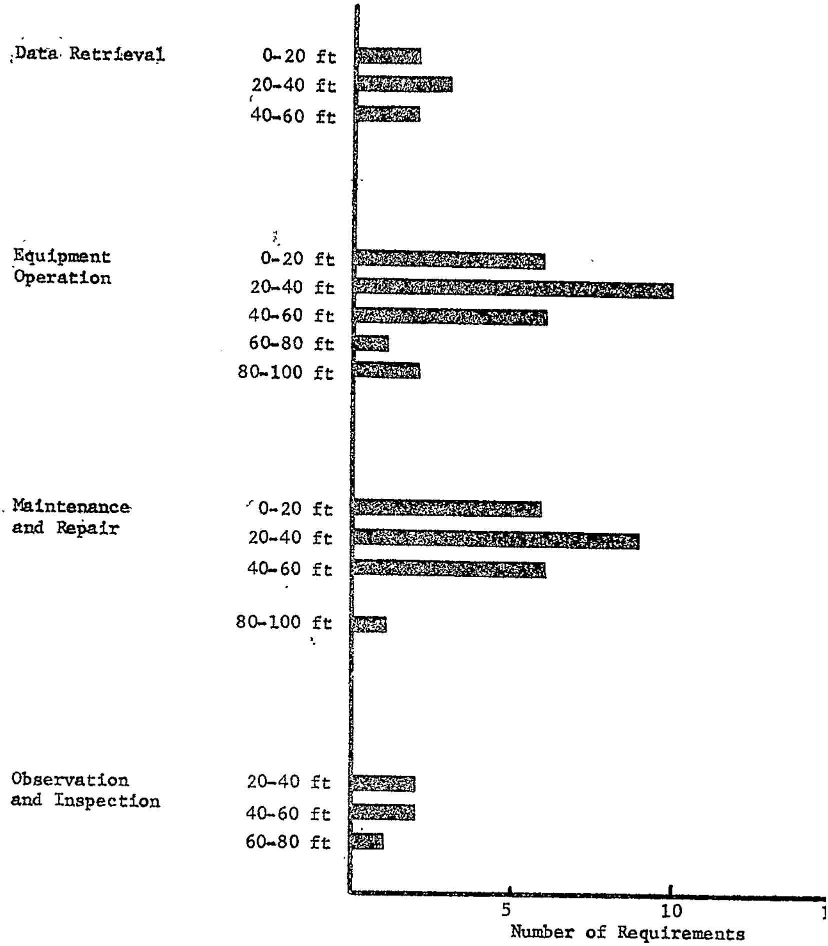

Figure IV-1 Translational Requirements

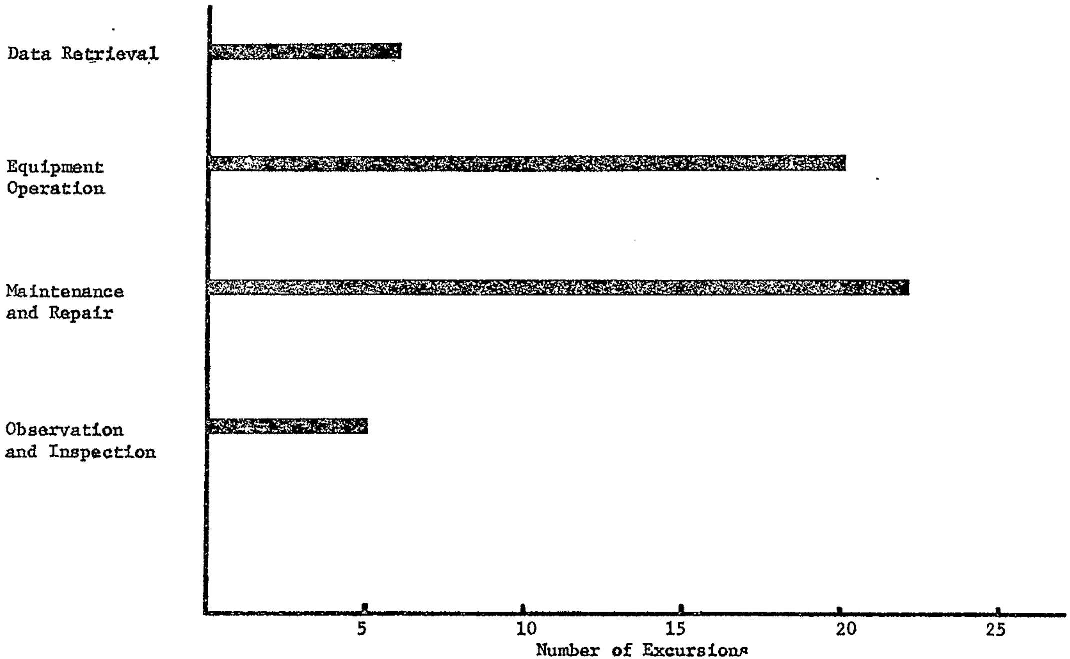

Figure IV-2 EVA Task Categories

Four additional tasks, involving data retrieval, could be performed remotely with the aid of a special tip device to remove and replace data packages. Without the tip attachment, EVA is necessary. None of these 10 tasks could be accomplished remotely with STEM systems or extendable trusses, since the device must maneuver to various locations and perform manipulative operations. The remaining 49 tasks must be performed in the EVA mode. This indicates that the major Serpentuator application would be as a means of astronaut EVA transport. These results are illustrated in Figure IV-3.

In addition to transporting the astronaut, 55 of the 59 EVA tasks require transport of cargo, including experiment equipment or tools to be used at the worksite. The graph in Figure IV-4 compares cargo transfer distances and the accuracy with which the cargo must be positioned. Gross positional accuracy is defined as linear accuracy of 0 to 1 ft and angular accuracy of 0 to 30°. Fine positional accuracy is defined as linear accuracy of 0 to 2 inches and angular accuracy of 0 to 5°.

About 90% of the tasks involve transport of 60-lb or less. Of these, 80% require fine positioning accuracy. Data concerning cargo volume is not available.

The EVA mobility aids selected for comparison with Serpentuator include handrails, stowable tubular extendable member (STEM) systems, hand-held maneuvering unit (HHMU), backpack-type astronaut maneuvering unit (AMU) and space taxi. Pertinent operational parameters of the HHMU, AMU, and Serpentuator are listed in Table IV-4 for reference. The listed parameters are very gross estimates based on preliminary designs.

Table IV-4 EVA Mobility Devices

	Weight	Volume	Range	Stabilization	Velocity
Serpentuator	250 lbs.	40 ft^3	60 ft	Manual or automatic	2 fps
AMU	168 lbs.	1.3 ft^3	200 ft	Automatic	1 fps
HHMU	7.51 lbs.	0.5 ft^3	25 ft	None	0.5 fps

In many cases, graphical comparison on the basis of each parameter was not practical. These devices range from the simplest handrail

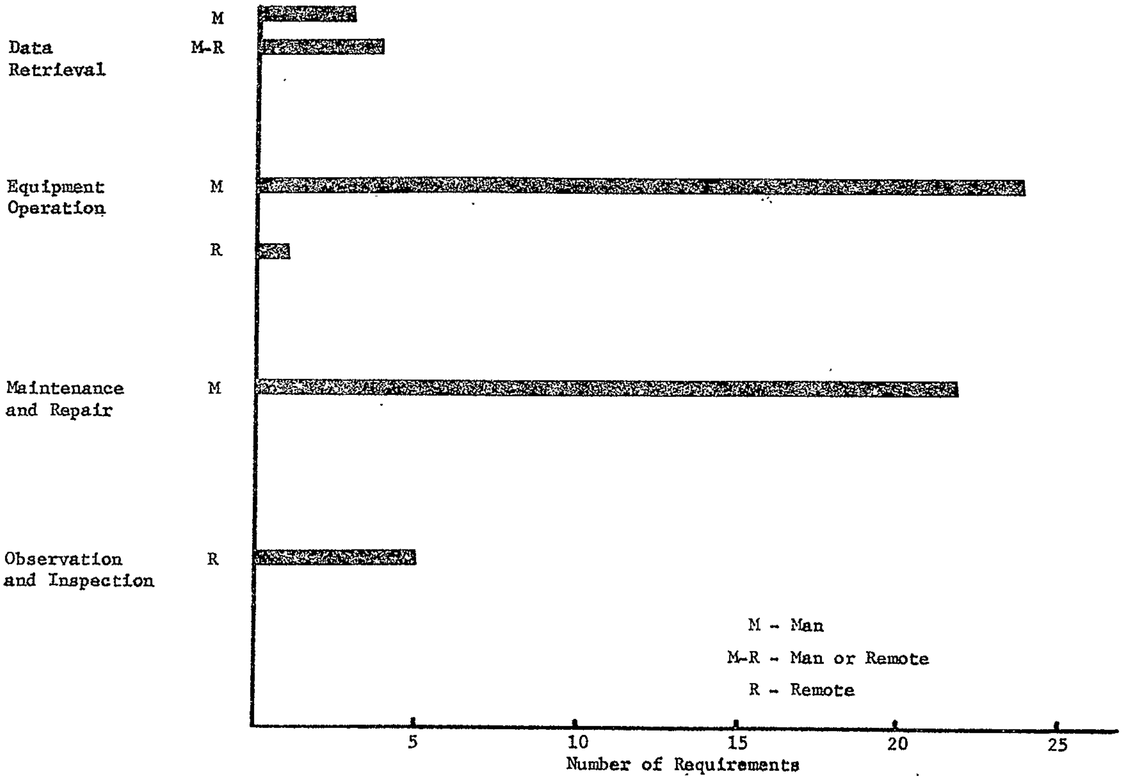

Figure IV-3 Operational Modes

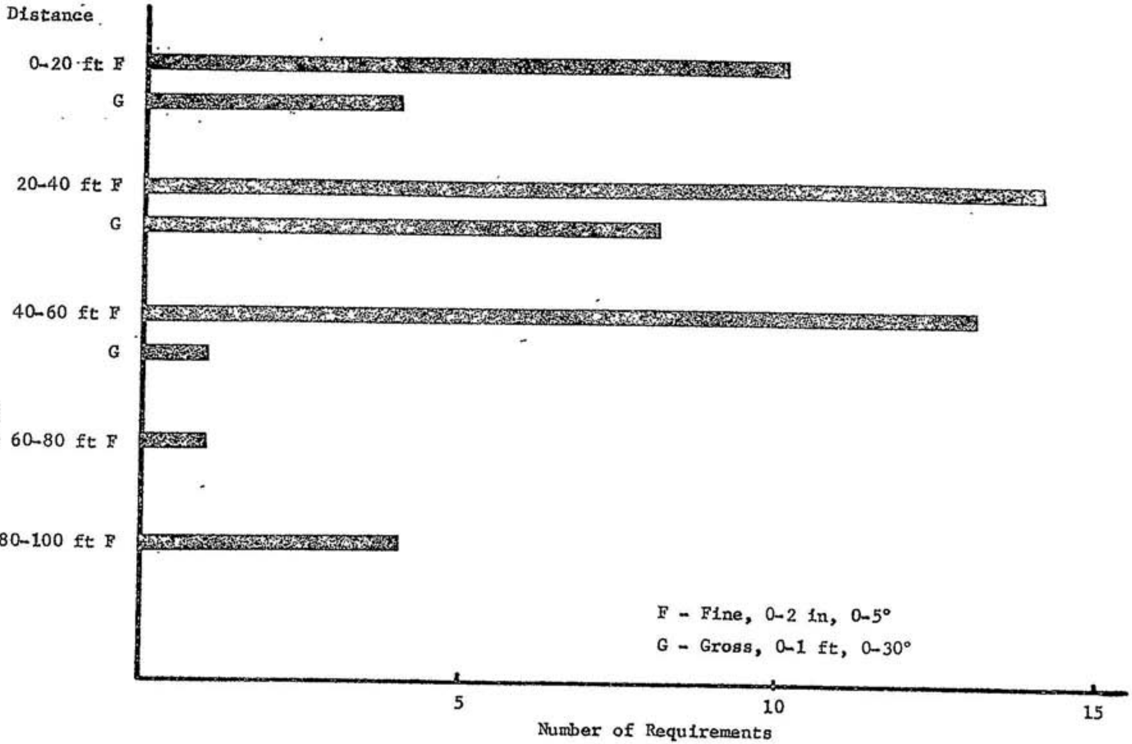

Figure IV-4 Mass Transfer Distance and Positional Accuracy Requirements system to the most sophisticated automatic maneuvering device with a self-contained life supported system. In general, the Astronaut Maneuvering Unit (AMU) is most useful for tasks involving relatively large distances. The HHMU presents significant stability problems, since it provides no automatic stabilization. Extendable booms such as STEM, are generally capable of moving in one direction only, and are a one for one comparison basis are not sufficiently versatile for a large variety of tasks. Space Taxi's would be suitable only where large distances and times are involved, and from the preceding this involves a very small number of applications. Since the Serpentuator would be designed for 60 ft or less, these were not considered competing devices.

In summary then the EVA requirements and the basis for the comparisons of Serpentuator, HHMU, AMU, STEM and manual are for distances of 60 ft or less, with cargo of 60 lb or less, positional accuracies of 2 inches or less, time durations per excursion of 2-4 hours, and a large number of excursions.

a. Excursion Time - Most of the EVA excursion time is concerned with actual performance of the work task, rather than translation to the worksite. Therefore, the potential time reductions using any of the powered devices do not appear significant, since translational distances are relatively short. For example, a translation distance of 60 ft (120 ft round trip) requires 1 minute with Serpentuator, based on a tip velocity of 2 fps. The time required for handrail translation is 6 minutes, based on an average velocity of 1/3 fps. EVA excursions for the 11 experiments range from 2 to 4 hours, with approximately 30 minutes allowed for egress/ingress operations. Thus, the time saving with Serpentuator amounts to about 5 minutes out of a minimum of 90 minutes, or a maximum reduction of 6%. The greatest distance astronauts must travel, within a 60-ft radius sphere, is 430 ft. With handrails, this would require 24 minutes of the total 4-hour task time. Using the Serpentuator, this time is reduced to 4 minutes, resulting in a total advantage of 8%. This maximum distance is for one task only, whereas the next greatest distance is 200 ft. With other powered units, translation times for such distances would be similarly reduced. The AMU, for example, will travel at an average velocity of 1 fps; and the HHMU, an average velocity of 0.5 fps is expected. Obviously since the translational time involved is a very small percentage of the total time this parameter is not an important consideration.

b. Energy Considerations - The energy saving with Serpentuator is also not presented in graphical form, since this factor is insignificant for such short translational distances. Considering a round-trip distance of 120 ft, the astronaut would expend an average 150 BTU (44 watt-hr) translating to and from the worksite with a handrail. With Serpentuator, this translation would require a total energy of 7 watt-hour, 5 for the astronaut and 2 to drive the Serpentuator. These are approximate figures only, based on metabolic rates of 1500 BTU/Hr for handrail translation and 950 BTU/Hr for a stationary astronaut, and an estimated 100 watts of electrical energy required to drive the Serpentuator. The astronaut would save 550 BTU (160 watts) using Serpentuator translation, with 100 watts required for the Serpentuator. Thus, the total power saving amounts to 60 watts.

The results of a Martin simulation study (Ref 7) were used to determine the energy consumption of the AMU and HHMU. Two separate maneuvers were designed to evaluate the translational capabilities of these units. In the first, the test subject started from rest, established a velocity vector toward the target, and then coasted to the target. In the second maneuver, the subject was given an initial velocity vector and was required to arrest his approach to attain a stabilized holding pattern at the target. The total distance travelled in these two maneuvers was about 40 ft.

Using the AMU, the average total impulse needed to complete the two maneuvers was 56 lb-sec. The average velocity attained was 0.9 fps for the first maneuver, and the initial velocity for the second part of the maneuver was 1 fps. With the HHMU, the average total impulse required was 11 lb-sec. The average velocity attained was 0.6 fps for the first part of the maneuver, and the initial velocity for the second part of the maneuver was 1 fps.

The simulation indicated that training time is a significant factor in task performance. During the simulation, three test subjects performed each maneuver three times. The total impulse, as well as the total time required to complete the maneuver, varied considerably for each run. For example, in the first maneuver, the total impulse for the AMU varied from 12 to 28 lb-sec; and the total time varied from 27 to 47 seconds. Using a Serpentuator with programmed trajectories to specified worksites, training time would be significantly reduced.

Time to store and service does not vary significantly among the different devices. Assuming no equipment failures, the Serpentuator merely returns to stand-by configuration by a programmed trajectory. The other powered maneuvering units are stored inside the spacecraft. The propellant for these units must be replaced periodically, but this only involves insertion of a new tank. Neither storage nor propellant resupply requires a significant amount of time.

c. Crew Safety - The most important advantage of using a Serpentuator verses the HHMU, AMU, and manual translation is greater astronaut safety. This safety advantage results largely from Serpentuator characteristics in the event of system failure, rather than from increased reliability of the system itself. AAP presently requires a system reliability of .995. Any EVA mobility device for the program must meet this requirement. Consequently, a safety reliability comparison is reduced to determining which device can most easily meet or exceed this standard. We are as yet unable to estimate this for any of the candidate systems, since they are still in the preliminary design stage.

As a systems concept, the Serpentuator shows significant advantages for crew safety problems. In the event of a difficulty such as astronaut incapacitation due to visor fogging or temporary blackout, the Serpentuator would be superior to the other powered techniques currently available. With the other techniques, a second astronaut would be required to go EVA, using either manual translation or some other maneuvering unit. This rescue would be slow and tedious, since the disabled astronaut would have to be both stabilized and transported by the second astronaut. The Serpentuator could be returned automatically. If the failure occurred in the life support system, time becomes a critical factor. A limited 30-minutes oxygen supply is available for emergency situations. Consequently, the astronaut must return, ingress, and pressurize the airlock within 30 minutes. Assuming a minimum of 10 minutes for ingress and pressurization, the astronaut has only 20 minutes to detach any work restraints and translate to the airlock. This allows little margin for error if he is more than a few feet from the airlock and restrained to the worksite.

With Serpentuator as the prime mode of EVA transport, rescue becomes both rapid and automatic. A second astronaut would be needed only to aid ingress operations. The Serpentuator tip could return to the airlock in less than two minutes from any possible configuration. Thus, although this system does not provide significant time reductions in normal operation, it offers clear advantages under emergency conditions.

Assuming a translational equipment failure for the Serpentuator, the astronaut would be attached to the spacecraft by at least a semi-rigid boom. He could return to the airlock by manual translation using the Serpentuator as a handrail. This would require installation of a handrail from the Serpentuator base to the airlock. In contrast, failure of an AMU or HHMU would require either rescue by a second astronaut or translation using available handrails. But if the astronaut is in a free-flying mode of operation, it is doubtful that he could reach a handrail. Another alternative would be to reel in the stranded astronaut using the tether, but this is impractical at distances over 25 feet, due to the build-up of angular momentum.

A previous Martin Marietta study (Ref 11) investigated the difficulties associated with the tether. While this study was primarily concerned with the problem of maintaining two orbiting bodies (subject to differential drag acceleration) in close proximity using a normally slack tether, the problem of retrieving a tethered object was also studied. Even for the simple cases studied, it was found that direct reel-in of the tethered body resulted in a spiraling trajectory and high tangential velocities at close range. Retrieval could be accomplished only under limited conditions by applying a sequence of tugs to the body, with the tether remaining slack the rest of the time (with the obvious possibility of becoming entangled). The study suggested the possibility of extending the retrieval technique to more general cases by attaching the tether to the spacecraft through a pivoting boom.

Using the Serpentuator as this boom, astronaut retrieval with the tether becomes more practical. If the astronaut is not close enough for direct pickup by the Serpentuator, two retrieval techniques are possible. Neglecting the effect of differential drag acceleration, which is path dependent, the increase in angular momentum is proportional to the square of the difference between initial and final radial distance from the spacecraft. If the initial angular momentum and separation distance are not too large, the tether could be used to pull the astronaut within range of the Serpentuator. Then the Serpentuator would simply pick him up and return him to the spacecraft.

For high initial angular momentum or separation distance, the tether would be attached to the Serpentuator tip. By proper positioning of the Serpentuator and a sequence of tugs (or direct reel-in) the astronaut could be brought within range of the tip. The astronaut's angular momentum could be transferred to the spacecraft by matching tip velocity to astronaut velocity for acquisition, and then gradually slowing the Serpentuator. The Serpentuator would then pick up the astronaut and return him to the spacecraft.

V. CONCEPTUAL DESIGNS

A. Introduction

The conceptual design effort consisted of three separate study areas:

1. Conceptual design of the Inserp relative to Experiment M487;

2. Conceptual design for a remote-controlled Exserp for Saturn V Dry Workshop;

3. Conceptual designs for Exserp hermetically sealed joints.

The Inserp application for M487 was examined for feasibility then compared to the present "fireman's pole" method. The Exserp was studied for two specific tasks and examined methods to guide, stabilize, translate and rendezvous by remote control. The hermetically sealed joints were examined to determine if the bellows could be eliminated.

B. Inserp Conceptual Design

The conceptual design for an intravehicular Serpentuator (Inserp) was based on the cargo transport requirements for Experiment M487, Habitability of Crew Quarters. As described in Section III, this experiment involves transferring equipment packages from the MDA, through the AM, and into the OWS crew quarters area. The Inserp would be located in the forward compartment of the OWS. Equations of motion describing Serpentuator tip location have been programmed for the digital computer to determine the actual movement required for this application.

The model used in this analysis consisted of five links, each 3.75 ft long, with a 3.75 ft rigid extension from the tip joint to the center of the package. The tip yaw joint was limited to an angular movement of $\pm 100^\circ$. Elbow joints were restricted to 45° angular movement in one direction. This restriction was imposed to determine whether the same basic elbow joint of the Exserp could be used for this Inserp application. Thus, the basic Exserp configuration would be tested. This was not a significant restriction, however, and did not influence the results.

1. Programmed Motion

In its initial position, the Serpentuator and attached package were located inside the MDA. The package was then moved out through the AM tunnel by repeatedly stepping the individual joint angles, keeping the package center within four inches of the center line of the tunnel.

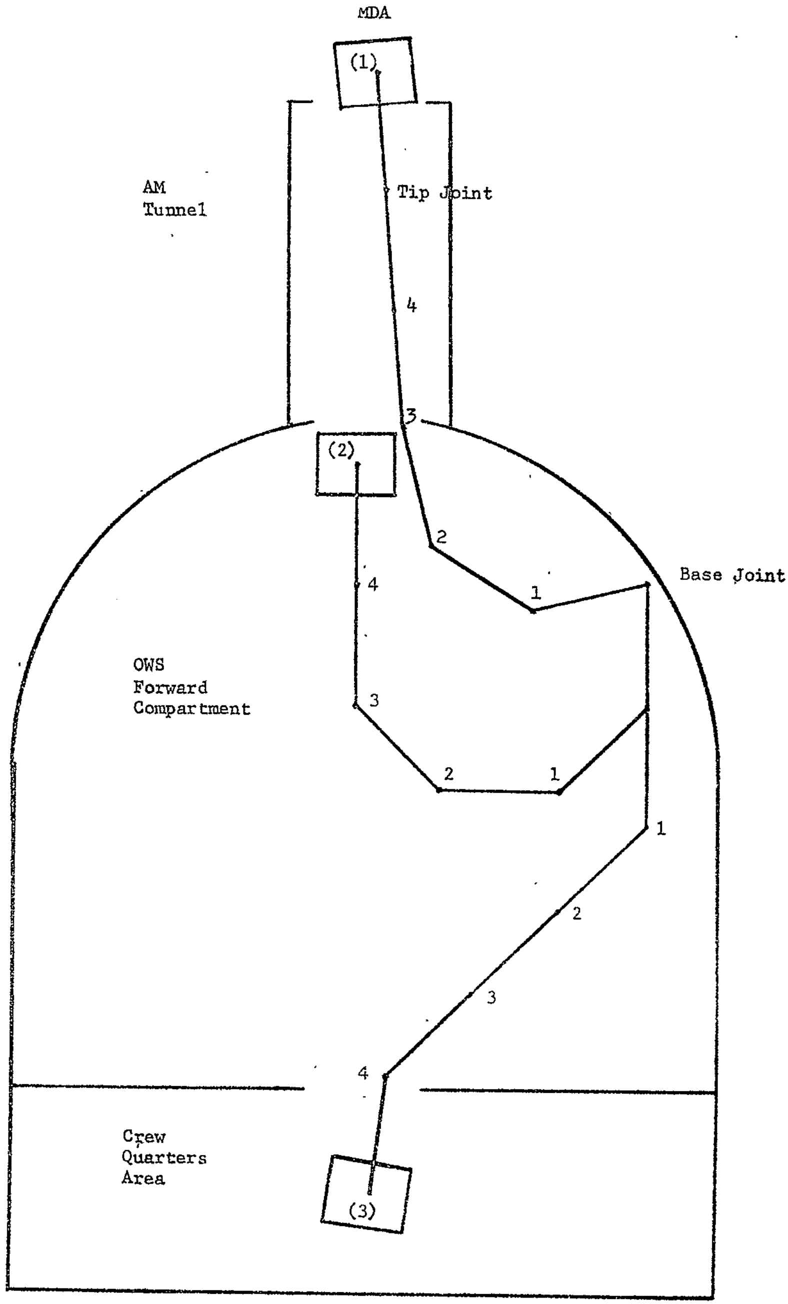

Fig. V-1 INSERP Positions for Equipment Transfer

The sizes of these angular steps were determined using the digital computer.

The computer was programmed to increment each angle and solve for the joint and tip positions. The first angle incremented is elbow joint #3. When the off-center deviation reaches four inches, the base angle is automatically incremented to move the tip four inches off center in the opposite direction. The angle of joint #3 is again incremented and the process is repeated until this angle reaches 45°. Then the angles of joint #4 and the base joint are incremented in the same manner, moving the package into the OWS forward compartment.

Once inside the OWS, the package is positioned above the entrance hatch to the crew quarters area. It is moved through the hatch by again incrementing individual joint angles. Figure V-1 illustrates the different Serpentuator positions when the package is located 1) Inside the MDA, 2) In the OWS forward compartment, and 3) In the crew quarters area. The entire process requires a total of 70 steps. This large number of steps is needed to achieve the essentially straight-line movement for the package, since angular motion of any joint results in package movement along an arc.

Further analysis is necessary to determine the actuator accuracy required for the described motion, and to determine the effects of dynamic loads on the Serpentuator. Such analysis may indicate that it is impossible to move the packages through the hatches without impacting the sides. In this event, Serpentuator motion would be limited to moving packages across the OWS forward compartment, with astronauts manually transporting them through the AM, and into the crew quarters area.

2. Inserp-ETD Comparison

This equipment transfer is currently planned with the Equipment Transfer Device (ETD), which resembles a "skateboard" that rides on a rail. The six-sided rail, or "fireman's pole," extends from the MDA, through the AM, across the OWS forward compartment, and into the crew quarters area. The section of the rail that passes through the OWS is launched inside the S-IVB tank, and must be installed by the crew. The rest of the rail is launched in sections within the MDA. These sections must be mounted on pre-installed brackets in the MDA and AM, and joined with the OWS section. The ETD itself consists of a platform for package attachment and a set of eight ball-bearing wheels that ride on the rail. The wheels are arranged to ride on four sides of the rail, preventing the ETD from tilting or twisting.

Using this device, the astronaut attaches a package to the ETD platform and pulls himself and the ETD along the rail. Once the ETD is moving, he may simply ride along with it, stabilizing his motion by holding onto the platform. The ETD is equipped with a hand-operated brake, permitting the astronaut to stop at any desired location. He will move through the hatches either by pushing the ETD ahead of him or by pulling it through after him. As the astronaut gains experience operating the ETD in zero-g conditions, he may be able to pass through the hatches riding on the platform. This would depend on the size of the package and the skill of the astronaut.

Neutral buoyancy and zero-g tests in a KC-135 aircraft flying parabolic trajectories have evaluated the astronaut's ability to move a package along a handrail without mechanical aids (Ref. 8). In these tests the subject would grasp the fireman's pole in one hand, the package in the other, and lock his legs lightly around the pole for stability. The subjects were able to safely and accurately transfer 60 to 80 lb packages, and suggested that a 90 to 100 lb load maximum appears reasonable for one-man manual transfer. In the KC-135 tests, the subject's legs tended to involuntarily unlock and float apart, resulting in a loss of directional stability. Further tests were recommended to completely verify the concept.

Using the ETD, an astronaut does not have a positive restraint to control his motion while transporting and installing the equipment packages. It is presently felt that he should be in complete control at all times while performing these tasks. Consequently, another transfer device, which restrains the astronaut to the pole and extends out to the walls for equipment installation, is currently under study by AAP personnel.

The Experiment M487 Task Analysis (8 July 1968) by Martin Marietta AAP personnel indicates that 51 round trips between the MDA and OWS are planned, requiring 5 of the total 44 man-hours allotted to this experiment. After all equipment packages have been transferred to the OWS, the fireman's pole must be removed from the AM tunnel and hatches to permit depressurization for EVA tasks.

A Serpentuator could reduce the time required to transfer these packages by approximately two man-hours (40%) or the total time allotted to the experiment by 5%. It would also provide a restraint for packages to be installed in the OWS forward compartment. The Serpentuator would position the package at the proper mounting location, where a restrained astronaut would remove and install the equipment. For installation tasks in the crew quarters area, the Serpentuator would transfer equipment to an astronaut inside the hatch, using pre-programmed motion. This astronaut would be equipped with a movable restraint system, allowing him to control his movement to the storage location. In this manner, he would maintain complete control at all times, eliminating objections to the present mode of equipment transfer. Metabolic costs would also be reduced, since the astronaut would not have to manually move packages out of the MDA into the OWS area.

In addition, Serpentuator installation in the OWS would allow operational testing of the Exserp concept as an EVA mobility aid, within the safe confines of the workshop. This testing could be performed in conjunction with experiment M508, which evaluates other EVA equipment and mobility aids.

C. Exserp Conceptual Design for Dry Workshop Application

This segment of the report describes conceptual design considerations for a remote controlled Exserp for two specific applications; 1) To move a cargo container which will fit in a section of the CSM and 2) To make a hose connection at this location. This was broken down into two considerations. The first was the basic method of guiding the Serpentuator tip to the immediate vicinity of the work station and the second was the tip manipulator requirements to remove the payload.

1. Guidance and Control

To establish the remote guidance and control method, it was assumed that the operator would probably not be able to view the entire Serpentuator at any time since the viewing port in relation to the roll orientation of the CSM is undefined. Eliminating visual guidance, several other modes were considered. The first possibility was television monitoring of the Serpentuator as it traverses between work stations. The points that should be observed at all times include the individual segments, the tip, and any objects within the Serpentuator line of motion. Obviously this mode would require a large number of monitoring units to cover all possible Serpentuator configurations, and the display requirements alone would seem to rule out this mode of guidance.

An alternate method of Exserp guidance would involve sensors located in the joints to measure their angular deflection. With a miniature model of the OWS cluster and attached Exserp, it would be possible to drive the Serpentuator model relative to the cluster model, and thus display the parent system movement. The operator could then use this model display to guide the Exserp to work locations while avoiding spacecraft structures. Conversely, this miniature model could also serve as a working control system to provide command signals to the parent Serpentuator. Thus the model would provide both the command signals and visual display. This technique offers interesting possibilities since it would provide the flexibility of being able to move the tip arbitrarily from one point to another, and built-in safety features could be easily incorporated by merely increasing the boundaries of the cluster. In addition, the computer requirements would be minimal. A

TV camera on the tip would still be required.

The most feasible control method appears to be automatic guidance to the worksite with pre-programmed motion for each Serpentuator mission. The operator would merely select the correct trajectory from a card library, for example, and insert it into a reader that translates this information into control commands. The Exserp would be guided to the worksite but would not dock automatically. This sequence of automatic maneuvers would place the Serpentuator tip at the worksite, within the error limits of the sensors and joints. To return, the outbound sequence would be merely reversed.

With the aid of TV monitors at the tip, the operator would manually provide final vernier correction to reach the target and perform tasks. The change in control modes can be made at his discretion when the worksite is within range of the TV monitors. The effective range of the monitors will depend on illumination of the worksite. Artificial lighting provided by the manipulator system would be focused to avoid glare.

The complexity of the rendezvous and docking maneuvers results from the non-rigid nature of the Serpentuator. Clutch slippage permits the Serpentuator shape to change when small loads are applied. Consequently, the Exserp tip would tend to move away from the docking site. Slow execution of maneuvers should minimize these loads and prevent excessive movement. Also, brakes of the main links could be used to keep these links rigid and thus only the tip would move. This would make automatic retrieval of the payload much easier. Solution of this stability problem requires further definition of the docking device, tip load coupling to the spacecraft and the resulting loads. However, it is obvious that some type of rigid attachment of the tip to the cluster is required for stabilization.

2. Tip Manipulation System

The tip manipulator system of the Serpentuator must allow adequate information feedback between the operator and the worksite. It should be easily controlled to give the operator as much feel as possible for the operations being performed. Figure V-2 illustrates the general design for this manipulator system. Unsurprisingly, the system is anthropometric, designed to give the operator some physical feeling of control. The manipulator "hands" contain piezoelectric grip sensors on the surface used to grasp materials. These sensors provide electric signals that can be visually displayed in terms of force on the grasping surface.

Figure shows three different views of this manipulator system. Arrows at the joints indicate the motion of the stabilizing bars and manipulator arms. The tip of each stabilizing bar is equipped with a ring device which attaches to a pin at the worksite for stabilization.

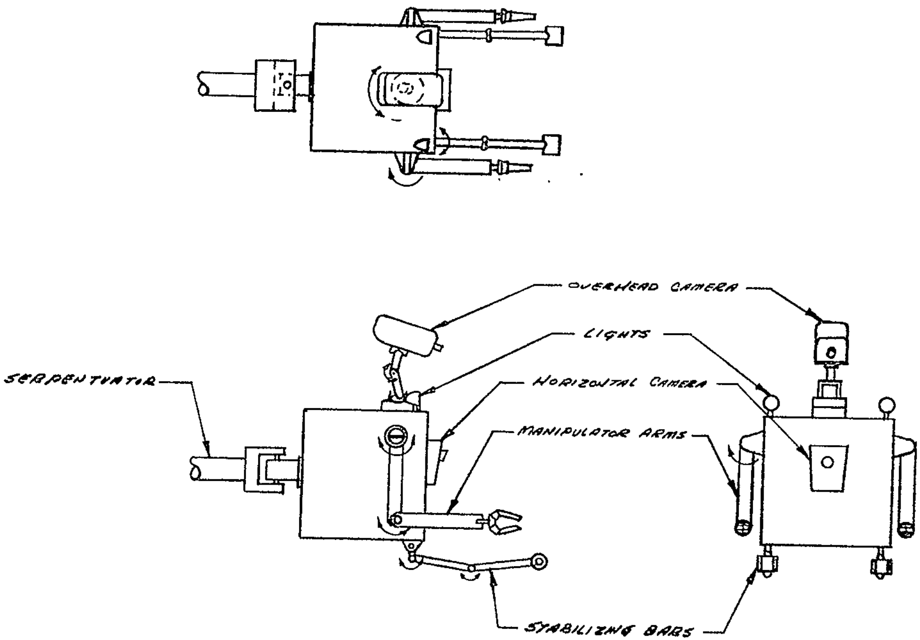

Figure V-2 Tip Manipulator System

The manipulator hand can grip like a vise and rotate about an axis defined by the centerline of the lower arm cylinder. The horizontal camera is a secondary monitoring unit to give the operator a different view of the work area. Over head lights illuminate the target so that one of the two TV cameras has a clear view at all times. The primary television camera is mounted on top of the manipulator box and can move as shown by the arrows in Figure V-2.

3. Cargo Transfer

For the AAP program the interior of the Service Module (SM) has been modified considerably from the SM desinged for lunar flights. A cross sectional view shows that the module is divided into six pie-shaped compartments. At the center is a 1-5/6 foot diameter cylinder. At this writing, it appears that bay #6 is the only one available for use in cargo transport. However, this section has a Reaction Control System (RCS) unit mounted on the outside and explosive removal of the spacecraft skin would damage the unit. Bay #1 (adjoining Bay #6) contains equipment and storage tanks that could be interchanged with the tank in the lower section of Bay #6. This would leave two-thirds of Bay #1 open for cargo and would possibly allow explosive removal of the protective skin.

There are no definite plans for breakdown of the cargo compartment into sections and as yet, no specific designs for fastening these sections to the CSM. The compartment in Bay #1 would be about 5.5 ft wide at the outside, tapering back to the central cylinder wall. Conceivably, this bay could be divided into eight drawers, each 2 by 2.25 ft at the outside. These drawers could be easily handled by the manipulator. Each drawer would be fastened to the bay by two lever-released bolts, which could be freed without applying any force to the vehicle. Each drawer would have handles for the manipulator hands to grasp. If larger cargo modules are needed, the eight-drawer system can be modified to make drawers of greater width or length, but the depth is fixed at four feet. If the cargo is to be taken inside the OWS through the AM, it must fit through the 40-inch hatch between the AM and the OWS.

For those cargo packages which do not go immediately inside the OWS, a platform with the same shape as the drawer could be mounted on the struts near the AM hatch. The cargo drawer could be placed flush to the platform and secured with hydraulically actuated side clamps. It does not seem logical, however, to use this device for cargo to be transported through the AM. It would be much more practical to transfer the drawer directly to the hatch and immediately take it inside the spacecraft. If the cargo box is too large to enter the AM, EVA would be required to transfer its contents inside. This EVA is not needed for direct transfer of cargo into the AM. An auxiliary television camera could be mounted on a strut near the AM to aid in securing the cargo package.

A cargo transfer from the CSM to the OWS would be accomplished by a sequence of operator-selected events. With the Serpentuator in its stowed position, the operator selects a programmed routine to guide the tip to the cargo section of the SM, As the tip approaches the cargo storage bay, the operator provides manual control with the aid of the TV monitor. Using the vernier control board he positions the manipulator to dock with the first cargo drawer. The stabilizing bars are connected and electronic sensing informs the operator when both bars are securely docked. The overhead camera and lights are focused to allow viewing as the manipulator arms begin to remove the drawer. The two levers are released separately without applying force to the spacecraft. Next, the manipulator arms grip the two handles to pull the free drawer out of the SM. At the same time the stabilizing bars are disconnected.

The second phase begins with selection of the return control mode. The Serpentuator reverses its programmed motion and moves toward the AM. As it approaches, the operator switches to vernier control and visually executes the rendezvous maneuver. If the drawer is to be taken into the OWS, the operator maneuvers the tip to the AM hatch where the drawer is taken inside. If the drawer is to be left outside, the manipulator can be docked with the securing platform. In either case the auxiliary television system can aid the operator.

4. Liquid Hydrogen Transfer

Replenishment of the fuel cell hydrogen storage tank in the OWS will be required intermittently. The Serpentuator manipulator system designed for cargo retrieval could make the hose connections between the CSM and OWS storage tanks. However, the locations and equipment to perform this fuel transfer need further definition.

Liquid hydrogen will be stored in three spherical tanks in the CSM. Each tank is paired with a similar liquid oxygen tank. These tandem tanks are located in Bays #1, 3 and 5. The tanks in Bay #1 would be moved to Bay #6 if the cargo compartment is designed as previously described.

The location of the fuel cell storage tank within the dry workshop has not been specified. To use the Serpentuator in making hose connections for hydrogen transfer, the inlets to the OWS tanks must be within range of the Exserp. A convenient location for the inlet valve would be just below the IU on the S-IVB, on the circumference where access Bays 1, 3, 5 would not be obstructed by the ATM.

The hose must be protected during launch but quickly deployed in orbit. It could be conveniently stored on the AM near the S-IVB interface. The hose connection must also be easily handled by the manipulator system. Such a connection must be attached to the tank inlet with both hands so that no torque is applied to the vehicle. It could be disconnected quickly by a push-pull device that releases the attachment.

This sequence of maneuvers would be initiated with a command for the Serpentuator to go to the AM to pick up the hose end. A programmed trajectory transfers the tip to the inlet valve on the S-IVB. The manipulator is docked visually using the stabilizer bars to secure it to the spacecraft. The manipulator hands connect the hose to the inlet valve, one hand holding the valve as the other twists the hose fitting to the inlet. The Serpentuator then returns to the AM to pick up the other hose end. A new trajectory directs the manipulator to the storage tank outlet on the service module. Again, the hose connection is made as described above.

When hydrogen transfer is completed, the manipulator disconnects the hose by holding the SM outlet valve with one hand and pulling the hose fitting free. This action requires very little force and applies negligible force to the spacecraft. A similar disconnect is performed at the S-IVB inlet after the manipulator is guided automatically from the SM to the OWS.

D. Hermetically Sealed Joints

This part of Task B was concerned with the design of two types of hermetically sealed joints: an elbow joint capable of 45° rotation, and a rotary joint capable of ± 200° rotation. From investigations of the various actuators, seals, and lubricants compatible with Serpentuator operational and environmental requirements for the rotary and elbow joints, it was concluded that the design criteria can probably be met without resorting to metal bellows. This is desirable since the metal bellows restricts the angular capability of the elbow joints and increases the weight and stowage area. In addition, a suitable metal rotary bellows to accommodate ± 200° rotation is not available. Metal bellows do prevent lubricant outgassing and contamination, however.

One approach for the rotary joint would utilize United Shoe's hermetically-sealed harmonic drive unit with enclosed torque motor and clutch, and a wet lubricating process similar to Ball Brothers Vac Kote would be applied to the bearings, wave generator, and torque motor brushes. This process involves a very thin film of organic lubricant and shows very little weight loss in vacuum. A dry lubricant similar to the Vac Kote (MOS_2) would be applied to the flex-spine, circular spline, and bearing outboard. The weight loss of this "dry" lubricant is unmeasurable. A dynamic seal such as the Aeroquip "Omiseal", type AR10110, would still be necessary to prevent contamination during neutral-buoyancy tests and during launch and would serve as a hermetic seal. The rotating surface of this seal would be dry-lubricated the same as the flex-spline, Since the dry lubricant is not suitable for neutral-buoyancy tests, a protective cover would be required for this environment. This problem is considered again in section VI and a slightly different approach and more specific recommendations are provided in section VI and Appendix B.

There appears to be no difficulty in acquiring a metal bellows for either the single-pivot or three-pivot elbow joints. The most reliable approach seems to be a harmonic drive similar to the one described above, driving a ball-screw mechanism enclosed in a bellows. The harmonic drive would be hermetically sealed with torque motor and clutch enclosed. A wet lubricant would be applied prior to assembly and run-in. The flex-spline, external bearing, and ball screw would be dry-lubricated and enclosed in a bellows to prevent entrance of foreign matter during launch. Thus, even if the bellows failed during operation the Serpentuator could continue to function and no outgassing or contamination would result.

VI. OPERATIONAL REQUIREMENTS

A. Introduction

This effort involved definition of the orbital operational requirements for a Serpentuator system. The guidelines for this analysis were our previous studies, general system requirements (as outlined in Ref 3), and additional specifications furnished by NASA. The main objective of this effort was to establish requirements for the preliminary design of flight-prototype link and rotary actuators. Various aspects of the existing design were analyzed to determine the changes necessary to flight qualify these actuators.

In addition to the design considerations related to the Serpentuator joints and assembly, several other areas were investigated to determine operational requirements of the Serpentuator. These included environmental considerations, preliminary error analysis, a preliminary investigation of control modes, safety requirements, and umbilical management. In all cases, these investigations were of a preliminary nature and were intended to specify gross requirements only.

B. Detailed Joint Design Recommendations

This section includes comments relative to the details of the base roll and elbow joint designs to qualify the existing Serpentuator (MSFC P/N 500227) for flight.

In general, it was found that all standard elastimer seals fail to meet either the temperature requirements or are only marginal in the hard vacuum of space. Lubricants also create a problem at the temperature extremes. The neoprene bellows is not feasible from both vacuum and temperature considerations. Since the existing torque motors and brakes are rated at only -40°, they (as well as the lubricants) would require further testing or incorporation of either a heater or insulation. Space qualified motors, if available, should be specified. The internal temperature of the Serpentuator structure could be held fairly constant (within $\pm$ 20°F) using insulating material on the exterior of the structure. This would reduce problems with thermal expansion, motor operation, and lubrication. However, the insulation would also retain heat generated by the motors thus presenting another possible problem area. A method for removing this internal heat would have to be provided if a significant temperature increase occurred. Also, the use of insulating material would increase the weight and volume of the Serpentuator.

In general, certain lubricants and anti-friction treatments currently used on space hardware appear feasible for the Serpentuator elbow joint pivot points and bushings, as well as the bearings. Two such lubricants are resin-bonded dispersions with teflon, specifically Emralon 310 and Emralon 315 (produced by Acheson Colloids Co., Port Huron, Michigan).

Both lubricants provide a low-friction, corrosion resistant film, with a bearing load capacity in the order of 20,000 to 30,000 psi. Emralon 310 shows better adhesion characteristics, while Emralon 315 is better at higher temperatures (400°F).

Outlined in Appendix B are our recommendations to space qualify th existing hardware. These changes refer to specific drawings of the existing hardware supplied by NASA. In addition, two drawings illustra ting the recommended changes are included.

C. Structural Design Considerations

Structural aspects of the existing Serpentuator design were inves- tigated for changes necessary to obtain a flight-qualified item. Desig factors were evaluated for both the Serpentuator assembly and specific joints, with emphasis on the joint design requirements for the antici- pated space environment. This analysis was based on the design criteri of the preliminary detail specifications document CP003M00018 and the joint drawings furnished by NASA.

Specific comments and recommendations on each item affecting the structural design are reported in Appendix . These are divided into two sections: 1) those affecting only the Serpentuator joint as define in the NASA drawings, and 2) those pertaining to the Serpentuator assem Comments are coded to the paragraph numbers of the specification docume CP003M00018 and are restricted to those elements affecting structural design.

The conclusions were that the individual joints of the present design are sufficiently strong and no structural problems would be anticipated. The Serpentuator tip velocity should be limited to .5 ft/sec and the jogging control mode could possibly excite the res- onant bending mode.

D. Preliminary Error Analysis

This effort involved investigation of Serpentuator accuracy re- quirements and resulting implications for the control mode and indivi- dual joint assemblies. Accuracy limits are essential for determining system control requirements, such as the nature of tip sensors (i.e., wide-angle versus narrow-angle). This is especially important for un- manned, remote operation. The control requirements can be approached from two directions, either by estimating accuracy capabilities on the basis of existing control and joint design criteria, or by estab- lishing accuracy requirements to be achieved by these designs. The method presented is general and gives tip position and accuracy for arbitrary inputs. The example used here appears to be a "worst-case" condition.

Considering an n-segment Serpentuator with base roll, and yaw only at the tip, the tip position is given by

$$X = \sum_{k=1}^{n} R_k \cos\left(\sum_{j=1}^{k} \psi_j\right)$$

$$Y = \cos\phi \sum_{k=1}^{n} R_k \sin\left(\sum_{j=1}^{k} \psi_j\right)$$

$$Z = \sin\phi \sum_{k=1}^{n} R_k \sin\left(\sum_{j=1}^{k} \psi_j\right)$$

where ϕ is the base roll angle, ψ_k is the yaw angle at joint k, and R_k is the length of segment k.

The partial derivatives of these equations are given by

$$\frac{\partial X}{\partial \phi} = 0$$

$$\frac{\partial X}{\partial \psi_k} = \frac{\partial X}{\partial \psi_{k+1}} - R_k \sin\left(\sum_{j=1}^{k} \psi_j\right)$$

$$\frac{\partial Y}{\partial \phi} = -\sin\phi \sum_{k=1}^{n} R_k \sin\left(\sum_{j=1}^{k} \psi_j\right)$$

$$\frac{\partial Y}{\partial \psi_k} = \frac{\partial Y}{\partial \psi_{k+1}} + R_k \cos\phi \cos\left(\sum_{j=1}^{k} \psi_j\right)$$

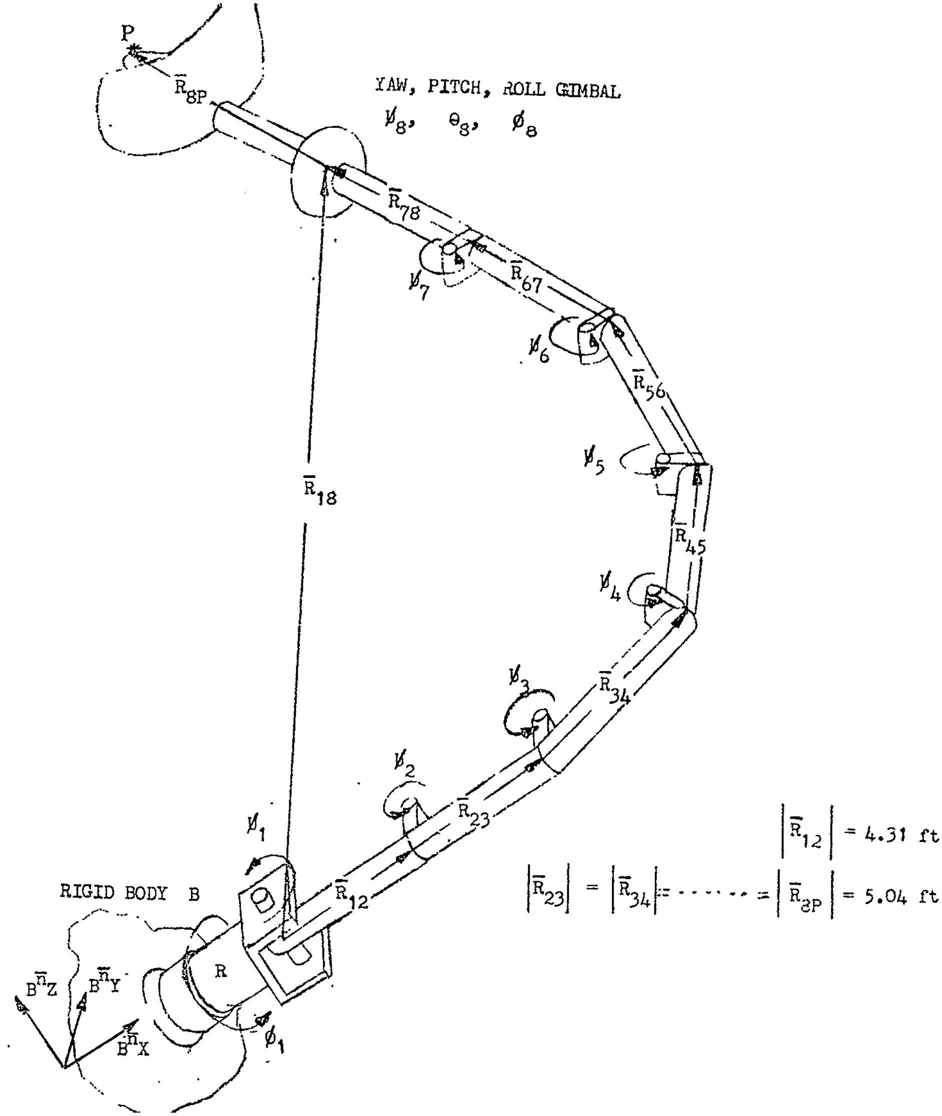

Figure VI-1 - Nomenclature Used To Describe Serpentuator

$$\frac{\partial Z}{\partial \emptyset} = \cos\emptyset \sum_{k=1}^{n} R_k \sin\left(\sum_{j=1}^{n} \psi_j\right)$$

$$\frac{\partial Z}{\partial \psi_k} = \frac{\partial Z}{\partial \psi_{k+1}} + R_k \sin\emptyset \cos\left(\sum_{j=1}^{k} \psi_j\right)$$

The approximate tip errors are then given by the Jacobian Matrix:

$$\begin{bmatrix} \Delta X \\ \\ \Delta Y \\ \\ \Delta Z \end{bmatrix} = \begin{bmatrix} \frac{\partial X}{\partial \emptyset} & \frac{\partial X}{\partial \psi_1} & \frac{\partial X}{\partial \psi_2} & \cdots & \frac{\partial X}{\partial \psi_n} \\ \\ \frac{\partial Y}{\partial \emptyset} & \frac{\partial Y}{\partial \psi_1} & \frac{\partial Y}{\partial \psi_2} & \cdots & \frac{\partial Y}{\partial \psi_n} \\ \\ \frac{\partial Z}{\partial \emptyset} & \frac{\partial Z}{\partial \psi_1} & \frac{\partial Z}{\partial \psi_2} & \cdots & \frac{\partial Z}{\partial \psi_n} \end{bmatrix} \begin{bmatrix} \Delta \emptyset \\ \Delta \psi_1 \\ \Delta \psi_2 \\ \cdot \\ \cdot \\ \cdot \\ \Delta \psi_n \end{bmatrix}$$

These equations were programmed for the digital computer. Thus the tip position errors for any Serpentuator configuration can be determined for a given joint accuracy. Conversely, the allowable joint angle errors can be determined for any given positioning accuracy.

For example, consider an eight segment, 40-ft Serpentuator, assuming equal angle errors ($\Delta\psi$) at each yaw joint and the following segment lengths.

$R_1 = 4.31$ ft

R_2 thru $R_8 = 5.04$ ft

Considering first the position error in the Y-direction due to yaw-angle errors, it can be seen that this error will be a maximum with all of the angles at the zero position. The error in the Y-direction is then given by

$$\Delta Y = \Delta \psi \sum_{k=1}^{8} KR_k$$

which, for the given dimensions is

$$\Delta Y = 180.71 \Delta \psi$$

If a positioning accuracy of ± 2 inches is desired (the fine positioning accuracy requirement in section IV) the resulting maximum allowable error in the yaw joint angle is approximately 0.05°. Identical results are obtained for the X-direction, if ψ_1 equals -90° and ψ_2 thru ψ_8 equal 0°, and for the Z-direction if ϕ equals 90° and ψ_1 thru ψ_8 equal 0°. This maximum error is a worst-case condition based on a particular Serpentuator position, with equal errors at all joints and the same direction for all errors. Assuming the probability of a positive error equals the probability of a negative error, the probability (P) of all eight angle errors being in the same direction is

$$P = \left(\frac{1}{2}\right)^8 = 0.00391$$

or the probability that all eight angle errors will not be in the same direction is

$$1-P - 0.996$$

...ging the Serpentuator to this worst-case error condition would be extremely conservative, since it assumes maximum allowable error at all joints, and the same direction for all errors.

Position error is a function of the individual joint angles, and varies for different Serpentuator positions. For example, for ATM film retrieval, which was simulated in a separate Martin Marietta study (Ref 9), the worst-case position error for the 13 steps involved is 19.3 inches per degree of angle error, assuming equal magnitude errors at each joint, including the base roll joint. With an angular error of 0.05 degrees, the resulting worst-case position error is 0.96 inches.

The problem of achieving a joint accuracy of 0.05 degrees has not been investigated and as discussed previously, would be unduly harsh. However, it does illustrate the difficulty of achieving the fine positional accuracy requirement of section IV. Even with closed loop control this requirement appears severe. A joint accuracy of 1/3 degree would allow a worst-case positioning error of one foot, which appears reasonable The ability of current designs to achieve this accuracy, considering motor transients, on-off command uncertainty, joint tolerances, etc., has not yet been investigated. Empirical data for existing hardware designs would greatly facilitate this analysis.

E. Controls Effort

The Serpentuator control mode which has been considered allows the movement of only one joint at a time. Both manual control-with the astronaut selecting the joint motion, and programmed control-with the Serpentuator moving along a predetermined trajectory, have been investigated.

There are numerous problems associated with the manual control mode. A significant problem results from the fact that an astronaut riding on the tip cannot see the extended links behind him. Thus he has no knowledge of the Serpentuator position other than his memory of the motion, and would have trouble preventing the Serpentuator from striking the spacecraft. Except for the base roll, gross translation is accomplished by a yaw rotation. Thus, a major portion of the tip motion is in the plane of the links. Since the astronaut cannot see the links behind him, he has no knowledge of the location of this plane. Thus, a yaw motion commanded by the astronaut may not produce the desired direction of travel. This was illustrated by the simulation effort discussed later. Similar problems would exist with control commanded at the base of the Serpentuator with the links out of view. Also, the sensor and display requirements for this operation are considerable.

A more attractive manual control mode is the model command technique discussed in section V. In this technique the operator manually places the Serpentuator model relative to the cluster model to the desired location. The angular deflections are then read from a potentiometer etc., and then commands the parent Serpentuator to the same relative work station on the actual cluster. Built-in safety features can be incorporated by merely increasing the cluster boundaries. Furthermore, the flexibility of moving arbitrarily from one point to another is inherent. Any TV sensors located on the parent Serpentuator would be for observation only and the display requirements would not be intimate to the actual control (Final vernier tip placement excluded). Computer requirements would be minimal.

Other options involve the use of a computer in conjunction with the Serpentuator to calculate trajectories to the desired work areas. Using the computer, the control system could possibly be designed so the astronaut would effectively have "stick" control of the Serpentuator. That is, pushing the stick forward would drive him forward, pulling the stick back would drive him back, and similar control for left, right, up and down. The other possible control mode with the computer would involve direct computation of trajectories to the desired tip location. With this technique, the astronaut would set in the desired final tip location and the computer would calculate the trajectory and supply the required command signals. Both of these computer connected techniques would be complex, due to the number of joints to move, and the constraints imposed by the spacecraft structure. The size of computer required, and the calculation time involved, would make this type of control system extremely complex and impractical.

A control mode which appears practical is the use of pre-programmed trajectories to place the Serpentuator tip in a given location. To allow complete tip coverage within a 40 ft radius sphere, approximately 250 pre-programmed trajectories would be required and would provide positioning of the tip within a 10 ft cube. This number could be reduced when the Serpentuator base mounting location is specified, since the above includes points which are inside the spacecraft. To change from one cubic area to another, the Serpentuator tip would first return to the neutral position and then travel to the second area. This limits the required trajectories to be equal to the number of areas covered. To allow arbitrary translation from one point to another would require approximately 32,000 trajectories, and thus, is impractical.

After the pre-programmed trajectory has placed the tip within the 10 cubic ft area, the astronaut would use manual vernier control to adjust his position at the worksite. The manual control would preferably move just the tip joint, although if more motion is required, vernier control of the main joints may be considered. The pre-programmed trajectories would be calculated to result in a minimum of final adjustment at the specified worksites, thus requiring only small adjustment of the Serpentuator joint angles. The adjusted joint angles would be returned to their pre-programmed positions prior to reversal of the trajectory for return to the spacecraft. This would be accomplished either automatically, using a memory, or manually, using a null indicator. The manual null is preferable, since then it is not necessary to repeat each step that a particular angle was moved. This could be significant if a joint was moved back and forth in achieving the final tip location.

The pre-programmed trajectories also allow rapid retrieval of the Serpentuator, which is not available with manual control, unless the computer techniques are being used. With manual control, retrieval would be accomplished either manually, or with memory circuits to reverse the deployment sequence. In either case, the retrieval would not necessarily be rapid, since it would essentially be a reversal of a non-optimum deployment sequence. If the astronaut spent 10 minutes adjusting the joints for deployment, it is reasonable to expect that retrieval could also require 10 minutes. The pre-programmed trajectories would be optimized prior to flight, and thus would allow much faster deployment and retrieval.

A very brief simulation of the Serpentuator was conducted by Martin Marietta Corporation in relation to another effort (Ref 9), using the fixed base, servo-powered Space Operations Simulator, which is controlled by a hybrid computer. The purpose of this simulation was to investigate Serpentuator type control problems and to simulate actual motion, so that various control approaches could be tested with man in the loop. Either a pre-programmed trajectory or a manual mode of operation could be selected in the simulation.

The test subject was allowed approximately two hours to become familiar with the simulator controls. At the end of this training time, the Serpentuator was put in a known orientation, and the test subject flew to a prescribed location with a given orientation. No constraints were imposed, such as minimizing time or avoiding obstacles. Even without restraints, maneuvers requiring the use of more than tip control were difficult to perform. Thus, due to the difficulties involved, manual control does not appear to be a desirable mode of operation. The manual mode could possibly be used as a backup mode in the event of failure of the automatic mode.

F. Systems Considerations

From safety considerations, it is essential that the astronaut remain attached to the Serpentuator at all times and for automatic retrieval it is desirable for the Serpentuator to remain rigid while the astronaut is performing tasks. If the Serpentuator were not rigid, and a joint slipped, the position of the Serpentuator would not be known unless monitored in some manner and motion reversal would not automatically return the astronaut to the airlock.

This implies that it is necessary to provide restraints at the worksite, so that loads created in the work task would not be transmitted to the Serpentuator. This would reduce the capability for performance of tasks at nonscheduled work areas, but would be satisfactory for the majority of the EVA tasks.

In order to determine the loads a Serpentuator must handle without slippage and when restraints are not used, it is necessary to determine the loads which are created by the astronaut on the tip. No data is available concerning the forces produced by an astronaut performing work tasks in a zero-g environment. This data must be generated before an accurate determination of the Serpentuator load capability can be established. Data is available, however, concerning the forces produced by an astronaut due to limb movement (Ref 5). This data indicates that the <u>maximum</u> forces produced by normal arm or leg movements is less than 5 pounds. Therefore, the Serpentuator must be capable of handling a 5 pound force and the resulting moments at the joints, if it is to remain rigid even during translations. If a 60-ft Serpentuator is used, a moment of 300 ft-lbs could be produced at the base joint due to astronaut movements. These moments would be produced by an astronaut moving his arms or legs to accomplish the specified work task (or moving while the Serpentuator translation is occurring). The moments would be cyclic in nature, with an average frequency of less than one cycle per second, and would therefore, not be applied to the Serpentuator over an extended period of time.

The loads produced by the performance of work tasks will probably be somewhat higher than those produced by limb motions. These loads should be determined either by neutral buoyancy simulation of the Serpentuator system, or by a separate simulation of typical work tasks. These loads would determine the joint requirements if restraints were not used at the worksite. If the Serpentuator cannot handle a minimum 5-g force at the tip, its shape would necessarily change, compounding the control problem. Thus it seems the Serpentuator must be designed to handle this minimum force at the tip without moving, or else the system should be designed so that only the tip moves due to tip forces. In this manner, the tip could be returned to its initial position (preferably manually, with a null indicator) prior to initiation of the return trajectory.

G. Umbilical Considerations

It is necessary to attach and retain the umbilical along the length of the Serpentuator to remove the umbilical management problem. In this manner, the umbilical would be completely controlled by the Serpentuator and would be continuously available. The attachment must be designed so that the umbilical can be easily removed by the astronaut, and in the event of an emergency the Serpentuator could be used as a handrail.

The problems associated with extended exposure of the umbilical to the space environment were briefly investigated. Apparently the major problem with a soft umbilical is deterioration due to ultraviolet radiation from the sun. This problem could be solved by shielding the umbilical with metallic braid, or by using flexible metal hose for the umbilical. The higher pressure drop in a flexible metal hose would probably require a larger diameter hose, since the pressure drop is inversely proportional to the fifth power of the diameter. Therefore, a small increase in diameter significantly reduces the pressure drop. A complete trade-off study is necessary to determine the requirements (weight, volume, shielding or insulation, power for circulating pumps, etc.) for each type of umbilical line and to select the best type for this application. In either case, the concept appears feasible.

VII - SPACE QUALIFICATION OF HINGE JOINT

A. Introduction

This section (in direct response to Reference 4) presents an end item specification for the Serpentuator elbow hinge assembly, modification to the Serpentuator system end item specification (under separate cover) and a test plan to space-qualify the elbow hinge assembly.

B. Serpentuator System End Item Specification

Although we did not delete the requirement in the specification, the desirability of manual control appears questionable. A brief simulation on our six-degree-of-freedom moving-base simulator indicated that the manual control mode may involve considerable operator difficulties and a great deal of training. Although automatic retrieval after a sequence of manual operations could be accomplished either by reversing all sequences or by automatically computing a return trajectory, neither alternative is particularly desirable. The first requires wasted motion and energy, while the second adds considerable complexity and problems of development and reliability. The question essentially involves the necessity of including a manual mode. Although this mode might be desirable for going from one arbitrary point to another (assuming the operator could satisfactorily accomplish this), preprogrammed trajectories to specified locations achieve the same result. Manual control could very possibly then be required only for final tip adjustment. The tip adjustment control requirement would then depend upon the accuracy and repeatability of the main control lengths. This could be accomplished either with a man on the tip or remotely. A great deal of effort is required in this area to adequately determine the main length accuracy and repeatability, the feasibility of tip manual control only, the nature of tip sensors required for remote operations, the ability of an astronaut maneuver successfully to a desired point using tip control only, etc. The present neutral buoyance testing program for Exserp should provide extremely good data toward resolving these questions. Other than this item, the contract End Item Specification is quite complete and only minor modifications were required. Principally, our studies showed that a jogging control may be undesirable, for the designated design, and velocity should be restricted to a low level. The other modifications were: 1) Updating the applicable documents, 2) Adding system interface requirements and 3) Adding the launch environments for the ATM. The revised specification is included under separate cover.

C. Serpentuator Hinge Joint Specification

This item was required as a separate document since the test plan requested was oriented specifically to the hinge joint. This specification was oriented along the lines of the system specification and follows that specification quite closely. It does, however, provide a specific control document for the hinge joint and could easily be modified to provide a specification for a different hinge joint design.

D. Test Plan for Hinge Joint Assembly

The Test Plan presents the tests required for the development, qualification and acceptance test phases and provides the definition of the test objectives and procedures to demonstrate these requirements.

The testing concept complies with the NASA philosophy of testing at the highest hardware level consistent with a good technical test approach. Thus testing of the hinge joint will be primarily accomplished at the subsystem level. Component level testing is required only for the bellows. This is due to the hermetically sealed qualities of the design and since the bellows is critical to this concept a high level of testing of this element is required to ensure this capability.

It is anticipated that no major testing will be required in the materials area, assuming that the temperature requirements are firmly established and the system is designed for this. The temperature requirements listed in the test plan are rather severe, and, from our very brief, analysis may not be required. This requirement depends solely on the application. In any event, this does not appear to present a limitation. Contact with several vendors indicated that although their lubricants had not been tested to the very severe environment, they did not anticipate difficulty in achieving satisfactory operation at these extremes. Piece parts selection from the AAP qualified parts list and materials selection per the latest bi-weekly non-metallics materials limiting should be sufficient to satisfy individual component requirements without extensive testing.

FOREWORD

This End Item specification for the Serpentuator hinge joint assembly is based on the existing Exserp neutral buoyancy model and the hermetically sealed concept.

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1.0 SCOPE

This part of this specification establishes the requirements for performance, design, test and qualification of one type of equipment identified as the Serpentuator Hinge Assembly, a subassembly of EI #003018, Serpentuator, for Apollo Applications Program AAP-4.

This specification requires that the Serpentuator Hinge Assembly, as a part of and in conjunction with the assembled Serpentuator, function as a method of transporting an astronaut and his equipment from an EVA hatch to an external cluster work station. The Hinge Assembly shall be designed to operate within the mission requirements of NASA Program Directive No. 5 for AAP-3/AAP-4.

2.0 APPLICABLE DOCUMENTS

The following documents of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced here and other detail content of Sections 3, 4, 5, and 10 to follow, the detail content of Sections 3, 4, 5, and 10 shall be considered a superseding requirement.

Specifications:

Military

MIL-C-50150	Connectors, Electric, Type AN; February 4, 1965
MIL-W-5086A	Wire, Electrical, 600-Volt, Copper, Aircraft; April 6, 1962
MIL-E-6051C	Electrical-electronic System Compatibility and Interference Control Requirements for Aeronautical Weapon Systems; September 10, 1964
MIL-I-6181D with Ch 3	Interference Control Requirements, Aircraft Equipment; June 1, 1962
MIL-B-7883	Brazing of Steels, Copper, Copper Alloys, and Nickel Alloys; January 23, 1954
MIL-P-116E	Preservation, Methods of; November 1, 1966
MIL-V-173B	Varnish, Moisture- and Fungus-Resistant (For the Treatment of Communications, Electronics, and Associated Electrical Equipment); January 19, 1961
MIL-I-8500B	Interchangability and Replacability of Component Parts for Aircraft and Missiles
MIL-C-26482D	Connector, Electric, Circular, Miniature, Quick Disconnect (Navy); May 10, 1966

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MSFC-SPEC-135	Welding, Fusion, Specification for
MSFC-SPEC-219A	Connectors, Flat Conductor Flexible Electrical Cable; May 5, 1966

MSFC-SPEC-220B	Cable, Flat Conductor, Flexible, Electrical, Copper; January 28, 1966
MSFC-SPEC-250 (Amendment 1)	Protective Finishes for Space Vehicle Structures and Associated Flight Equipment, General Specification for; February 28, 1963 (February 28, 1964)
MSFC-SPEC-259A	Radiographic Inspection, Soundness Requirements for Fusion Welds in .25 Inch and Thicker Aluminum and Magnesium Plate Material, Specification for; April 9, 1965
10M32447	Human Engineering Design Constraints for AAP Experiments

Standards:

Military

MIL-STD-810B	Environmental Test Methods for Aerospace and Ground Equipment; June 15, 1967
MIL-STD-130B (with Ch 1)	Identification and Marking of US Military Property; April 24, 1962
MIL-STD-143A	Specifications and Standards, Order and Precedence for Selection of; May 14, 1963
MS-33586A	Metals, Definition of Dissimilar; December 16, 1958

George C. Marshall Space Flight Center

MSFC-STD-343 (Suppl. 1) (w/Detail Spec)	Preservation, Packaging, Packing, Handling, and Shipping of Space Vehicle Supplies and Associated Equipment, General Standard for
MSFC-STD-154	Printed Circuit Design and Construction, Standard for; March 29, 1963
MSFC-STD-267A	Human Engineering Design Criteria, Standard for; September 23, 1966
MSFC-STD-271A	Fabrication of Welded Electronic Modules, Standard for; October 29, 1964
MSFC-STD-421	Electrical Support Equipment, General Design Requirements for; August 18, 1964

Drawings:

George C. Marshall Space Flight Center

500227	Assembly, Serpentuator ..
10M30111A	Failure-Effects Analysis, Procedure for Performing
10M09302	Preservation, Packing, and Packaging of Parts, Specification for; May 16, 1960
40M39526A/2	Cables, Electrical, Shielded; June 1967
40M39513	Wire, Electrical, Hook-up; Revision A, April 25, 1966
50M02435	ATM Logistics Plan; January 10, 1968
50M02425	Checkout Requirements Document
50M12725	ATM Electromagnetic Compatibility Control Plan; February 15, 1967
50M02417	Performance and Design Requirements, Apollo Telescope Mount (ATM) System, General Specification for

Publications:

NASA

NPC 200-2	Quality Program Provisions for Space System Contractors; April 20, 1962
NPC 200-4A	Quality Requirements for Hand Soldering of Electrical Connections; August 1964
NASA SP-6001	Apollo Terminology; August 1963
TM X-53139	Reference Atmosphere for Patrick AFB, Florida; (Annual)
TM X-53328	Terrestrial Environment Criteria Guidelines for Use in Space Vehicle Development; February 1, 1967.
TM X-53521	Space Environment Criteria Guidelines for Use in Space Vehicle Development; 1967 Rev.

3200.059	Program Directive No. 5 Flight Mission Directive for AAP-3/AAP-4
SE-008-001-1	Project Apollo Coordinate System Standard
ASD-QA-09-67-1	Apollo and Apollo Applications Safety Program Plan; dated May 1967

George C. Marshall Space Flight Center

MSFC-PPD-600	Preferred Parts Listing, Electrical, Vol I & II
MSFC-TLS-488	Technical Specifications Listing
13M06634	Launch Vehicle to Spacecraft Functional Launch Requirements, AAP-4
50M02408A	Environmental Design and Qualification Criteria for ATM Components; February 1, 1968
50M02411A	ATM Configuration Management Plan; November 17, 1967

Handbooks

NHB 5300.5	Apollo Applications Reliability and Quality Assurance Program Plan; May, 1967
NHB 8080.3	Apollo Application Test Requirements; October 13, 1967

3.0 REQUIREMENTS

The Serpentuator Hinge Assembly shall meet the performance, definition, design and construction requirements specified in this section. The performance requirements specified in 3.1 establish the capability of the Hinge Assembly. Definition requirements specified in 3.2 establish the mechanical and functional relationship of the Hinge Assembly to other equipment and facilities. Design and construction requirements are specified in 3.3.

3.1 Performance - The Serpentuator Hinge Assembly shall be designed to accomplish the performance requirements of this specification. The performance requirements are specified in terms of functional characteristics and operability requirements.

3.1.1 Serpentuator Hinge Assembly Functional Characteristics

3.1.1.1 Primary Performance Characteristics - The Serpentuator Hinge Assembly, a sub-assembly of EI #003018, Serpentuator, shall contain the means to provide movement, independently and in a common plane, to adjoining sub-assemblies of the Serpentuator. It shall, as a part of and in conjunction with, all assembled Serpentuator sub-systems and components be capable of supporting and transporting an astronaut and his cargo to and from an EVA hatch to a specified external work station. The Serpentuator shall be installed and checked out on the launch vehicle assigned for flight mission AAP-4.

3.1.1.1.1 Preflight

3.1.1.1.1.1 Stand-by Time - The Serpentuator Hinge Assembly shall be capable of successful operation after exposure for TBD hours to the environment encountered during loading the Saturn IB vehicle propellant tanks.

3.1.1.1.1.2 Checkout - The Serpentuator Hinge Assembly shall be capable of undergoing checkout procedures during test, prelaunch and launch operations to verify operational capability. Checkout requirements are defined in MSFC Document 50M02425, ATM Checkout Requirements Document.

3.1.1.1.1.3 Prelaunch Loads - During prelaunch operations, the Serpentuator Hinge Assembly shall meet the requirements of the applicable loads and factors of safety specified in 3.1.2.4.1 and 3.1.2.8.1.

3.1.1.2 Secondary Performance Characteristics

3.1.1.2.1 External Profile - The Serpentuator Hinge Assembly shall conform to the external profile and envelope dimensions given in Figure TBD.

3.1.1.2.2 Internal Profile - The internal profile of the Serpentuator Hinge Assembly shall be a product of design which shall incorporate the requirements of this document.

3.1.1.2.3 Flight Loads - During launch and flight operations the Serpentuator Hinge Assembly shall be capable of meeting the requirements specified in 3.1.2.8.2, 3.1.2.8.3 and 10.2.

3.1.1.2.4 Mechanical/Structural System

3.1.1.2.4.1 General Configuration - The Serpentuator Hinge Assembly shall consist of the following major components: electric torque motor, brake, gearing, limit switch cams, mechanical stops and an actuator arm (driver) to drive the elbow hinge (driven). The pivot shall be hermetically sealed in a metal bellows. All other internal parts and mechanisms will be hermetically sealed at each flange end of the hinge assembly. All internal mechanisms shall be self-lubricating. (Ref. MSFC Drawings TBD)

3.1.1.2.4.2 Weight - The total weight of the Serpentuator Hinge Assembly shall not exceed TBD pounds.

3.1.1.2.4.3 Operational Loads, Structural - The Serpentuator Hinge Assembly shall be capable of meeting the following operational loads requirements: (See Fig. TBD)

a. Maximum torque output (driving torque imposed on hinge by motor) - TBD Ft Lbs.
b. Axial Loads - TBD Lbs.
c. Shear Loads at flanges (in any direction) - TBD Lbs.
d. Bending Moments (in any plane) - TBD Ft Lbs.
e. Twisting Torques (in any plane) - TBD Ft Lbs.
f. Deflections (in any plane) - TBD Inches.
g. Internal Pressure - TBD PSI.

3.1.1.2.4.4 Hinge Assembly Movement - The Serpentuator Hinge Assembly shall be positioned by electric motors. The assembly motor shall incorporate a braking system capable of stopping and holding the driven leg in any intermediate position. The assembly shall be designed to provide a movement of from 0° - 45° in the yaw plane in the driven leg.

3.1.1.2.4.4.1 Gearing - Gearing shall be selected such that the maximum listed angular velocity and acceleration are not exceeded when the hinge assembly is activated by the maximum speed control motor (3.1.1.2.4.4.2). Gears shall be designed for a minimum of TBD operations.

a. Maximum Angular Velocity - TBD.
b. Maximum Angular Acceleration - TBD.

3.1.1.2.4.4.2 Torque Motor - The motor shall be selected to match the gearing (3.1.1.2.4.4.1) such that the maximum angular velocity and acceleration are not exceeded. The maximum rate of motor torque buildup permitted is TBD. (Ref. Fig. TBD). The motor shall be designed for a minimum of TBD hours.

3.1.1.2.4.4.2.1 Brake - The maximum rate of braking torque onset is TBD (Ref. Fig. TBD).

3.1.1.2.4.4.3 Hinge Assembly Rigidity - The Hinge Assembly shall be mechanically restrained in position after removal of power. When not in operation, the assembly must present a rigidity approaching the permanent deformation torque of the structure but not exceed the slip torque of the brake which is TBD Ft-Lbs.

3.1.1.2.5 Electrical System - The Serpentuator Hinge Assembly shall be designed to operate on 28 ± 2 VDC source of power. The power required to operate the assembly shall not exceed 150 W. All cabling shall be protected to eliminate damage. Wires shall be shielded where required. The electrical system shall comply with the criteria listed in 10.1. The Hinge Assembly shall be grounded to the ATM rack structure.

3.1.2 Operability

3.1.2.1 Reliability - The overall reliability of the Hinge Assembly shall be greater than TBD for a period of TBD.

3.1.2.1.1 Failure Effects Analysis - A failure effects analysis in accordance with MSFC Drawing 10M30111A shall be conducted to determine the effect of all potential Hinge Assembly failure modes on the ATM Mission. No single failure mode of any mechanical or electromechanical component shall cause the loss of any flight or ground-crew member, prevent the continuation of the mission or, in the event of a second failure in the same area, prevent a successful abort of AAP-4 primary mission.

3.1.2.1.2 Ground Support Equipment (GSE) Reliability - Reliability of maintenance equipment and other GSE shall be such as to not degrade the overall reliability of the Hinge Assembly.

3.1.2.2 Maintainability - The following prelaunch maintainability requirements shall be considered in Hinge Assembly design:

a. Accessibility to all critical components shall be assured.

b. Maintenance action shall be performed in a minimum of time with minimum disturbance to other systems and adjacent equipment.

c. Maximum interchangability of equipment shall be a design goal.

d. Replacement of defective components rather than replacement of an entire module where feasible.

3.1.2.2.1 Maintenance Requirements - The Hinge Assembly shall be designed for prelaunch maintenance actions which include removal and replacement operations requiring a minimum of testing to verify system integrity. All mechanisms must be self-lubricating and sealed so as to require no maintenance in space. A method for detection of defects/malfunctions, both prior to and during system operation, shall be provided.

3.1.2.2.2 Maintenance and Repair Cycle - Not applicable.

3.1.2.3 Design Useful Life - The predicted operational life of the Hinge Assembly shall be based on a duty cycle that includes:

a. All testing prior to and following delivery.

b. Nominal elapsed time for ATM system ground operations (transportation to KSC, checkout, assembly of space vehicle, launch preparations) of 120 days.

c. ATM mission, orbital operational period of 56 days.

d. Orbital storage period of 6 months.

e. The predicted number of EVA film removal/replacement operational cycles shall be 4 with a maximum duration of 3.0 hours.

3.1.2.3.1 Shelf Life - The Hinge Assembly shall function in accordance with the requirements of this specification after storage for up to one year in a protected environment.

3.1.2.4 Natural Environment - The natural environmental extremes specified in 3.1.2.4.1 thru 3.1.2.4.4 shall be used in the design and analysis for the Hinge Assembly. The Hinge Assembly will be exposed to the environments contained within the SLA during prelaunch and launch operations. Only those environmental extremes encountered by the Hinge Assembly shall be used in its design.

3.1.2.4.1 Ground Environment - The Hinge Assembly shall be designed to withstand, without damage, the environmental conditions and prelaunch loads specified in applicable portions of TM X-53328 during transportation, ground handling, test and checkout. Prelaunch environments internal to the SLA shall be as defined by MSFC Drawing 13M06634.

3.1.2.4.2 Atmospheric Flight - The Hinge Assembly shall be designed to withstand environmental conditions specified in applicable portions of NASA TM X-53139.

3.1.2.4.3 Orbital Environments - The Hinge Assembly shall be capable of withstanding and operating with a space environment of the AAP-4 ATM/LM orbit. This environment shall include vacuum, radiation, micrometeoroid, temperature and other applicable conditions as specified in TM X-53521.

3.1.2.4.4 Thermal - The Hinge Assembly shall be designed to withstand thermal stresses and thermal shock resulting from atmospheric conditions defined in TM X-53328, TM X-53139, TM X-53521 and as defined herein.

a. Thermal Environmental Extremes

Vehicle Condition	External Environment T_{max} (°F)	T_{min} (°F)
Ground hold and ascent flight	TBD	TBD
Orbital coast/storage	TBD	TBD
Active mode	TBD	TBD

3.1.2.5 Transportability - Provisions shall be made for protection of the Hinge Assembly during normal handling, transit, and storage by preservation processes that comply with MIL-P-116E, and MSFC-STD-343. Provisions shall be made in the Hinge Assembly structure for tie-down, lift, and attachment points. All handling and transportation equipment shall be compatible with structural and environmental limits defined for the respective areas encountered.

3.1.2.6 Human Performance - The Hinge Assembly shall be designed in accordance with the human engineering requirements of MSFC-STD-267A and MSFC 10M32447. In addition, the design shall consider the following:

a. The Hinge Assembly shall be painted an optimum color. The selection of color and type of paint shall consider factors of reflectance, delineation treatment, thermal absorption and illumination levels.

3.1.2.7 Safety - Requirements for the Hinge Assembly necessary to preclude or to limit hazards to personnel and equipment shall be as specified herein.

3.1.2.7.1 Ground Personnel Safety - The Hinge Assembly shall be designed to ensure that every reasonable precaution is exercised to limit, or to eliminate, where possible, hazards to personnel who are engaged in manufacture, test, transport, storage, operation, or maintenance. Standard industrial and NASA Personnel safety practices and regulations shall prevail insofar as they exist. Any personnel hazard that is peculiar to the Hinge Assembly shall be covered by a special regulation or procedure.

3.1.2.7.2 Mission Personnel and Equipment Safety - The design of the Hinge Assembly shall incorporate all feasible methods of reducing hazards and accidents during activities of the AAP-3/4 and 5 missions and shall include, but not to be limited to, the following:

a. Safety shields or covers shall be provided to preclude tearing of astronaut suits which may come into contact with any sharp edges.

b. Equipment and structures shall be designed with a minimum of projections. Protuberances and sharp edges shall be eliminated or minimized.

3.1.2.8 Induced Environment - The Hinge Assembly shall be designed to withstand any induced environment or combination of induced environments specified herein.

3.1.2.8.1 Ground Handling and Transportation Loads - Handling of the Hinge Assembly from checkout to final installation on the launch vehicle at KSC shall not exceed the following load environment.

Hoisting - vertical acceleration of 2.0 g.

Jacking - vertical acceleration of 2.0 g in combination with a horizontal acceleration of 0.5 g (any axis) for all jacking operations.

Transportation - support equipment shall be provided to transport the Hinge Assembly from one location to another.

The Hinge Assembly shall be designed to withstand transportation loads of 2 g's in the axial or lateral direction and any resulting combination.

3.1.2.8.2 Launch Environments - The Hinge Assembly shall operate in accordance with its performance specifications after being subjected (during boost phase) to the launch vehicle induced environments defined in Appendix 10.2 of this document.

3.1.2.8.3 Orbital Operations - The Hinge Assembly shall be designed to withstand induced environments (i.e., docking loads, maneuver loads, etc.) resulting from orbital operations as defined herein.

3.1.2.8.3.1 Orbital Docking Loads - The Hinge Assembly shall be compatible with docking loads based on the parameters in 3.1.2.8.3.1.1.

3.1.2.8.3.1.1 Impact Velocities - Maximum impact velocities encountered during docking shall be:

a.	Axial Velocity	0.1 to 1.0 feet per second
b.	Lateral Velocity	0.0 to 0.5 feet per second
c.	Angular Velocity	0.0 to 1.0 degree/second about any axis

3.2 CEI Definition

3.2.1 Interface Requirements - The Hinge Assembly shall be designed to interface with other systems and components of the EI #003018, Serpentuator. Detail interface requirements will be defined in individual Interface Control Documents (ICD).

3.2.1.1 Detailed Interface Definition - Detailed interface definitions shall be defined in the following ICDs.

a. Hinge Assembly to TBD Physical, Functional and Procedural ICD No. TBD.

3.2.2 Component Identification - TBD

3.2.2.1 Government Furnished Property List - TBD

3.2.2.2 Engineering Critical Components List - TBD

3.2.2.3 Logistic Critical Components List - TBD

3.2.3 Technical Manuals - TBD

3.3 Design and Construction

3.3.1 General Design Features - The Hinge Assembly general design features shall be in accordance with requirements specified herein. Complete structural analyses shall be conducted on all items, components, and sub-systems giving special consideration to vibration amplification, shock factors, allowable deflection, surge phenomena, acceleration factors, and thermal conditions. These analytical investigations and test results shall verify a safety factor on all items, components, and sub-systems equal to or greater than those listed in 3.3.1.1.

3.3.1.1 Factors of Safety and Strength Allowable - The factors of safety listed below are minimum values and shall be applied (in addition to shock, "G" load, and vibration factors):

a. General Structure

Yield factor of safety	1.10
Ultimate factor of safety	1.50

b. Pressure Spheres

Proof pressure	1.5 times limit pressure
Burst pressure	2.5 times limit pressure

c. Pneumatic Systems

Flexible hose, tubing, ducts, and fittings less than 1.5 inch diameter:

Proof pressure	2.00 times limit pressure
Burst pressure	4.00 times limit pressure

Flexible hose, tubing, ducts, and fittings of 1.5 inch diameter or greater:

Proof pressure	1.50 times limit pressure
Burst pressure	2.50 times limit pressure

Actuating cylinders, valves, filters, and switches:

Proof pressure	1.50 times limit pressure
Burst pressure	2.50 times limit pressure

Reservoirs:

Proof pressure	1.50 times limit pressure
Yield pressure	1.10 times limit pressure
Burst pressure	2.00 times limit pressure

3.3.1.2 Electrical - Electrical engineering practices and procedures shall be in accordance with Standard MSFC-STD-421, and Appendix 10.1 of ATM General Systems Specification, 50M02417.

3.3.1.2.1 Harnesses and Cables - Wiring shall consist of cable harnesses where practicable. Flat cable in accordance with specification MSFC-SPEC-220 shall be used for harnesses which cross gimbals. Harnesses expected to be exposed to high temperatures shall be flexible armor. Wire used in harnesses shall conform to specification MIL-W-5086, with MSFC Drawings 40M39513, and 40M39526. Interconnecting cables between experiment instruments shall be suitably shielded against electromagnetic interference in accordance with MSFC Drawing 50M12725.

3.3.1.2.2 Connectors - Electrical connectors shall conform to MIL-C-5015 and MIL-C-26482. Flat cable connectors shall conform to MSFC-SPEC-219.

3.3.1.2.3 Bonding and Grounding - Electrical bonding and grounding shall be in accordance with MSFC Drawing 50M12725.

3.3.1.2.4 Switches - Switches used in the Hinge Assembly shall conform to the following requirements:

a. Component position switches shall be kept to the minimum consistent with checkout requirements. Sequencing shall not be dependent on proper operation of position switches.

b. Switches shall be hermetically sealed.

3.3.1.2.5 Modules and Printed Circuits - Fabrication of welded electronic modules shall conform to the requirements of Standard MSFC-STD-271. Printed circuits shall be in accordance with Standard MSFC-STD-154.

3.3.1.2.6 Brazing, Soldering and Welding - Brazing and soldering shall be in accordance with specification MIL-B-7883 and NASA Publication NPC 200-4. Fusion welding shall be in accordance with Specification MSFC-SPEC-135 and fusion welds shall be subjected to inspection in accordance with Specification MSFC-SPEC-259.

3.3.1.2.7 Electromagnetic Interference - Electrical and electronic equipment shall be designed and installed so as to limit electromagnetic and electrostatic interference as specified in Specification MIL-I-6181 and MIL-E-6051. Control plans and tests for electromagnetic interference shall conform to MSFC document 50M12725.

3.3.1.2.8 Vacuum Welding - The design of the Hinge Assembly shall consider vacuum welding and incorporate methods of preventing bonding of surfaces requiring relative motion.

3.3.2 Selection of Specifications and Standards - Specifications and standards not specified herein, but necessary for the control and development of the Hinge Assembly shall be selected from MSFC-TSL-488. When specifications cannot be selected from the above index, Standard MIL-STD-143 shall be used as a guide in selecting specifications. However, approval of the procuring activity shall be obtained prior to use of selected specifications.

3.3.2.1 Drawings - The Hinge Assembly drawings shall be in accordance with the MSFC 50M02411.

3.3.3 Materials, Parts and Processes - Materials, parts and processes for the Hinge Assembly shall be selected in accordance with the requirements of paragraph 3.2 of Specification 50M02417 and the requirements of the specifications and standards chosen in accordance with paragraph 3.3.2 above. Compliance with the requirements of applicable specifications or standards shall be demonstrated by test data or analysis.

3.3.4 Standard and Commercial Parts - MS, AN, and MIL Standard parts, components, and assemblies shall be used whenever practicable. Commercially available parts, components, and assemblies fabricated or procured in accordance with or in conformance to, the Marshall Space Flight Center's PPD-600, volumes 1 and 2, may be used providing standard parts, components, and assemblies are not readily available and the parts be of sufficient quality to meet the performance, environmental, and reliability requirements imposed herein. Commercial utility parts such as screws, bolts, nuts, cotter pins, etc., shall not be subject to the foregoing provisions but must be replaceable with standard parts without alteration to component or structure.

3.3.5 Moisture and Fungus Resistance - Except as otherwise required by detail design considerations, only materials which resist the corrosive action of salt air and damage from moisture and fungus shall be used. The use of materials which are nutrients for fungus shall not be prohibited in hermetically sealed assemblies. Suitable protective coatings which will not lose their protective characteristics during the normal course of inspection, maintenance, and testing may be used. Applications of moisture and fungus resisting varnish shall conform to specification MIL-V-173. The treated surface must pass the fungus tests specified in MIL-STD-810B.

3.3.6 Corrosion of Metal Parts - Metallic materials used in construction of the Hinge Assembly shall be chosen for their corrosion resistance characteristics. Metal parts shall be protected from corrosion by stress relieving, plating, anodizing, chemical coatings, organic finishes, and combinations thereof, as required.

3.3.6.1 Dissimilar Metals - The Hinge Assembly shall be so designed as to avoid the use of dissimilar metals in contact with one another. Dissimilar metals, as defined in MS33586, shall not be used in combination unless they are suitably coated to prevent electrolytic corrosion.

3.3.6.2 Finish - The finish of the Hinge Assembly shall be in accordance with MSFC-SPEC-250.

3.3.7 Interchangability and Replacability - The Hinge Assembly shall be designed for ease of manufacture, assembly, inspection, and maintenance. The parts shall be interchangable or replacable in accordance with MIL-I-8500.

3.3.8 Workmanship - The Hinge Assembly shall be designed, constructed, and finished in a quality manner. Defective plating, machine screw assemblage, welding, brazing, de-burring, cleaning and defective marking of parts shall be cause for rejection. Areas not covered by this paragraph shall be in accordance with manufacturing practices that will produce equipment free of defects.

3.3.9 Identification - Identification and marking of the Hinge Assembly and parts requiring identification shall be in accordance with MIL-STD-130.

4.0 TEST REQUIREMENTS

4.1 Performance/Design Requirements Verification Matrix - The performance/design requirements verification matrix for the CEI is shown in Table VII-1 herein.

4.2 Test Assessment - The following are the requirements for verification of the design CEI. This verification shall determine acceptance of the Contractors design and development engineering. Successful completion of these inspections, demonstrations and test shall constitute qualification of this CEI.

4.2.1 Phase I Test/Verification

4.2.1.1 Engineering Test and Evaluation - The following requirements of Section 3 shall be verified by engineering development tests and evaluation:

3.1.1.2.3	3.1.1.2.4.4.2.1
3.1.1.2.4.3	3.1.1.2.4.4.3
3.1.1.2.4.4	3.1.1.2.5
3.1.1.2.4.4.1	3.3.1.1
3.1.1.2.4.4.2	

4.2.1.3 Formal Qualification Tests - The following subparagraphs specify the requirements for and method of verifying that each requirement of Section 3 has been satisfied.

4.2.1.3.1 Inspection - The following requirements of Section 3 shall be verified by inspection of the CEI:

3.1.1.2.1	3.3.2
3.1.1.2.2	3.3.2.1
3.1.1.2.4.1	3.3.3
3.1.1.2.4.2	3.3.4
3.2.1.1	3.3.5
3.3.1.2	3.3.6
3.3.1.2.1	3.3.6.1
3.3.1.2.2	3.3.6.2
3.3.1.2.3	3.3.7
3.3.1.2.4	3.3.8
3.3.1.2.5	3.3.9
3.3.1.2.6	

4.2.1.3.2 Analysis - The following requirements of Section 3 shall be verified by review of the CEI drawings and/or analytical data:

3.1.1.2.5	3.1.2.7.2
3.1.2.1	3.1.2.8.1
3.1.2.1.1	3.1.2.8.3.1
3.1.2.1.2	3.1.2.8.3.1.1
3.1.2.2	3.2.1
3.1.2.2.1	3.3.1.1
3.1.2.3	3.3.3
3.1.2.3.1	3.3.4
3.1.2.4.1	3.3.5
3.1.2.5	3.3.6
3.1.2.6	3.3.6.1
3.1.2.7	3.3.7
3.1.2.7.1	

4.2.1.3.3 Tests - The following requirements of Section 3 shall be verified by tests:

3.1.1.2.3	3.1.2.3
3.1.1.2.4.3	3.1.2.4.2
3.1.1.2.4.4	3.1.2.4.3
3.1.1.2.4.4.1	3.1.2.4.4
3.1.1.2.4.4.2	3.1.2.8.2
3.1.1.2.4.4.2.1	3.3.1.1
3.1.1.2.4.4.3	3.3.1.2.7
3.1.1.2.5	

4.2.1.4 Reliability Test and Analysis - The following requirements of Section 3 shall be verified by reliability analysis:

3.1.2.1.1	3.1.2.2.1
3.1.2.1.2	3.1.2.3
3.1.2.2.2	3.1.2.3.1

4.2.1.5 Engineering Critical Component Qualification - Non-metallic materials used in the design of the CEI will be selected and qualified in accordance with MSC-KA-D-67-13.

Table VII-1 Verification Requirements

CEI Section 3.0 Requirement Ref	Verification Method Develop	Qual	Accept.
3.1.1.1.1 Pre-flight	NA	NA	NA
1.1	2b	2b	NA
1.2	2b	2b	NA
1.3	NA	NA	NA
3.1.1.2 Sec Performance	NA	NA	NA
2.1	2c	2c	2c
2.2	2c	2c	2c
2.3	NA	NA	NA
2.4	NA	NA	NA
2.4.1	2c	2c	2c
2.4.2	2c	2c	2c
2.4.3	1	1	2b
2.4.4	1	1	1
2.4.4.1	1	1	1
2.4.4.2	1	1	1
2.4.4.2.1	1	1	1
2.4.4.3	1	1	NA
2.5	1	1	1
3.1.2 Operability	NA	NA	NA
2.1	2b	2b	NA
2.1.1	2b	2b	NA
2.1.2	2b	2b	NA
2.2	2b	2b	NA
2.2.1	2b	2b	NA
2.2.2	NA	NA	NA
2.3	2b	2b	NA
2.3.1	2b	2b	NA
2.4	NA	NA	NA
2.4.1	2b	2b	NA
2.4.2	1	1	1
2.4.3	1	1	1
2.4.4	1	1	1
2.5	2b	2b	NA
2.6	2b	2b	NA
2.7	2b	2b	NA
2.7.1	2b	2b	NA

Verification Method

1. Test
2. Assessment
   a. Similarity
   b. Analysis
   c. Inspection
   d. Demonstration
   e. Validation of Records

N/A Not Applicable

CEI Section 3.0 Requirement Ref	Verification Method Develop	Qual	Accept.
3.1.2.7.2	2b	2b	NA
2.8	NA	NA	NA
2.8.1	2b	2b	NA
2.8.2	1	1	NA
2.8.3	NA	NA	NA
2.8.3.1	2b	2b	NA
2.8.3.1.1	2b	2b	NA
3.2 CEI Definition	NA	NA	NA
3.2.1 Interface Req.	TBD	TBD	TBD
3.2.1.1	TBD	TBD	TBD
2.2.1	TBD	TBD	TBD
2.2.2	TBD	TBD	TBD
2.2.3	TBD	TBD	TBD
3.3 Design & Construction	NA	NA	NA
3.3.1	NA	NA	NA
3.3.1.1	1	1	1
1.2	NA	2c	2c
1.2.1	NA	2c	2c
1.2.2	2b	2c	2c
1.2.3	2c	2c	2c
1.2.4	2c	2c	2c
1.2.5	2c	2c	2c
1.2.6	2c	2c	2c
1.2.7	2b	1	1
1.2.8	2b	2b	NA
3.3.2	NA	2c	2c
3.3.2.1	NA	2c	2c
3.3.3	2b	2c	2c
3.3.4	2b	2c	2c
3.3.5	2b	2c	2c
3.3.6	2b	2c	2c
3.3.6.1	2b	2c	2c
3.3.6.2	NA	2c	2c
3.3.7	2b	2c	2c
3.3.8	NA	2c	2c
3.3.9	NA	2c	2c

5.0 PREPARATION FOR DELIVERY

5.1 Protection from Natural Environment - The Hinge Assembly and its components shall be protected from natural environmental extremes which exceed the design requirements specified in Section 3. Environmental extremes specified in NASA TM X-53328 and TM X-53139 shall be used as a basis for providing protection to the Hinge Assembly.

5.2 Preservation, Packaging, and Packing - Preservation, packaging, and packing methods shall be as specified in Drawing 10M09302. Components and spare parts shall be packaged in accordance with Level A. Packing shall be designed to Level B. Protection shall be provided against damage from repeated handling. Containers such as cleated panel boxes, open slat crates, and cartons shall be used as applicable.

5.2.1 Repair Parts - Repair parts listed on the loose equipment list shall be shipped separately from the Hinge Assembly. The following criteria shall be used in preparing the loose items shipment list:

a. Facilitate economical shipment.
b. Prevent damage to critical parts.
c. Permit installation of environmental control devices used during shipment.

The loose item equipment list shall be approved by the procuring agency prior to implementation.

5.2.2 Package Construction - Packages shall be constructed with provisions to permit unpacking for periodic inspection and repacking of the inspected items in the original container. Packages shall also be constructed to immobilize and cushion the items against damage during shipping and handling.

5.2.3 Protective Devices - Provisions shall be made to install protective devices on the Hinge Assembly, as required, to prevent damage during shipment.

5.4 Shipping - Adequate provisions shall be established for safely transporting the Hine Assembly with the load limits specified in 3.1.2.8.1. Shipping shall be in accordance with MSFC 50M02435.

10.0 APPENDIX

10.1 Electrical Design Criteria - The electrical design criteria specified herein shall apply to all ATMS electrical systems, subsystems, and components except the following:

a. Experiments.

b. Where the requirements of this Appendix conflict with the detail requirements of Section 3 of this document, the require ments of Section 3 shall take precedence.

10.1.1 Transient Voltages - No temporary or permanent damage or degraded performance shall be experienced in any equipment when a positive or negative 50 volt pulse of 10-microseconds maximum time width is injected onto the 28 volt (nominal) DC supply lead or its return.

10.1.2 Ripple Tolerance - Equipment must operate satisfactorily when the input power includes ripple of 400-millivolts peak-to-peak at any frequency between 10 Hz and 20 KHz.

10.1.3 Input Voltage - The voltage level at the input to each electrical component shall be 24 to 32 VDC (28 VDC nominal).

10.1.4 Circuit Protection - Circuit protection shall be included as part of the Hinge Assembly networks to interrupt power if the component should draw excessive current.

10.1.5 Electromagnetic Compatibility - Bonding, shielding, and electromagnetic compatibility are defined by MSFC Drawing 50M12725.

10.1.6 DC Return - Each electrical component shall have the ATM 28 VDC power return and ATM 5 VDC return isolated by one megohm resistance from each other and from structure ground. Any deviations shall have the concurrence of this office. These two returns shall be combined only at the ATM system single-point ground.

10.1.7 Component Resistance - Electrical components shall have a minimum of 50 megohms resistance between connector pins and ground (with all internal switches open) at an applied voltage of 500 VDC. No component switch or relay shall have a resistance exceeding 0.05 ohm. Electrical components shall have sufficient dielectric strength to prevent current leakage exceeding 1000 microamperes through any connector pin to ground when subject to 1000 volts rms 60 Hz for 1 minute.

10.2 Lauch Vehicle Induced Environments

10.2.1 Launch Vehicle Loads - The Hinge Assembly shall be capable of withstanding the launch vehicle induced loads defined herein or resulting from the accelerations defined herein. The Load Sign Convention and Pitch and Yaw Planes for the ATM payload module are defined in Figure 10.2-1.

10.2.1.1 Longitudinal Loads - The maximum longitudinal loads encountered by the Hinge Assembly are specified in Figure 10.2-2.

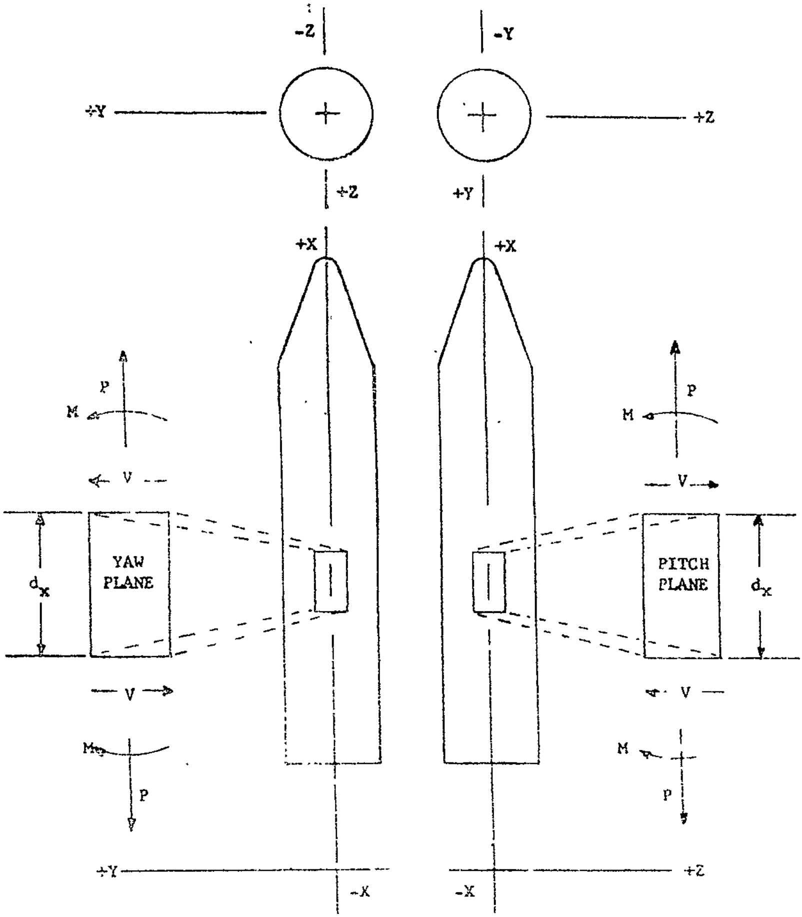
10.2.1.2 Liftoff Accelerations - The balanced accelerations encountered by the Hinge Assembly at LV liftoff are specified in Figures 10.2-3 and 10.2-4.

10.2.1.3 Max Q-Alpha - The balanced accelerations experienced by the Hinge Assembly at Max Q-Alpha are specified in Figure 10.2-5.

10.2.1.4 IECO - The maximum balanced accelerations experienced by the Hinge Assembly at S-IB stage inboard engine cutoff (IECO) are specified in Figure 10.2-6.

10.2.2 Moments of Inertia - The moments of inertia encountered by the Hinge Assembly are specified in Figure 10.2-7.

10.2.3 Vibration and Acoustics - The Hinge Assembly shall withstand the vibration environment defined in MSFC Document 50M02408 and the acoustic environments defined in Figures 10.2-8 and 10.2-9.

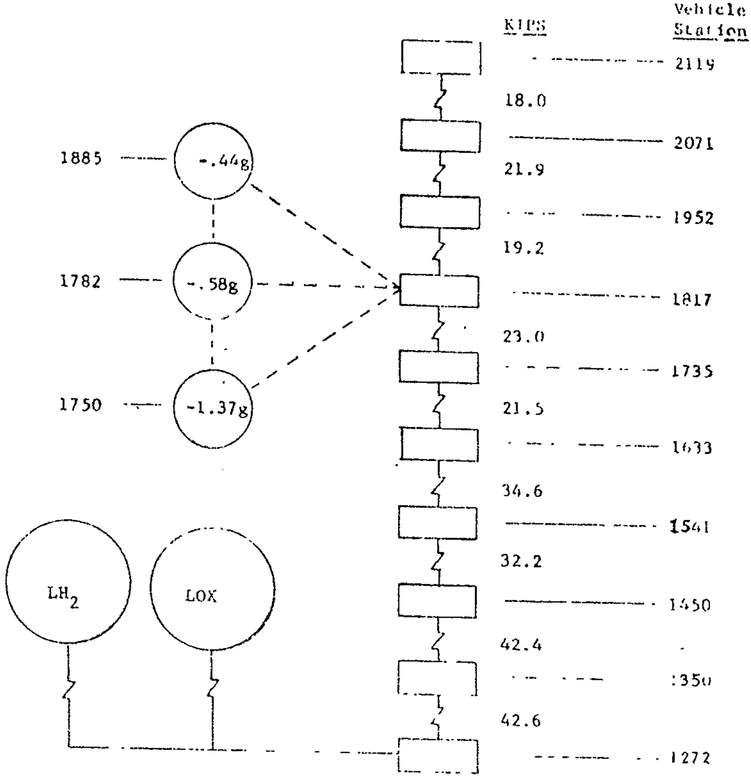


NOTES: (1) Positive convention shown.

(2) Yaw plane is defined by LV X and Y axes, pitch plane by LV X and Z axes.

(3) Abbreviations: M = bending moment, V = shear force, P = longtitudinal load, and d_x = increment length.

ATM Vehicle
Load Sign Convention and Planes Definition
Figure 10.2-1



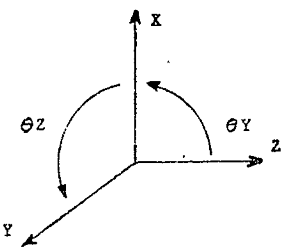
AAP-4/ATM Vehicle
Maximum Longtitudinal Reversal Loads
S-IB/S-IVB Separation

Figure 10.2-2

VEH. STA.	$\ddot{X}$ (g)	$\ddot{Y}$ (g)	$\ddot{Z}$ (g)	$\ddot{\theta}_y$ (g/in)	$\ddot{\theta}_z$ (g/in)	MAX. LOAD CONDITION
1885	(-.345)+2.92	±0.067	±0.155	±.00059	±.00013	LONG. ACC. X (g)
	+1.29	±0.598	±1.46	±.00820	±.00226	LAT. ACC. Y (g)
	+1.30	±0.585	±1.47	±.0072	±.00249	LAT. ACC. Z (g)
	+1.55	±0.312	±0.772	±.0123	±.00033	ROT. ACC. θ_y (g/in)
	+1.44	±0.022	±0.581	±.0014	±.00625	ROT. ACC. θ_z (g/in)
1782	+2.20	±0.014	±0.117	±.00006	±.00006	LONG. ACC. X (g)
	+1.32	±0.308	±0.813	±.0034	±.0015	LAT. ACC. Y (g)
	+1.32	±0.308	±0.813	±.0034	±.0015	LAT. ACC. Z (g)
	+1.75	±0.026	±0.147	±.0101	±.0044	ROT. ACC. θ_y (g/in)
	+1.47	±0.019	±0.111	±.0100	±.0045	ROT. ACC. θ_z (g/in)
1750	(-2.11)+4.68	±0.216	±0.620	±.0047	±.0024	LONG. ACC. X (g)
	(-.655)+1.91	±0.266	±0.701	±.0014	±.0011	LAT. ACC. Y (g)
	+2.36	±0.265	±0.703	±.0028	±.0019	LAT. ACC. Z (g)
	+1.65	±0.180	±0.529	±.0234	±.0076	ROT. ACC. θ_y (g/in)
	+1.61	±0.105	±0.347	±.0151	±.0106	ROT. ACC. θ_z (g/in)

NOTES:

(1) Concentrated moment at a node = $\ddot{\theta}$ (g/in) x I (lb-in^2)
(2) Lateral g at distance d from a node = $\ddot{\theta}$ (g/in) x d
(3) Yaw plane is defined by LV X and Y axes (Fig. 10.2-1)



ATM Payload Module
Balanced Accelerations in Yaw Plane
Lift-Off Conditions

Figure 10.2-3

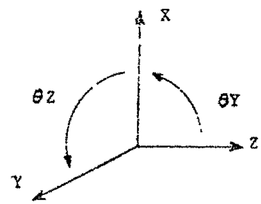
VEH. STA.	$\ddot{X}$ (g)	$\ddot{Y}$ (g)	$\ddot{Z}$ (g)	$\ddot{\theta}_y$ (g/in)	$\ddot{\theta}_z$ (g/in)	MAX. LOAD CONDITION
1885	(-.345)+2.92	+0.139	±0.053	±.0003	±.0016	LONG. ACC. X (g)
	+1.56	±1.420	±0.606	±.0030	±.0059	LAT. ACC. Y (g)
	+1.32	±1.410	±0.612	±.0028	±.0063	LAT. ACC. Z (g)
	+1.55	±0.798	±0.290	±.0050	±.0021	ROT. ACC. θ_y (g/in)
	+1.44	±0.098	±0.188	±.0007	±.0161	ROT. ACC. θ_z (g/in)
1782	+2.20	±0.107	±0.018	±.00004	±.00008	LONG. ACC. X (g)
	+1.32	±0.784	±0.320	±.0013	±.0038	LAT. ACC. Y (g)
	+1.30	±0.763	±0.320	±.0012	±.0037	LAT. ACC. Z (g)
	+1.75	±0.133	±0.029	±.0039	±.0114	ROT. ACC. θ_y (g/in)
	+1.47	±0.118	±0.012	±.0039	±.0116	ROT. ACC. θ_z (g/in)
1750	(-2.11)+4.68	±0.628	±0.216	±.0021	±.0053	LONG. ACC. X (g)
	(-.655)+3 28	±0.684	±0.237	±.0013	±.0037	LAT. ACC. Y (g)
	+2.36	±0.568	±0.281	±.0012	±.0043	LAT. ACC. Z (g)
	+1.71	±0.236	±0.076	±.0083	±.0147	ROT. ACC. θ_y (g/in)
	+1.61	±0.337	±0.106	±.0057	±.0279	ROT. ACC. θ_z (g/in)

NOTES:

(1) Concentrated moment at a node = $\ddot{\theta}$ (g/in) x I(lb-in^2)

(2) Lateral g at distance d from a node = $\ddot{\theta}$ (g/in) x d

(3) Pitch plane is defined by LV X and Z axes (Fig. 10.2-1)



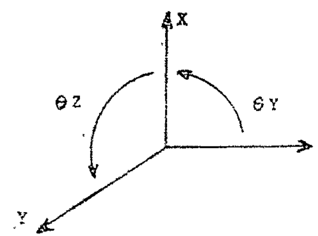
ATM Payload Module
Balanced Acceleration in Pitch Plane
Lift-Off Conditions

Figure 10.2-4

VEH. STA.	$\ddot{X}$ (g)	$\ddot{Y}$ (g)	$\ddot{Z}$ (g)	$\ddot{\theta}_y$ (g/in)	$\ddot{\theta}_z$ (g/in)	MAX. LOAD CONDITION
1885	+1.916	-------	±.384	±.00023	-------	LONG. ACC. X (g)
	+1.916	-------	±.384	±.00023	-------	LAT. ACC. Z (g)
	+1.916	-------	±.194	±.00099	-------	ROT. ACC. θ (g/in)
1782	+1.916	-------	±.353	±.00034	-------	LONG. ACC. (g)
	+1.916	-------	±.353	±.00034	-------	LAT. ACC. Z (g)
	+1.916	-------	±.104	±.00127	-------	ROT. ACC. θ (g/in)
1750	+1.916	-------	±.349	0	-------	LONG. ACC. X (g)
	+1.916	-------	±.349	0	-------	LAT. ACC. Z (g)
	+1.916	-------	±.120	±.00108	-------	ROT. ACC. θ (g/in)

NOTES:

(1) Concentrated moment at a node = $\ddot{\theta}$ (g/in) x I (lb-in^2)
(2) Lateral g at distance d from a node = θ (g/in) x d



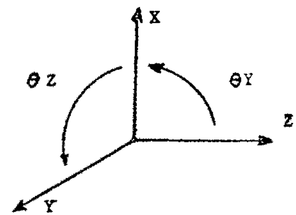
ATM Payload Module
Balanced Accelerations at Max Q-alpha

Figure 10.2-5

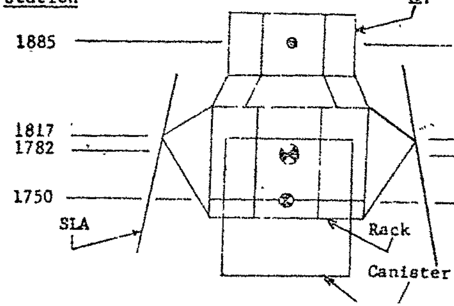
VEH. STA.	$\ddot{X}$ (g)	$\ddot{Y}$ (g)	$\ddot{Z}$ (g)	$\ddot{\theta}_y$ (g/in)	$\ddot{\theta}_z$ (g/in)	MAX. LOAD CONDITION
	+4.56	-------	±0.021	±.00005	-------	LONG. ACC. X (g)
1885	+4.56	-------	±0.021	±.00005	-------	LAT. ACC. Z (g)
	+4.56	-------	±0.021	±.00005	-------	ROT. ACC. θ (g/in)
	+4.56	-------	±0.026	±.00005	-------	LONG. ACC. X (g)
1782	+4.56	-------	±0.026	±.00005	-------	LAT. ACC. Z (g)
	+4.56	-------	±0.020	±.00005	-------	ROT. ACC. θ (g/in)
	+4.56	-------	±0.019	±.00005	-------	LONG. ACC. X (g)
1750	+4.56	-------	±0.019	±.00005	-------	LAT. ACC. Z (g)
	+4.56	-------	±0.019	±.00005	-------	ROT. ACC. θ (g/in)

NOTES:

(1) Concentrated moment at a node = $\ddot{\theta}$ (g/in) X I (lb-in^2)
(2) Lateral g at distance d from a node = $\ddot{\theta}$ (g/in) x d



ATM Payload Module
Balanced Accelerations
S-IB Inboard Engine Cutoff
Figure 10.2-6



Station	Item	Wt (Lbs)	Moment of Inertia Iy (Kip in^2)	Moment of Inertia Iz (Kip in^2)
1885	CG, LM Ascent Stage	10,500	20510	26666
1817	SLA Interface	14,287	55352	50859
1782	CG, ATM Rack			
1750	Canister Gimbal Canister CG, ±½"	5,063	19783	18097

ATM Payload Module
Moments of Inertia
Figure 10.2-7

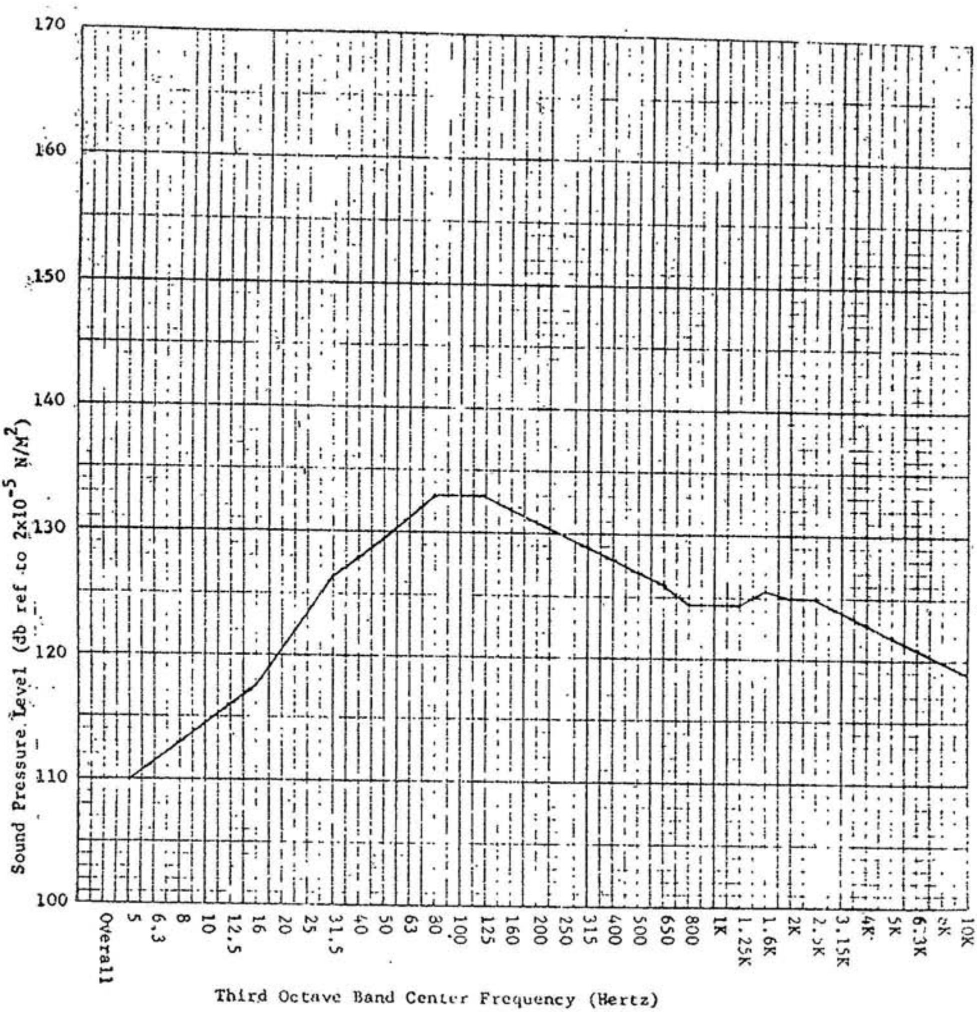
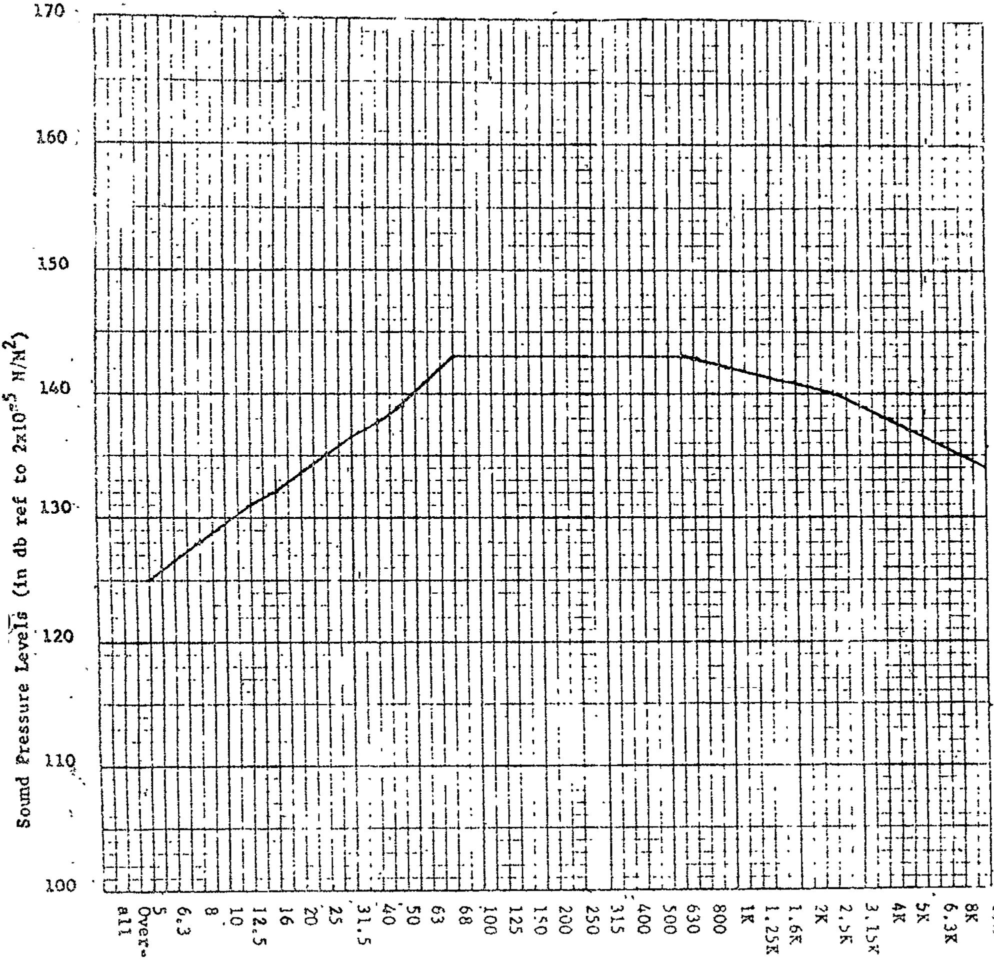


Figure 10.2-8 ATM Acoustic Criteria
Internal to the SIA



Third Octave Band Center Frequency (Hertz)

Figure 10.2-9 ATM Acoustic Criteria External to the SLA

TEST PLAN

FOR

SERPENTUATOR HINGE JOINT ASSEMBLY

FOREWORD

This test plan for the Serpentuator Hinge Joint Assembly was devised to flight qualify the existing design. If only the basic linkage mechanism itself should change only minor modifications to this test plan would be required. If, however, the hermetic seal concept should change then this test plan is inadequate, since additional qualification of individual components would be required.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Purpose - This test plan presents the Development Qualification and Acceptance Test Programs required for the Serpentuator link hinged joint, a sub-assembly of the EI #00318, Serpentuator, for Apollo Applications Program; AAP-4.

The development and qualification test programs shall establish by demonstration that the Serpentuator hinge joint design will perform its specified mission function when exposed to flight and design margin limits of functional and environmental requirements. The acceptance test program shall establish by demonstration that each unit meets a required operational level of functional and environmental test requirements prior to acceptance of an approved flight article.

1.2 Scope - Section 4.0 of this test plan defines the test activities required for development of the Serpentuator hinge joint and in particular, details the functional test that must be conducted to demonstrate the end item.

1.3 Hardware Description - The Serpentuator link hinge joint is a Category I hardware item as defined by Apollo Test Requirements NHB 8080.1. The Serpentuator hinge joint, as a part of and in conjunction with the assembled Serpentuator, functions as a method of transporting an astronaut and his equipment from an EVA hatch to an external spacecraft work station. The hinge joint assembly is designed to operate within the mission requirements of NASA Program Directive No. 5 for AAP-3/AAP-4.

2.0 APPLICABLE DOCUMENTS

2.1 <u>Military</u>	<u>Title</u>
MIL-STD-453 Change Notice 1	Inspection, Radiographic
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-810B (USAF)	Environmental Test Methods for Aerospace and Ground Equipment

2.2 <u>NASA</u>	<u>Title</u>
M-DE 8020.008B	Natural Environment and Physical Standards for the Apollo Program
MSC-KA-D-67-13	Procedure and Requirements for the Evaluation of Spacecraft Non-Metallic Materials
NPC 200-2	Quality Program Provisions for Space System Contractors
NPC 200-4	Quality Requirements for Hard Sodering of Electrical Connectors
NHB 8080.3	Apollo Applications Test Requirements
NPC 250-1	Reliability Program Provisions for Space Systems Contractors
NPC 500-1	Apollo Application Program Development Plan

3.0 RESPONSIBILITIES

3.1 Contractors Test Organization - Specific responsibilities and interrelationships for various aspects of test within the contractor organization are defined in Fig. (TBS)

3.2 Vendor Testing - Tests on vendor supplied components and materials will be performed to the limits specified in the contractors procurement drawings and specifications. The procurement contract will require the supplier to:

a. Submit test procedures for contractor approval prior to start of testing.

b. Notify the contractor of test schedules, and to perform tests in the presence of the contractor and NASA observers.

c. Provide test reports and failure reports as required.

d. Make product design and test procedure changes as directed by the contractor.

3.3 NASA Test Support - It shall be the prerogative of the NASA to approve various aspects of the test program including individual component qualification test specification sheets, test procedures, final test reports and overall test plan. NASA may witness any test and will identify the specific tests for which they desire prior notification.

NASA will assist the contractor in procurement of selected previously qualified components (i.e., Apollo, LM, Gemini) and piece part test data and will conduct non-metallic materials tests as required to implement the hardware development program.

3.4 Test Program Checkpoints - The Apollo Applications Program Development Plan NPC 500-1 and Apollo Applications Test Requirements (AATR) NHB 8080.3 establish key management checkpoints, which provide visibility of the status of design, manufacture and test. Active participation by the Serpentuator link hinge contractor will be required during the:

a. PDR - Preliminary Design Review - Conducted by the cognizant NASA Program Office to evaluate the basic design approach for each end item.

b. CDR - Critical Design Review - Conducted by the cognizant NASA Program Office to formally review the final design of the end item.

c. CI - Configuration Inspection - Conducted by the cognizant NASA Program Office for acceptance of contractually deliverable flight and ground hardware.

Note: It is assumed the contractor will not be the total Serpentuator contractor.

4.0 TEST ACTIVITIES

4.1 Master Test Schedule - The master test schedule for development of the CEI is presented in Fig. (TBS). This schedule is provided for program reference only and will not be maintained. Bi-weekly status reports from the contractor to NASA will detail the schedule status for program management purposes.

4.1.1 Component Test Schedule - Individual component test schedules shall be prepared (when required) reflecting development and qualification test phases and schedule.

4.2 Test Phases - The development and qualification of the Serpentuator hinge joint will require the integration and testing of the several components that comprise the joint sub-assembly. However, due to the nature and configuration of the hinge joint and the probable use of existing components and off the shelf designs; the development and qualifications of the joint will be conducted at the total subsystem level.

The test program, therefore, will consist of two distinct subsystem test phases; development testing and qualification testing.

4.2.1 Development Tests - These tests will be performed in support of new hardware design evaluation. They will be conducted in an engineering laboratory environment using bread or baseboard type hardware and shall verify the feasibility of the design approach. Data obtained from these tests will support the final design configuration decision.

4.2.2 Qualification Tests - Qualification testing will be performed on the final design production hardware which has been manufactured and acceptance tested to the end item specification. These tests will be conducted under controlled environments and test methods.

In addition to the tests required to demonstrate compliance with requirements of Section 3.0 of the CEI, certain tests shall be conducted to determine the margin of safety beyond the requirements of Section 3.0.

4.2.3 Acceptance Test - Acceptance tests are those tests performed on the complete CEI and on components of the CEI to demonstrate compliance to the design requirements as set forth in the end item specification

These tests shall be performed in accordance with NASA approved test procedures. Successful performance of all acceptance tests shall be a mandatory requirement prior to the CEI being shipped.

4.3 Certification Test Specification - A certification test specification shall be prepared for each end item to verify that the flight hardware design meets the performance/design requirements of Section 3.0 of the End Item Specification. The qualification test specification shall be approved by NASA prior to start of formal qualification testing. Qualification test procedures shall be submitted for review and formal qualification test reports shall be submitted for approval.

4.4 Test Methods - Testing of the end item shall be in accordance with MIL-STD-810B, Environmental Test Methods. This standard establishes uniform environmental test methods and procedures for determining the resistance of the equipment to effects of natural and induced environments.

4.5 Test Requirements - Tests required to demonstrate the end item design and operational performance parameters and capabilities are indicated in Table 1. Specific details of these tests are described below. Natural environmental requirements are indicated in Table 2. Testing for the natural environment shall be in accordance with standard test procedures of MIL-STD-810B.

The demonstration of the end item will require one (1) complete unit for development testing and one (1) complete unit for qualification testing.

4.6 Test Procedures - Operational performance tests required to demonstrate the end item design are described herein:

4.6.1 Examination - The unit shall be examined to assure compliance with the requirements of the end item specification. Such inspection shall include but shall not be limited to the requirements of identification markings, physical measurement, weight, finish, freedom of damage, and maintenance of workmanship standards.

4.6.2. Inspection of Weld - Dye penetrant and x-ray inspections are required on all welds in accordance with MIL-I-6866 and MIL-STD-453, respectively. All welds (other than bellows) shall be x-ray and dye penetrant inspected before and after proof pressure test. Inspection standards shall be in accordance with approved criteria. There shall be no cracks accepted.

Table I

Title of Test	Design Develop.	Design Qual.	Acceptance
Examination		x	x
Weld inspection	x	x	x
Operating pressure	x	x	x
Proof pressure	x	x	x
Burst pressure		x	
akage	x	x	x
Structural load		x	
Random Vib. (qual)		x	
Random Vib. (accept)	x	x	x
Orbital Temp Sim. (qual)		x	
Orbital Temp Sim. (accept)	x	x	x
Bench Operating (qual)		x	
Bench Operating (accept)	x	x	x
Shock		x	

TABLE II

ENVIRONMENT \ PHASE	PRELAUNCH MDA INT	PRELAUNCH MDA EXT	PRELAUNCH OWS INT	PRELAUNCH OWS EXT	LAUNCH & ASCENT MDA INT	LAUNCH & ASCENT MDA EXT	LAUNCH & ASCENT OWS INT	LAUNCH & ASCENT OWS EXT	ORBITAL COAST MDA INT	ORBITAL COAST MDA EXT	ORBITAL COAST OWS INT	ORBITAL COAST OWS EXT
TEMPERATURE (°F)	−40° TO 160°				60° TO 80°		LIQUID H_2 AND He GAS	CRYO	0° TO +100°	−140° TO +260°	−423° TO +100°	−355° TO +190°
PRESSURE (mmHg)	86.9 TO 1080.6	86.9 TO 760	86.9 TO 915.2	86.9 TO 760	1080.6 TO 264 IN 60 SEC	760 TO 10^{-8} IN 7 MIN		760 TO 10^{-8} IN 7 MIN	264 TO 77.6	10[illegible]		
HUMIDITY (% RH)	0 TO 100	15 TO 100	0 TO 100		0 TO 95	15 TO 95		0 TO 100	0 TO 100	N/A		
ATMOSPHERIC COMPOSITION	20% O_2 80% N_2 TO 100% N_2	20% O_2 80% N_2	20% O_2 80% N_2 OR 100% He OR LIQD H_2	20% O_2 80% N_2	100% N_2	20% O_2 80% N_2 TO 0 ATMOS		20% O_2 80% N_2 TO 0 ATMOS	100% N_2	N/A		
ACCELERATION (G)	4.0 FORE AND AFT 3.0 LATERAL		2.0 FORE AND AFT 1.0 LATERAL		7.0 FLIGHT AXIS 3.0 LATERAL AXIS NOTE 1				N/A			
VIBRATION	0.5 in DA, 5 – 19 cps, 10 G, 20 – 200 cps SINE, ALL AXES				NOTE 2		NOTES 3 & 4		N/A			
SHOCK	20 G DESIGN, 4" CORNER DROP, FLOOR DROP (NOTE 5)				520 G PEAK RESP. AT 2000 cps	3000 G PEAK RESP. AT 2000 cps	160 G PEAK RESPONSE AT 2000 cps		3000 G PEAK RESPONSE AT 2000 cps			
ACOUSTIC NOISE NOTE 22	N/A				137 db	142.5db	N/A	159 db	N/A			
RADIATION, (RAD/DAY)	N/A				N/A				0.90	1260	0.695	1260
EMI	NOTE 23		NOTE 24		NOTE 23		NOTE 24		NOTE 23		NOTE 24	
LIGHT	NOTE 6				N/A	NOTE 6	N/A	NOTE 6	N/A	NOTE 7	N/A	NOTE 7
AIR MOVEMENT (ft/min)	N/A	NOTE 8	N/A	NOTE 8	N/A	NOTE 8	N/A	NOTE 9	N/A			
CONTAMINANTS	NOTE 10	NOTES 11, 12, 13 & 14	NOTE 10	NOTES 11, 12, 13 & 14	N/A				N/A			
METEOROID	N/A				N/A				N/A	NOTE 15	N/A	NOTE 15

TABLE II

[illegible] / PHASE / ENVIRONMENT	[illegible]				[illegible]				[illegible]	
	MDA		OWS		MDA		OWS		[illegible]	
	INT	EXT	INT	EXT	INT	EXT	INT	EXT	INT	EXT
TEMPERATURE (°F)	50° TO 90°	−250° TO +250°	NOTE 21	−250° TO +250°	−35° TO +100°	−140° TO +260°	−50° TO +100°	−250° TO +250°	NOTE 16	−150° TO +600°
PRESSURE (mm Hg)	77.6 TO 264	10^{-8}	10^{-8} TO 264	10^{-8}	264 TO 10^{-8}	10^{-8}	264 TO 10^{-8}	10^{-8}	264 TO 760 IN 7 MIN	10^{-6} TO 760 IN 7 MIN
HUMIDITY (% RH)	30 TO 95	N/A	30 TO 95	N/A	0 TO 100	N/A	0 TO 100	N/A	0 TO 100	0 TO 100
ATMOSPHERIC COMPOSITION	70% O_2 30% N_2 TO 100% O_2 NOTE 17	N/A	70% O_2 30% N_2 TO 100% O_2 NOTE 17	N/A	100% TO 0% O_2	N/A	100% TO 0% O_2	N/A	100% O_2 TO 20% O_2 80% N_2	0% O_2 TO 20% O_2 80% N_2
ACCELERATION (G)	N/A				N/A				20.0 ALL AXES	
VIBRATION	20 TO 80cps, AT +3 db/oct 80 TO 2000cps AT 0.005 G^2/cps ALL AXES - OVERALL = 3.2 G rms				N/A				NOTE 18	
SHOCK	3000 G PEAK RESPONSE AT 2000 cps NOTE 25		130 G P PEAK RESPONSE AT 2000 cps NOTE 25		N/A				78 G SAWTOOTH 15 ms	
ACOUSTIC NOISE NOTE 22	55db	N/A	55db	N/A	N/A				N/A	
RADIATION (RAD/DAY)	0.90	1260	0.695	1260	0.90	1260	0.695	1260	N/A	
EMI	NOTE 23		NOTE 24		NOTE 23		NOTE 24		MIL - STD 826A	
LIGHT	NOTE 19	NOTE 7	NOTE 19	NOTE 7	N/A	NOTE 7	N/A	NOTE 7	NOTE 19	N/A
AIR MOVEMENT (FT/MIN)	15 TO 100 CABIN	N/A	15 TO 100 CABIN	N/A	N/A				15	N/A
CONTAMINANTS	NOTE 20	OVER BOARD DUMP MATERIAL	NOTE 20	OVER BOARD DUMP MATERIAL	N/A				NOTE 20	NOTES 11 & 13
METEROID	N/A	NOTE 15	N/A	NOTE 15	N/A	NOTE 15	N/A	NOTE 15	N/A	

TABLE II

Design Environments (Cont'd)

Notes:

1. When the mounting arrangement is unknown or subject to possible future change, the flight axis criteria shall govern for all axes.

2. A. Sine Evaluation Criteria
All axes (20 - 2000 cps at 1 octave/minute)

20 - 50 cps at .019 inch D.A. Disp.
50 - 2000 cps at 2.4 g's peak

B. Random Criteria

1) Applicable to Experiments M402, M487, D019, and D020 only

High Level Random Criteria
For all axes (duration five minutes/axis)
20 - 50 cps at +6 dB/octave
50 - 100 cps at 0.172 g^2/cps
100 - 200 cps at -9 dB/octave
200 - 500 cps at 0.021 g^2/cps
500 - 2000 cps at -3 dB/octave
2000 cps at 0.0051 g^2/cps
Overall = 6.2 Grms

2) Applicable to ESS and all experiments except M042, M487, D019 and D020

High Level Random Criteria all axes (duration five minutes/axis)
20 - 50 cps at +6 dB/octave
50 - 100 cps at 0.9 g^2/cps
100 - 270 cps at -12 dB/octave
270 - 500 cps at 0.021 g^2/cps
500 - 2000 cps at -3 dB/octave
2000 cps at 0.0051 g^2/cps
Overall = 10.3 Grms

3. Wall-mounted components - All axes
20 - 40 cps at 0.07 g^2/cps
40 - 100 cps at +6 dB/octave
100 - 700 cps at 0.4 g^2/cps
700 - 2000 cps at -8 dB/octave
Overall = 23.4 Grms

4. Bulkhead-mounted components - All axes
20 - 200 cps at +10 dB/octave
200 - 1000 cps at 2.0 g^2/cps
1000 - 2000 cps at -10 dB/octave
Overall = 48.8 Grms

5. Mil-STD-810, Method 516.

6. Mil-STD-810, Method 505.

7. 1.34×10^5 Lux, 2000 Å to 30000 Å

TABLE II

Design Environment (Cont'd)

8. NASA TM X-53328, Table 5.6C
9. NASA TM X-53328, Table 5.6A
10. MSFC-SPEC-164, MSFC-PROC-151 & MSFC-PROC-166
11. Fungus - Mil-STD-810, Method 508
12. Sand & Dust - Mil-STD-810, Method 510
13. Salt Fog - 5% Solution for 50 hours
14. Rain - 4 ± 1 inch/hour
15. 0.9925 Reliable (18 months), Environment NASA TM X-53521 dated February 1, 1967
16. $50^{\circ}F$ to $125^{\circ}F$ Internal, $40^{\circ}F$ to $200^{\circ}F$ wall, in 2 minutes
17. Allowable $CO_2 \leq 7.6$ mm Hg, CO $\leq 20 mg/m^3$, Contamination $\leq 50 mg/m^3$
18. All axes
    20 - 80 cps at +3 dB/octave
    80 - 400 cps at 0.006 g^2/cps
    400 - 2000 cps at -3 dB/octave
    Overall = 2.5 Grms
19. 250 Lux, 3500 Å to 7500 Å (sunlight through vehicle windows)
20. Salt Fog - 1% Solution for 48 hours
21. 40° to $100^{\circ}F$ wall; 65° to $80^{\circ}F$ atmosphere
22. Overall sound pressure level re 0.0002 dynes/cm^2
23. MSFC 50M12968 MDA EMC Control Plan
24. MSFC 50M13087 OWS EMC Control Plan
25. Shock loading encountered during emergency conditions

4.6.3 Pressure Requirements

4.6.3.1 Operating Pressure - The unit shall withstand a continuous interval operating pressure up to 15 psid. No leakage shall occur.

4.6.3.2 Proof Pressure - The unit shall withstand an internal proof pressure of 22.5 psid for 3 min.

There shall be no permanent deformation or loss of operating capability. No leakage shall occur.

4.6.3.3 Burst Pressure - The unit shall withstand an internal burst pressure of 30.0 psid for 1 min. without rupture. No leakage shall occur.

4.6.4 Leakage - The unit shall have no leakage at the operation, proof or burst pressures defined herein. Indicated external leakage from any part of the unit shall not exceed 3×10^{-10} scc/sec above background and noise on the X-1 scale of a Consolidated Electrodynamics Corp. Model 24-120A or an approved equivalent helium mass spectrometer utilizing a sniffing probe. The mass spectrometer shall have a minimum sensitivity of 3×10^{-10} scc/sec/div without the probe. The maximum sniffing rate shall be one and one-half (1-1/2) feet per minute. Background helium indication shall not exceed 35 counts for the 3×10^{-10} scc/sec/div sensitivity. The allowable background shall vary inversely proportional to mass spectrometer sensitivity variations from 3×10^{-10} scc/sec/div. The unit shall be pressurized with a mixture consisting of a minimum of 50% helium and the remainder nitrogen gas by volume. Prior to conducting the leakage test, air dry the interior of the unit for one hour at 250°F ± 20°F and then back flow through the unit at atmospheric pressure with dry nitrogen having a -30°F dewpoint or better. Leak checks shall be conducted in accordance with an approved vendor process.

4.6.5 Structural Static Load - The unit shall withstand structural static limit loads as defined in the end item specification. The unit shall withstand 1.5 times the limit load without permanent deformation and 1.75 times the limit load without failure.

4.6.6 Vibration (Random)

4.6.6.1 Random (Qualification) - The unit shall be exposed to the random vibration described in Figure 1 for 5 minutes along each axis. The unit shall be pressurized to operating pressure. After vibration, the bench operating test shall be performed. No leakage shall occur.

4.6.6.2 <u>Random (Acceptance)</u> - The unit shall be exposed to random vibration described in Figure 2 for 120 seconds along each axis. The unit shall be pressurized to operating pressure. After vibration, the bench operating test shall be performed. No leakage shall occur.

4.6.7 <u>Orbital Temperature Simulation</u>

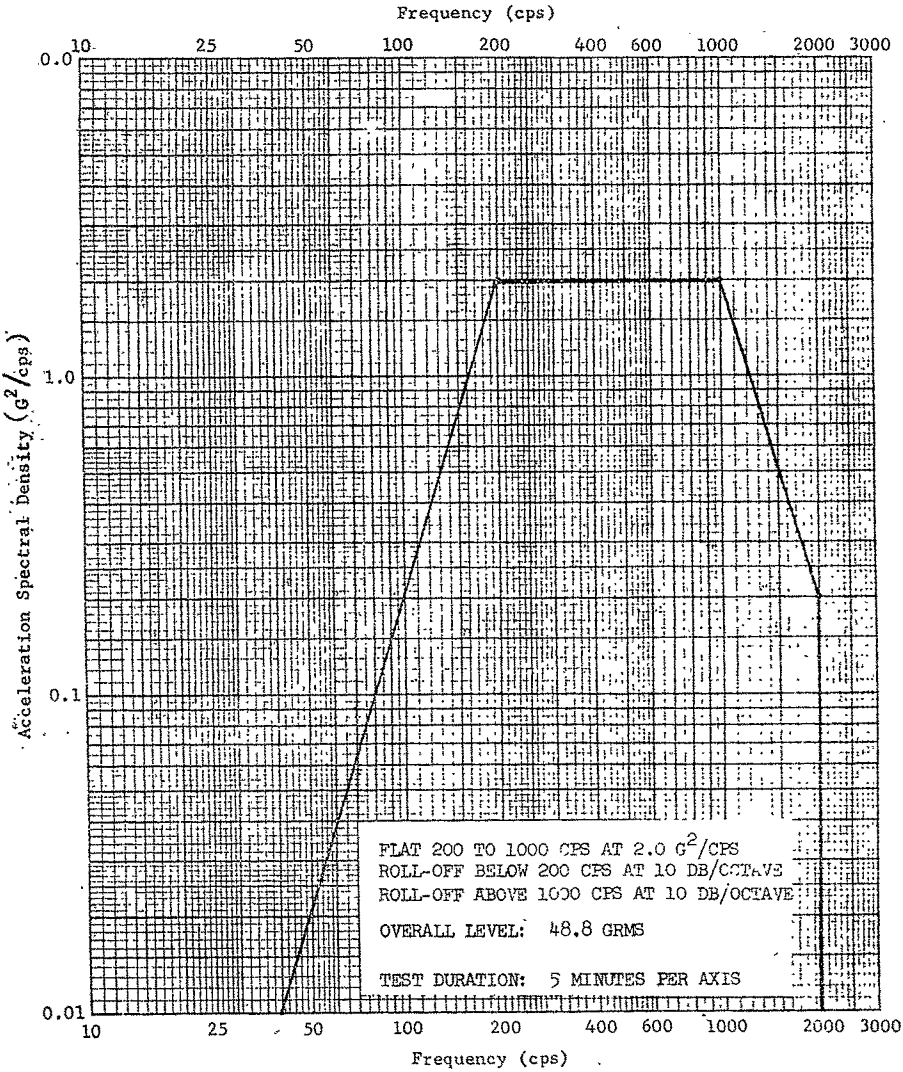
4.6.7.1 <u>Orbital Temperature Simulation (Qualification)</u> - The pressurized unit shall be placed in a vacuum chamber. The chamber pressure shall be reduced to 10^{-4} mm of Hg or less, and the wall temperature reduced to -250°F. After chamber temperature and pressure stabilization, the unit shall be cycled continuously through its operating parameters for a period of 6.5 hours. The chamber wall temperature shall then be increased to +250°F within a one (1) hour period, the unit cycled for 7 hours with the wall temperature at this temperature. At the completion of the 7 hour period, the chamber wall temperature shall be reduced in one (1) hour to -250°F and the unit cycled until its temperature has stabilized, or for 6.5 hours, whichever is shorter.

4.6.7.2 <u>Orbital Temperature Simulation (Acceptance)</u> - Same as Orbital Temperature Simulation (Qualification) except that low temperature shall be TBD and the high temperature shall be TBD. Operating times shall be TBD and TBD respectively.

4.6.8 <u>Bench Operating</u> - The Bench Operating (Acceptance) test will be conducted before and after each environmental test to detect any failure of the unit to function correctly, unless otherwise stated.

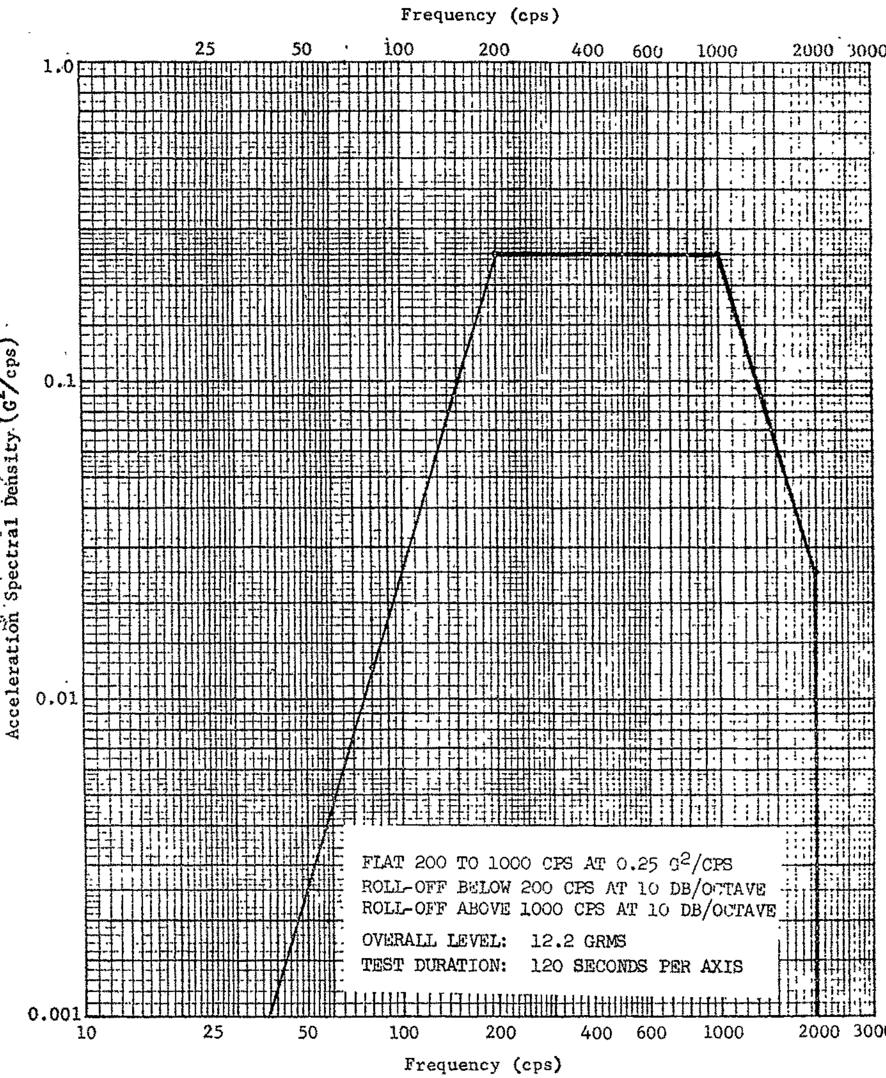
4.6.8.1 <u>Bench Operating (Acceptance)</u> - The unit shall operate continuously at ambient bench conditions, through all functional parameters defined in the operational procedure specification while in the pressurized condition. Ten complete cycles shall be performed. No leakage shall occur.

4.6.8.2 <u>Bench Operating (Qualification)</u> - The unit shall operate continuously, at ambient bench conditions, through all functional parameters defined in the operational procedure specification. The unit shall withstand 1000 cycles at operating pressure and 500 cycles at proof pressure. At the conclusion of the above requirements, the unit shall be operated at operating pressure until failure conditions occur. After the initial 1500 cycles the unit shall be considered qualified.

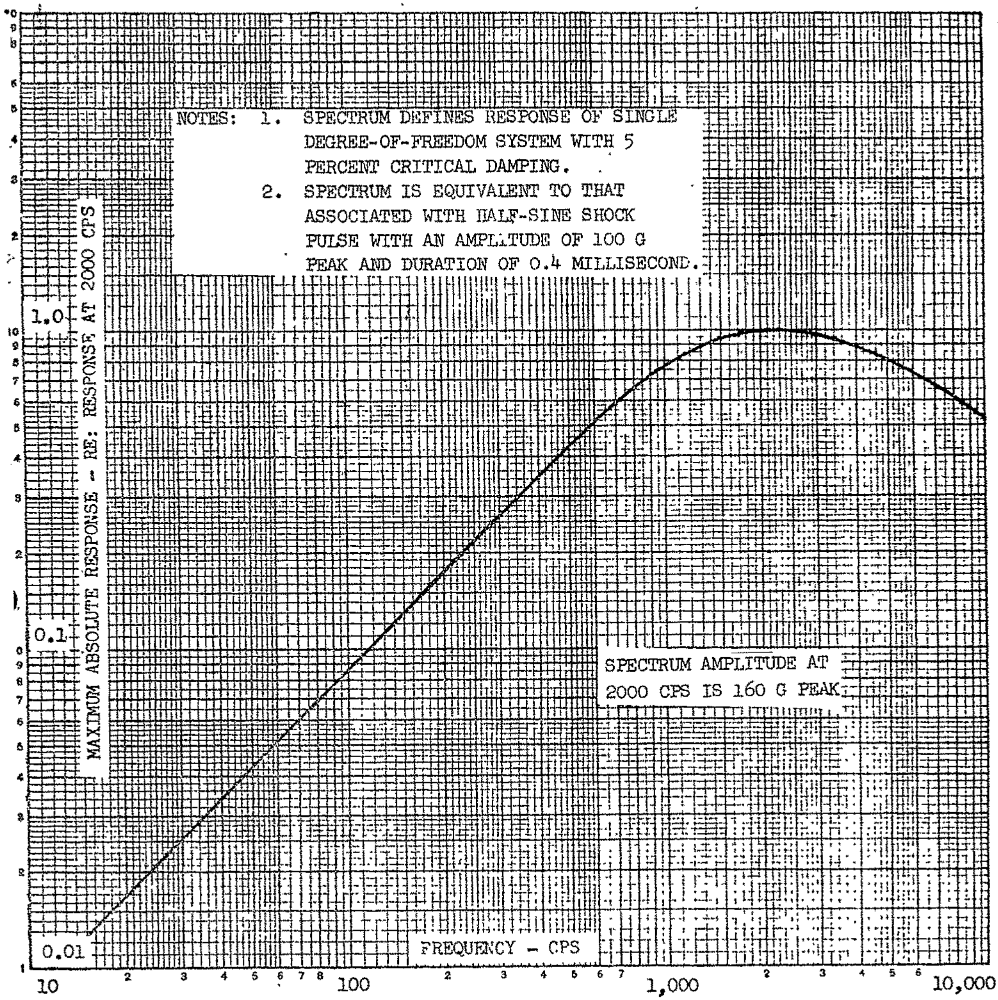


Qualification Random Vibration Specification

Fig /.



Acceptance Random
Vibration Specification
Fig 2.



Pyrotechnic Shock Specification (Normalized Shock Response Spectrum) Flight AAP-2 Experiments and Equipment

Figure 3

4.6.9 Shock, Non-Operating - The shock pulse described in Figure 3 shall be applied 3 times in each direction along the longitudinal and lateral axes of the unit.

4.7 Failure Reporting - A component or end item rejected for any reason during test maybe reworked or replaced to correct the defect(s) in accordance with NASA approved contractor process and Quality Assurance procedures. The extent of retesting required will be determined by the contractor subject to approval of the designated NASA representative. Log book records will show reason for all such rejects, retests performed and corrective action taken.

4.8 Test Documentation - In order to assure uniform test program control and properly assess test data, test specification, test procedures and test reports shall be prepared and contain all the necessary requirements as defined in NASA publication NPC 250-1.

4.9 CEI Verification Requirements - Successful completion of the following CEI verification requirements shall determine acceptance of the Contractors CEI design and performance requirements, and shall demonstrate qualification of this end item, (Table III).

TABLE III

Verification Requirements

CEI Section 3.0 Requirement Ref	Verification Method Develop	Qual	Accept.
3.1.1.1.1 Pre-flight	NA	NA	NA
1.1	2b	2b	NA
1.2	2b	2b	NA
1.3	NA	NA	NA
3.1.1.2 Sec Performance	NA	NA	NA
2.1	2c	2c	2c
2.2	2c	2c	2c
2.3	NA	NA	NA
2.4	NA	NA	NA
2.4.1	2c	2c	2c
2.4.2	2c	2c	2c
2.4.3	1	1	2b
2.4.4	1	1	1
2.4.4.1	1	1	1
2.4.4.2	1	1	1
2.4.4.2.1	1	1	1
2.4.4.3	1	1	NA
2.5	1	1	1
3.1.2 Operability	NA	NA	NA
2.1	2b	2b	NA
2.1.1	2b	2b	NA
2.1.2	2b	2b	NA
2.2	2b	2b	NA
2.2.1	2b	2b	NA
2.2.2	NA	NA	NA
2.3	2b	2b	NA
2.3.1	2b	2b	NA
2.4	NA	NA	NA
2.4.1	2b	2b	NA
2.4.2	1	1	1
2.4.3	1	1	1
2.4.4	1	1	1
2.5	2b	2b	NA
2.6	2b	2b	NA
2.7	2b	2b	NA
2.7.1	2b	2b	NA

Verification Method

1. Test
2. Assessment
   a. Similarity
   b. Analysis
   c. Inspection
   d. Demonstration
   e. Validation of Records

N/A Not Applicable

TABLE III

Verification Requirements
(Continued)

CEI Section 3.0 Requirement Ref	Verification Method Develop	Qual	Accept.
3.1.2.7.2	2b	2b	NA
2.8	NA	NA	NA
2.8.1	2b	2b	NA
2.8.2	1	1	NA
2.8.3	NA	NA	NA
2.8.3.1	2b	2b	NA
2.8.3.1.1	2b	2b	NA
3.2 CEI Definition	NA	NA	NA
3.2.1	TBD	TBD	TBD
3.2.1.1			
2.2.1			
2.2.2			
2.2.3			
3.3 Design & construction Construction	NA	NA	NA
3.3.1	NA	NA	NA
3.3.1.1	1	1	1
1.2	NA	2c	2c
1.2.1	NA	2c	2c
1.2.2	2b	2c	2c
1.2.3	2c	2c	2c
1.2.4	2c	2c	2c
1.2.5	2c	2c	2c
1.2.6	2c	2c	2c
1.2.7	2b	1	1
1.2.8	2b	2b	NA
3.3.2	NA	2c	2c
2.1	NA	2c	2c
3.3.3	2b	2c	2c
3.3.4	2b	2c	2c
3.3.5	2b	2c	2c
3.3.6	2b	2c	2c
3.6.1	2b	2c	2c
3.6.2	NA	2c	2c
3.3.7	2b	2c	2c
3.3.8	NA	2c	2c
3.3.9	NA	2c	2c

APPENDIX A

AAP EXPERIMENTS SUMMARY

appendix contains a summary of the AAP experiments and possible Serpentuator applications analyzed in Task A. The experiments are grouped in three categories: experiments with Serpentuator applications for equipment positioning or deployment, experiments with Serpentuator EVA applications, and experiments with no Serpentuator applications.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
D020 Alternate Restraints Evaluation	Experiment is to evaluate the capability of the MOL foot, leg, pelvic, and waist restraints to position the astronaut in maintenance and precision tasks. A secondary objective is the evaluation of the M508 tools with the MOL restraints, and the MOL tools with the M508 restraints in tasks performed on the M508 task board for comparison purposes. This experiment is a source of data for experiment M055, Time and Motion Study, and the film requirements of D020, including recovery, are satisfied by M055.	Two crew members are required for performance of experiment. One crew member will perform maintenance type tasks using MOL and M508 restraints and tools as aids in accomplishing these tasks. Second crew member will photograph task performance and record verbal evaluation of restraints. A total of 936 minutes is required for completion of the experiment tasks.	Serpentuator could be used as an astronaut positioning aid while performing tasks.
S019 UV Stellar Astronomy	Experiment is to achieve useful design of a wide angle ultraviolet spectrograph; to obtain a large number of stellar spectra to permit study of UV line spectra and spectral energy distribution of stars; and to obtain low dispersion UV spectra in a large number of milky-way fields. Experiment equipment consists of a spectrograph camera to measure and record the desired data. Camera is hard mounted in MDA Scientific Airlock. The entire spacecraft must be oriented so that the experiment optical axis is aligned (Continued)	Experiment requires two crew members to unstow experiment and set up in MDA Scientific Airlock. Target is acquired, camera focused, and film exposed for a minimum of 5 seconds. Five exposures are obtained for each star field studied. Three fields are examined on five night passes. Four more night passes are used for milky-way observations. At the conclusion of the experiment the camera is stowed with film intact for later processing on earth.	The Serpentuator could be used as an aid to unstow, position, and secure equipment. Would require Serpentuator installed in the MDA.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S019 (Continued)	within ± 2° of the desired target, with drift rates of less than 0.05°/sec.		
S022 Low Z Cosmic Ray	Experiment is to study composition of heavy primary cosmic ray nuclei to yield information on the origin of primary cosmic radiation. Experiment uses a nuclear emulsion stack that records the track or trace of the particle or nucleus as it passes through the emulsion.	Emulsion stack deployed from vehicle on a boom for exposure to radiation. A set of gimbals mounted on the end of the boom serve to orient the package in the proper direction. At the conclusion of the experiment, the boom is retracted, and the emulsion stack is retrieved by EVA.	Serpentuator could be used to deploy and retrieve emulsion stack. The Serpentuator would allow pointing of the package, eliminating the need for a separate gimbal system for the experiment. Would also eliminate need for EVA.
S023 High Z Cosmic Ray	Experiment is to study charged nuclei having a nuclear charge, Z, greater than or equal to that of calcium, and with energies between 50 and 300 MeV per nuclear. The emulsion stacks used are composed of two halves which face each other when they are not exposed. The stacks are extended on a boom and unfolded to allow determination between traces which occur before and after deployment.	Emulsion stacks deployed on boom during translunar orbit at a distance greater than 10 earth radii. Emulsion stacks remain deployed for remainder of mission. At the conclusion of the experiment, the emulsion stacks are retrieved by EVA.	Emulsion stacks could be deployed and retrieved by the Serpentuator eliminating need for EVA.
S049 IR Interferometer Spectrometer	Experiment is to obtain information on the spectral emittance data from selected targets by observing the infrared spectra emitted by the earth's atmosphere and surface.	Astronaut required to orient spacecraft so that spectrometer is pointing at desired target and hold pointing within ± 1 degree from 12 seconds. Instrument must also be pointed into space periodically (Continued)	Possible Serpentuator application of mounting of sensor. Serpentuator could then be used to point sensor into space for calibration, thus eliminating need to reorient entire spacecraft.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S049 (Continued)		for calibration readings. Number of experiment repetitions is unspecified. Approximately 3 hours total time is required.	
S063 UV Airglow Horizon Photography	Experiment is to observe visible airglow, UV nightglow, UV twilight airglow, and UV earthlight by means of direct camera photography. Main experiment equipment is a 35 mm camera equipped with removable lens and film magazines. Experiment is performed in MDA. Spacecraft must be pointed to within 1/2 degree of the intended direction for each picture exposure.	Astronaut will orient the spacecraft such that the camera is coarse pointed at the target. Camera will then be fine pointed using adjustments provided on the mount. Exposure will then be initiated. The camera will then be moved to the second, third, and fourth positions in MDA with the pointing and exposure sequence being repeated at each position. Experiment will be repeated for a minimum of four sequences. Photography will continue until all film is used. Film returned to earth for processing.	Camera could be moved and secured in the four positions automatically by the Serpentuator, eliminating the need for astronaut to carry cameras from window to window. Would require Serpentuator mounted in the MDA.
S065 Multiband Terrsun Photography	Experiment is to obtain information and experience relative to the field of optics and spectral reflectance in support of future orbital photography. Experiment will be accomplished by study of simultaneous exposures with four different film/filter combinations. Equipment used will be a 4 unit set of Hasselblad (Continued)	Astronaut will unstow and mount cameras near MDA windows, and manually point the camera cluster line of sight at the preselected scene. The time, magazine number, frame number, and any unusual window conditions will be recorded by the astronaut. The shutter exposes the film on all four cameras simul- (Continued)	Serpentuator could be used to unstow and mount cameras. This would require Serpentuator installed in the MDA.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S065 (Continued)	cameras, which will be bore-sighted prior to flight. A total of 900 exposures per camera will be available in 24 film magazines. Spacecraft spin rates not to exceed 5°/min during exposure.	taneously. The experiments will be repeated for 900 exposures. Film will be returned for processing.	
S067 Gamma-Ray and X-Ray Spectroscopy	Experiment is to measure the energy spectra of gamma-ray and x-ray emissions from cosmic sources and to interpret these spectra in terms of astrophysical phenomena. The experiment will employ two sensors to cover a major portion of the 1 KeV to 10 MeV range. The sensors are to be deployed on a boom in order to reduce interference from spacecraft sources. The boom length should be on the order of the spacecraft dimensions or larger. The boom cable must be able to transmit pulses of fast rise time (0.1-1μsec) without excessive distortion.	Upon obtaining orbit, the detectors will be uncaged and the boom extended to the observing position. The detector system must then be calibrated with a weak radioactive source and checked for operation. Data will be accumulated as the spacecraft rolls as is stabilized for other experiments. Selected sources will be observed by controlling spacecraft attitude so that the detectors point at an object of interest. Data will be stored on magnetic tape. At the conclusion of the experiment the boom is retracted.	Serpentuator could be used as the boom to extend the detector package. The length of the Serpentuator is the same order of magnitude as the desired detector separation distance from the spacecraft. Serpentuator would point sensor at desired target, eliminating the need to orient the entire spacecraft.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
D021 Expandable Airlock	Experiment is to validate the design of an expandable, elastic, airlock for application to future manned orbital laboratories. This validation will be conducted along two lines. First, a general materials evaluation of the expandable structures technology, and second, the evaluation of the functional characteristics of a specific airlock interfaced with astronaut ingress-egress.	One crew member will go EVA to release the D021 canister restraint and observe the release, deployment, and pressurization of the airlock. He will then return to the AM until completion of the proof pressure test period. Then 2 crew members will go EVA. One member will perform ingress/egress operations while the other photographs the procedure and acts as a safety man. The airlock will remain pressurized for 15 days. At this time, one crew member will go EVA to inspect, photograph, and vent the airlock. Material samples will be returned from the airlock. The total experiment time is 2 hours.	EVA could be aided by use of the Serpentuator.
D022 Expandable Re-Entry Structures	Experiment is to demonstrate the ability of an astronaut to deploy and lock an expandable re-entry capsule and to install a payload in it. Experiment will also provide an in space expansion and rigidization of a chemically rigidized fluted core glass cloth panel.	One crew member goes EVA to perform panel rigidization. Panel package is unstowed and panel unfurled. Panel is inflated and chemical catalyst introduced. Results are photographed. The expandable re-entry vehicle is then unstowed and the crew member returns to spacecraft with this package and the rigidized panel. Crew member then expands the re-entry vehicle and inserts object into it. (Continued)	Serpentuator could be used to aid or eliminate EVA.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
D022 (Continued)		Expanded vehicle and panel is stowed for return to earth.	
M416 Propellant Mass	Experiment is to investigate the flight performance of new mass measuring systems in low gravity environment. Mapping of fluid mass distribution will be based on motion picture photography of fluid action supplemented by TV camera coverage.	Astronaut remotely turns an experiment and turns off experiment after 1 hour. EVA required to retrieve film from cameras.	Serpentuator could be used to replace or aid EVA.
M417 Liquid Interface Stability	Experiment is to provide information on low-g fluid dynamics in propellant tanks.	Cameras turned on remotely at liftoff. Cameras operate continuously for 10 minutes and then intermittently for two hours. EVA required to retrieve film.	Serpentuator could be used to aid or replace EVA.
M427 Strap Down Platform	Experiment is to generate information for present design studies pertaining to the use of strapdown platform for boost and in-orbit guidance.	Data taken during boost and first orbit of flight and recorded. 15 minutes EVA to retrieve the tape cartridge. This could be done during any EVA activity period.	Serpentuator could be used to replace or aid EVA.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S016 Trapped Particle Asymmetry Experiment	The purpose of this experiment is to extend range of measurements of trapped, charged - particle flux (esp. protons) in region of South Atlantic Anomaly. Will allow study of interaction of geomagnetically trapped protons with atmosphere. Objectives are: 1) extend measurements of Van Allen proton spectrum, 2) measure directional differential energy spectra for trapped protons, 3) measure pitch angle distribution of impinging protons, 4) search for trapped particles heavier than protons, 5) estimate energy deposited in outer layers of emulsion by energetic electrons. The emulsion stack is the only equipment directly involved in detecting and recording the changed particle flux. The emulsion stack must be shielded from radioactive sources prior to deployment and protected from heat exceeding 100°F at all times.	Equipment package, 4 x 5 x 6 weight 30 lbs. Must be mounted exterior to command module, beyond magnetic distortion introduced by the module. Possibly mounted on extendable boom, probably on telescope. Deployed by EVA prior to 4th orbit. Must retrieve package before re-entry by EVA.	Serpentuator could aid or eliminate EVA.
S039 Day-Night Camera System	Experiment is to photograph cloud cover in both the day and night portions of the earth. Experiment equipment (Continued)	Experiment completely installed prior to launch. Astronaut required to turn on power to the cameras. At start (Continued)	Serpentuator could be used to eliminate or aid EVA required to change or remove film from mapping camera.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S039 (Continued)	consists of an image orthicon camera and a mapping camera with identical fields of view and parallel optical axes. Cameras are hard mounted and remotely operated. Experiment to be conducted concurrently with S-040 Dielectric Tape Camera System experiment.	of the experiment, the camera lens covers are remotely removed and picture taking session begun. All camera parameters are automatically set. Experiment will be repeated as required to obtain coverage of desired target areas. EVA required to change or remove film from mapping camera.	
S042 Multiband Synoptic Photography	Experiment is to obtain multispectral synoptic steroscopic coverage over a selected portion of the earth s surface. The experiment will provide a means for measuring spectral reflectances of earth features from a remote position and provide data for correlation with an interpretation of results of other AAP remote sensor experiments.	No deployment is required. Astronaut maneuvers spacecraft so desired area is in camera field of view. Camera is switched on and film exposed. Exposure time is from 1 to 10 minutes. Camera shuts down automatically at end of exposure. Approximately 3.5 hours of film is available. EVA is required at conclusion of experiment for film retrieval.	Serpentuator could be used to eliminate or aid EVA for film retrieval.
S069 X-Ray Astronomy B	Experiment is to determine positions of know x-ray sources within several arc seconds, to measure the dimensions of the x-ray sources, and to observe objects of interest for x-ray emission. The equipments employed are: an x-ray detector which is mounted prior to flight on the outside of the MDA and is extended out (Continued)	An astronaut in the CM performs vehicle alignment. Astronaut in MDA must warm-up system, initiate automatic deployment of the x-ray detection unit from inside the MDA, acquire the source to be measured, monitor the data, shut the experiment down, and dump the data at the earliest time. This (Continued)	Serpentuator could be used to aid or eliminate EVA for film retrieval.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S069 (Continued)	from the MDA for use; an Electronics and Data Handling Package and the Control and Display Unit are mounted in the MDA for storage and are activated in the storage position. A camera for recording position data is mounted on the detector unit. Film from this camera may have to be retrieved by EVA unless a fiber optic light pipe is employed thru the MDA wall to the camera.	procedure is run for the 30 sources to be measured. At the completion of the experiment, the film from the unit must be retrieved.	
ATM-S052 White Light Coronagraph	Experiment is to determine the k component of the solar corona from 1.5 to 6 solar radii. Experiment equipment consists of a Lyst Coronagraph which occults the solar disc and permits photographing the dim solar corona. Four exposures are taken; one unpolarized and three using polaroid filters. Experiment axis is aligned to within ± 20 arc-sec of the center of the solar disc. Experiment is part of ATM package and is operated in conjunction with other experiments in this package.	Astronaut turns on power to experiment and directs coarse pointing of experiment to within 5 arc-min of sun center using ATM controls. Experiment external shutter opened and astronaut aligns to within 20 arc-sec of sun center. Astronaut selects desired mode of operation and photographs are taken. Experiment will be repeated as required to obtain coverage of selected targets. EVA required to replace and retrieve cameras. Cameras are returned to earth for film processing.	Serpentuator could be used to replace or aid EVA for replacement and retrieval of cameras.
ATM-S054 X-Ray Spectrograph Telescope	Experiment is to obtain images of x-ray flare events with a spatial resolution of a few (Continued)	Two modes of operation will be utilized. The first will be used when the sun is in a (Continued)	The film could be retrieved by the Serpentuator automatically or as aid to EVA retrieval.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
ATM-S054 (Continued)	arc-seconds, simultaneously record flare spectra, and follow the evolution of both the spatial image and spectral distribution during the onset, development, and decay of a flare. This experiment is part of the ATM package and will be operated in conjunction with the other experiments in this package.	quiescent stage, and will take photographs during non-flare periods using different band pass filters. The second mode of operation will take photographs during flare activity. The filters will be replaced by a transmission grating. Experiment repetitions is unspecified. Estimated time is 50 hours per 14 days in orbit. EVA is required every 14 days for film replacement.	
ATM-S056 X-Ray Telescope	Experiment is to gather data which will enable a better understanding of the processes occuring in the solar atmosphere, particularly during periods of solar flare activity. A grazing incidence optical system, in conjunction with six filters, will provide crude spectral resolution. Proportional counters will measure the spectral distribution of solar x-ray radiation during quiescent and active periods. This experiment is part of the ATM package and will be operated in conjunction with other experiments in this package.	Astronaut required to perform checkout of experiment equipment. Experiment must be pointed to within $\pm$ 1 arc-min of selected solar target. Astronaut activates experiment, selects exposure, and then camera automatically advances and exposes film. Procedure is repeated for the desired number of exposures. Experiment repetitions is unspecified. Depends on solar activity. At the conclusion of the experiment, the astronaut deactivates the experiment equipment. EVA is required to remove or replace film in camera.	Serpentuator could be used to aid or eliminate EVA for film retrieval.
ATM-S082A X-UV Spectroheliograph	Experiment is to obtain photographic images of the sun in the wavelength range from 150 (Continued)	When the experiment axis is pointed, power is turned on to the experiment. Astronaut (Continued)	Serpentuator could be used to aid or eliminate EVA for film retrieval.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
ATM-S082A (Continued)	to 650 angstroms. The instrument axis is initially pointed within one arc minute of the center of the solar disc. Pitch and yaw stability of less than 5 second drift in 20 minutes is required.	selects desired preprogrammed exposure sequence. When a series of exposures has been completed, the instrument aperture is closed and power turned off. The film is advanced automatically for the next exposure. EVA will be required for film retrieval and replacement.	
ATM-S083A UV Scanning Spectrometer	The experiment is to measure photoelectrically, the far ultra-violet emission-line spectrum from selected regions of the sun. A mirror is used to focus the solar radiation on a spectrometer. The astronaut selects the region to be sampled by looking at a video system focused on the output of the spectrometer which is displayed on the control panel. A camera makes periodic, automatic records of instrument pointing. Experiment is for the ATM flight.	The experiment is initially set-up prior to flight. The experiment package is stored in its rack and operates there. The control panel and monitor are in the LM. The camera is external to the spacecraft. One astronaut is required to initiate the experiment whenever the ATM is to be manned. The film from the external camera requires an EVA for retrieval. All other data is dumped at the appropriate time. Experiment repetitions is not yet determined.	Serpentuator could be used to aid or replace EVA for film retrieval.
T017 Meteoroid Impact and Erosion	This experiment is to measure the meteoroid erosion rate on a vycor glass surface and to obtain data about small meteoroids. From results of experiment it will be possible to: 1) estimate the lifetime of optical instruments in (Continued)	The experiment package size is 60 x 2.7 x 16 inches. Each panel is 7 x 17 x 1/4 inch aluminum frame holding a highly polished Vycor glass. Total experiment weight is approximately 13.5 pounds. Requires no power or recorder. (Continued)	Serpentuator could be used to aid or eliminate EVA for experiment retrieval.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
T017 (Continued)	space, 2) verify the Pegasus 1 1/2 mil data, and 3) estimate the number density of the comets and asteroids that create meteoroids.	Experiment package is mounted to T021 deployment mechanism which is mounted to AM strut #4 near EVA hatch. Panels are retrieved on AAP 3/4 by EVA. No repetitions.	
T021 Meteoroid Velocity and Impact	The meteoroid penetration flux-velocity experiment will measure the impact velocity (magnitude and direction) and the penetration depth into soft aluminum of meteoroids in the near-earth orbit with mass greater than $10^{-11.5}$ grams. The velocity is measured during flight and the impact plates are recovered for ground analysis.	The experiment package size is 41 x 55 x 5 inches with protective cover. Experiment is located, at launch, on airlock strut No. 4, near EVA hatch. Experiment is remotely operated and controlled Data retrieval is ground controlled and dumped once a week. Panels are retrieved at the end of AAP/2 and AAP/4 by EVA. Experiment T017 is deployed on the same AM strut. The experiment will be repeated twice.	Serpentuator could be used to aid or eliminate EVA for experiment retrieval.
T023 Surface Absorbed Materials	Experiment is to collect specimens of materials which absorb on the exterior of the spacecraft during various stages of insertion into orbit. Specimen collections are mounted prior to launch and are returned to earth for pastflight analysis.	The experiment is deployed and conducted automatically. Approximately 50 minutes of EVA is required at conclusion of the experiment for retrieval of the specimen collectors.	Specimens could be retrieved automatically by the Serpentuator or the Serp could aid EVA retrieval.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
D008 Radiation in Spacecraft	Experiment is to investigate radiation environment, shielding interactions, and dose rate levels to assure protection of astronauts against space radiation. Experiment equipment consists of one active and five passive dosimeters. The passive units are mounted in five different locations in the CM.	There are no crew procedures for the passive dosimeters. The active dosimeter will be placed in the following positions: 1. against the chest 2. between the legs in the groin area 3. under the left armpit 4. five different areas within the CM. The astronaut will leave the sensor head in the different locations for approximately 2 minutes. Data will be recorded on magnetic tape. Experiment operates continuously.	No Serpentuator application
D017 CO_2 Reduction	Experiment is to evaluate the operation of a Solid Electrolyte CO_2 Reduction Cell in weightlessness for an extended period of time. Reduction Cell produces CO and O_2.	Only astronaut participation consists of experiment activation and deactivation by an on-off switch, and occasional observance of a pilot light, which indicates power is on.	No Serpentuator application
D019 Suit Donning and Sleep Evaluation	Experiment is to evaluate the timelines and techniques of MOL pressure suit donning in a zero-g environment and to evaluate the effectiveness of the MOL sleep station. Experiment equipment consists of restraints which are used for the suit donning and sleep (Continued)	Astronaut will donn and doff suit two times, using suit donning station and technique. Astronaut will ingress/egress MOL sleep station. Suit donning, doffing, and sleep station ingress/egress will be photographed for later analysis.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
D019 (Continued)	stations and a MOL pressure suit. Voice comments and photography will record the results of the experiment.		
M018 In-Flight Vectorcardiogram	Vectorcardiogram monitoring of all 3 crewmen, 12 times each (each man every 3 days). Experiment time is 40 min. per run; 13 min. set up; 17 min. run, and 8 min. tear down. The subject wears the body vest and VCG electrodes from the signal conditioning equipment. The test run is composed of a 5 min. rest mode, 2 min. ergometer exercise, and 10 min. rest mode. The bicycle ergometer provides the work output measure to the recording equipment.	Experiment assumes all equipment is in OWS prior to start and ergometer is in place and connected. The Harness and Vest, Electrode Application Kit, and Biomedical cable are removed from storage and connected; the experiment is run; and equipment disconnected and stored. Experiment is repeated 36 times.	No Serpentuator application
M050 Metabolic Cost of In-Flight Tasks	Experiment measures the energy expenditure of each crewman during a three phase test with each test taking 1 hr. The phases are: a. resting and bicycle ergometer b. unsuited maintenance and constant work tasks c. suited maintenance and constant work tasks. The energy expenditure is calculated measuring the metabolic rate during specific tasks. Two crewmen are required for (continued)	The bicycle ergometer (5 ft^3), the Work Task Unit (3 ft^3), and the Metabolic Rate Unit (2 ft^3) must be positioned in a stored mode in the OWS. This equipment is then permanent in the OWS. All other equipment is initially stored in OWS. Each test requires that equipment be turned on and hoses connected. After each test equipment is turned off and stowed. Experiment is repeated 3 times for each of the 3 crewmen.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
M050 (Continued)	each test; one experimenter and one observer.		
M051 Cardiovascular Function	Experiment subjects crewman to negative pressure on lower body to determine effects of blood concentrations in space travel. Test measures blood pressure, volume changes in legs, and temperature. Two crewmen are required for each test. Subject is placed in vacuum chamber covering lower body area and data is recorded.	Install lower body negative pressure unit in Orbital Work Shop and set-up for operation. Remove equipment from storage, assemble and activate. Position in lower body negative pressure unit and perform tests. Disassemble equipment and store after each run. Equipment consists of temperature and blood pressure monitoring equipment, electrodes, cables, and plethysmograph for measuring leg volume. Experiment is repeated 12 times.	No Serpentuator application. Equipment moved from MDA to OWS as part of experiment M487.
M052 Bone and Muscle Changes	Experiment is the measurement of the waste produced by each crewman, the daily body mass of each crewman, the food residue after each meal, and the water intake. This is done to assess the alteration in musculoskeletal status during orbital flight, to evaluate water, electrolyte, and possible steroid changes.	All equipment is activated as part of M487. This experiment requires natural body functions of defecation and urination. Samples must be dried and stored or emptied to space. Also measured is the food residue from each intake and the body mass of each crewman once each day.	No Serpentuator application
M053 Human Vestibular Function	Experiment is divided into two parts: 1. Determine susceptibility of man to semicircular canal stimulation change as a (Continued)	Equipment is initially in operating position in the OWS. Equipment must be turned on and checked out. This requires that instrument panel cover (Continued)	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
M053 (Continued)	function of time in zero-g. Does his sensitivity to motion change? 2. Determine whether prolonged zero-g environment will change astronaut's gravity receptor function or not? Both tests are conducted by placing the subject in a rotating, tilt chair, properly instrumenting him, and subjecting him to various attitudes and rate changes as controlled by the observer.	be removed from console. After test, the instrument panel cover is replaced and equipment is left in place. Initial equipment positioning is charged to set up of OWS. Experiment is repeated 27 times.	
M055 Time and Motion Study	Experiment uses film sequences obtained during various experiments, as part of the experiment, to compare activities performed in one-g to the same activities performed in zero-g.	Experiment requires the loading and operation of on-board cameras during specified experiments. The experiment itself is performed on the ground following the flight.	No Serpentuator application
M056 Specimen Mass Measurement Device	The experiment is to evaluate and demonstrate the feasibility of mass measurement without gravity and to support the bio-medical experiments. The system employs a self contained unit which employs a mass pan suspended on plate-fulcra springs. The pan, with specimen, is displaced a fixed distance and its oscillations, when released are timed for 5 oscillation. The time is then read out as mass. This exper- (Continued)	Only the initial use for the standard mass measurement is charged to this experiment. If unit is stored when this experiment is run, the unit must be removed from storage, zeroed-in, tested and retained to storage. Unit is to 0.3 ft^3. One standard mass is measured. Experiment is activated each time food and drinks are taken, and twice daily for waste measurement.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
M056 (Continued)	iment uses a standard mass set to prove the concept. Other uses of the unit will be the food and drink and waste material measurement. One unit will be stored and operated in the CM, 2 stored in the MDA and operated in the Food Support and Waste Management Areas.		
M058 Body Mass Measurement Device	Experiment is to demonstrate the feasibility of the design of the body mass measurement system and to use the system to support the bio-medical experiments. The system is a self contained, spring/flexure pivot mounted chair. The chair is activated from a fixed displacement and the oscillations are timed. From this the mass is calculated.	The unit is initially stored in the MDA. It is approximately 8.4 cu. ft. The unit must be set up in the OWS where it is used and stored in the same position. All work is done with the astronaut in the chair and may be accomplished by the one man. Initial experiment transfer and storage is charged to OWS set up. Experiment is performed daily for each crewman.	No Serpentuator application
M415 Thermal Control Coatings	Experiment is to determine the degradation intensities of the thermal control coatings from launch environment, retro-rockets, and spacecraft tower jettison. In addition to the flight experiment, but not involving the vehicle, the effect of pre-launch environment will be measured. Experiment equipment consists of two panels, each containing 12 (Continued)	No astronaut participation required. Experiment automatically activated and operated. Data is telemetered to ground stations.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
M415 (Continued)	thermal sensors, mounted external to the vehicle. The sensor covers are removed at various stages of the flight. Data is taken from all sensors to measure differences in thermal conductivity.		
M423 Hydrostatic Gas Bearing	Experiment is to investigate the feasibility of reducing the flows to gas bearing gyros when these are operated in a zero-g environment.	Experiment completely automated. Requires no astronaut participation. Experiment is repeated once each orbit.	No Serpentuator application
M439 Star-Horizon Automatic Tracking	Experiment is to determine the navigational accuracy which can be attained when scattered sunlight in the upper atmosphere is used for navigational horizon determination.	Astronaut aligns vehicle so star acquisition is possible. Star is acquired and photometer swept through horizon to get desired reading. Entire operation requires 5 minutes after initial positioning of spacecraft. Experiment will be repeated 32 times.	No Serpentuator application
M479 Zero-G Flammability	Experiment is to study the effects of zero-g on flammability and the relative effectiveness of several extinguishing agents.	Astronaut sets up experiment equipment, installs the igniter and fuel, and actuates a switch which automatically starts the camera, ignites the fuel, and performs other necessary functions. Astronaut then vents the fuel chamber, installs new igniter and fuel, and repeats the experiment 76 times.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
M484 Orbital Work-shop Artificial "G"	Experiment is to simulate 1/6 "G" and hard vacuum lunar environment in order to conduct experiment M466.	Spacecraft will be spun up to 4-5 RPM to obtain the 1/6 "G" environment. At the conclusion of the experiment, the space-craft will be de-spun.	No Serpentuator application
M489 Heat Exchanger Service	Experiment is to develop an understanding of wicking evaporative heat exchangers (water boilers) so that system designs may be effected from requirements and analysis. Experiment equipment consists of two assemblies containing 6 different heat exchangers and support equipment. The only additional equipment required is the AM data system. Experiment is installed in the MDA prior to launch.	One astronaut required to per-form experiment. Approximately 2 hours will be required to initially service the exper-iment and one half hour for each experiment run. Astro-naut will select proper unit, turn on power to unit, monitor instrumentation, initiate T/M, and then turn power off. Operation is then repeated for different unit or power level. Experiment will be repeated for 45 runs of one half hour each.	No Serpentuator application
M492 Tube Joining in Space	Experiment is to demonstrate capability for joining tubular steel assemblies in a space environment using an exothermic brazing technique. Astronaut will assemble tubular assem-blies by exothermic techniques for ground evaluation of joint strength metallurgical properties, leak strength, vacuum storage, and physical flow of the brazing alloy. Experiment is performed in unpressurized OWS.	Experiment equipment is launched in operating position in MDA. Astronaut will per-form brazing operation on 8 tube specimens. Motion pic-ture photographs will be obtained of the brazing process. Tube specimens and film will be returned for analysis.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
M493 Electron Beam Welding	Experiment is to demonstrate the capabilities of electron beam welding in a space environment. Data for the determination of the experiment objectives will be accomplished by in-flight motion picture photography and post flight metallurgical examination and standard tensile testing of the returned weld specimens.	Experiment equipment is launched in operating position in MDA. Astronaut activates experiment and initiates first weld cycle. At completion of weld cycle, specimen is removed. Eight specimens are to be welded. Weld samples and film returned for analysis.	No Serpentuator application
M509 Astronaut Maneuvering Equipment	Experiment is to fly various maneuvering concepts inside the OWS to gain the knowledge and experience necessary to confidently select a particular maneuvering concept once mission requirements for a specific flight are known. The units to be tested are the Hand-held Maneuvering Unit, the Control Moment Gyro Maneuvering Unit, and the Rate Gyro Maneuvering Unit. The following tasks will be performed with each unit: 1. Stabilize, orient to proper attitude, and translate across OWS. 2. Retro-thrust, stop without contacting wall. 3. Stationkeep, maneuver around target for inspection. 4. Orient, translate across OWS. 5. Make mid course corrections (Continued)	Three maneuvering devices will be operated each time the experiment is run. One astronaut will serve as the subject while another will observe and assist. Through rotation, all three crew members will operate all three units. Each unit will be flown while the subject is in shirtsleeves and in a pressurized unit. A total of 8-1/2 man-hours is required for completion of the experiment.	No direct Serpentuator application. Application of Serpentuator as an EVA mobility aid could be tested in similar manner.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
M509 (Continued)	6. Retro-thrust, make terminal velocity and attitude corrections, and dock at work station.		
S005 Synoptic Terrain Photography	Experiment is to photograph certain pre-selected targets. The film is to be returned to earth and evaluated. Two modes will be used; 1. Take photos every five seconds for evaluation as strips and 2. Take double photos of areas five seconds apart.	Unstow camera and mount, mount to S/C at window, load with film and proceed to photograph pre-selected targets. Stow film in CM for return to earth. Different camera settings and filters will be required. Experiment will be repeated as required to complete desired photographic coverage.	No Serpentuator application
S006 Synoptic Weather Photograph	This experiment is the same as S005 with the exception that this experiment photograph for weather purposes while S005 is for terrain study and mapping. The photos for this experiment will be interspersed with those taken for S005 and, in some cases, the same photos will be used for experiments.	The camera set up for S005 is used for this experiment also. Different settings, filters, etc. will be required as situations occur. Experiment will be repeated as required to complete photo coverage of pre-selected list of targets as well as certain weather systems if encountered.	No Serpentuator application
S009 Nuclear Emulsion	Experiment is to study the cosmic radiation incident upon the earth's atmosphere under less than 0.3 gm/cm^2 of material and to study the charge spectrum of cosmic rays. The experiment will also obtain detailed chemical composition (Continued)	The experiment will be launched with the cover in place over the exposure face. An astronaut will remove the package from the container in the MDA, release the cover, swing it around to the opposite face and replace the (Continued)	No Serpentuator application.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S009 (Continued)	of the heavy primary nuclear and search for rare particles. The experiment consists of a nuclear emulsion and experiment container.	emulsion package in the MDA container. The experiment will remain in this configuration throughout the dormant period.	
S015 The Influence of Zero Gravity on Single Human Cells	Living human cells are studied while they are maintained in tissue cultures during orbital flight duration. The studies require photographing cells, changing microscope magnification, and changing cultures. Experiment is done in CM.	Equipment is removed from storage and set up in CM where it remains. Equipment consists of camera, tissue culture unit (27 in^3), and experiment package (1/4 ft^3). Experiment consists of the following phases. 1. Camera cycle starting and microscope focusing. 2. Specimen feeding by pushing button. 3. Initiate bio pack feed cycles and restorative cycles.	No Serpentuator application
S017 X-Ray Astronomy	Experiment is to determine the positions of known X-ray sources to a few seconds of arc; to measure the dimensions of X-ray sources, and to observe objects of interest for X-ray emission. The equipments employed are: an X-ray detector mounted and calibrated before launch; an Astronaut Display Unit which serves to present necessary information to the astronaut (Continued)	An astronaut in the LM remotely removes the experiment protective cover, turns on experiment power, and align the IMU. The source to be measured is acquired and the data monitored. Tape recorder is used to record counting rates and oral comments. Experiment will be repeated for up to 20 sources. No data or equipment to be physically returned to earth.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S017 (Continued)	performing the experiment; and a data handling system.		
S018 Micrometeorite Collection	Experiment is to measure size distribution, number of impacts, and fluxes of micrometeorite particles. Microbiological materials will be exposed to test their survival characteristics in space. Sterile surfaces are to be exposed in an attempt to collect viable microbiological materials. The meteoroid collection device consists of a series of nesting rectangular boxes of three sections. It is deployed through the MDA scientific airlock using an extension rod. The collection surfaces collect the small micrometeorites and measure the fluxes of larger micrometeorite particles.	Astronaut unstows experiment package, installs it in the MDA scientific airlock, and deploys the micrometeorite collection device. If there are thruster firings or waste dumps, the collection device shall be withdrawn until the contamination has cleared, and then be redeployed. The total deployed time shall be 8 hours. After completion of the experiment, the collection device is stowed for post-flight analysis.	No Serpentuator application. Extension rod is an integral part of the collection device.
S020 UV X-Ray Solar Photography	Experiment is to study solar radiation in the extreme ultraviolet and soft x-ray regions. The solar spectrum will be photographed and the film returned to earth for processing. Experiment equipment consists of a grazing incidence spectrograph which will be mounted in the MDA Scientific Airlock. The experiment photographs (Continued)	Astronaut receives ground commands during periods of high solar activity. Experiment is set up and sun acquired in field of view. Astronaut then initiates the exposure, terminates the exposure, advances the film and repeats the exposure sequence. A total of 10 film strips are to be exposed. At the conclusion of the (Continued)	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S020 (Continued)	directly into the sun and requires spacecraft attitude hold of $\pm$ 1/4°. About 200 minutes of exposure time required, with longest continuous exposure of 1 hour. Experiment may be performed concurrently with ATM experiments.	experiment, the camera with film intact is stowed for later processing on earth.	
S027 Galactic X-Ray Mapping	Experiment is to study galactic x-ray sources. Experiment will survey a portion of the sky for location of x-ray sources; make a spectral analysis of the located sources; and attempt to establish whether the apparent background radiation is real. The detector is mounted and flown inside the instrument unit of a S-IVB vehicle.	No astronaut participation required. The sensor is remotely deployed from ground, and data is acquired for 1 orbit. Data is dumped while over a ground station. Spacecraft is then rolled to a new orientation, and new data acquired. Experiment will be repeated 3 times.	No Serpentuator application
S040 Dielectric Tape Camera System	Experiment is to obtain high resolution television images of cloud cover, using a dielectric tape camera. The target area is located and photographed for 1 to 2 minutes. There is a total of 15 minutes of tape available. The data is transmitted to ground when all tape has been used. The experiment is repeated for 100 targets.	Astronaut required to point the experiment senior at the target by orienting the spacecraft. The camera tape strip must be moving opposite to the orbital motion. Astronaut remotely starts and stops the picture taking sequence. Data transmission may be controlled by ground stations. Experiment will be repeated for 100 targets.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S041 Millimeter Wave Propagation	Experiment is to provide new information about millimeter wave propagation in the atmosphere. Ground station receives signal from spacecraft and measures carrier signal amplitude, sideband signal amplitude, relative signal phase difference, and attenuation of signal through the atmosphere.	Ground facility notifies astronaut when he is within range of station. Astronaut orients spacecraft, turns on transmitter, records signal power level, upper and lower sideband phase difference, and transmitter ambient temperature. At the conclusion of the transmission period, astronaut turns off transmitter. Experiment will be repeated 12 times.	No Serpentuator application
S043 Infrared Temperature Sounding	Experiment is to determine the vertical temperature profile of the atmosphere, and to measure the solar radiation reflected from the Earth's surface and the top of cloud layers. Experiment equipment consists of a spectrometer of modified Ebert design, which measures spectral radiance. Data in digital form an telemetered to ground. Auxiliary information supplied by a boresighted camera and astronaut comments.	Astronaut will orient the spacecraft such that the spectrometer is aligned within 10 degrees of the desired target. When the target area appears in the viewfinder, the astronaut will switch the instrument to run mode. A minimum of 180 seconds will be required before the instrument is returned to standby mode. It is estimated that about 15 minutes per orbit and 25 hours total is required for the experiment.	No Serpentuator application
S045 IR Filter Wedge Spectrometer	Experiment is to expand the knowledge of reflected solar energy, and emitted thermal energy, from earth. The spectrometer consists of a filter wedge, telescope lens, chopper, detector, and drive motor. (Continued)	Astronaut required to switch on power to the instrument approximately 5 minutes before taking data. Astronaut will maneuver the spacecraft until the target area appears in the sensor field of view. Another (Continued)	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S045 (Continued)	The detector is cooled with liquid nitrogen. The spectrometer will be operated for periods of several minutes over preselected target areas. Data will be recorded on magnetic tape for ground evaluation.	switch will begin a scan for approximately one minute, at which time the astronaut will turn off the experiment. The experiment is repeated for 30 targets.	
S046 Visible Radiation Polarization Measurement	Experiment is to make quantitative measurements of light emerging from the earth's atmosphere as a function of wave length, polarization, viewing angle, and run angle. The sensor is mounted to the vehicle, requiring vehicle alignment for target acquisition. Astronaut must have access to the sensor to change filters.	Astronaut removes experiment external cover, turns power on, and extends sensor head for unobstructed view. The spacecraft will then be oriented to acquire the proper target and data taken. Procedure is repeated for other targets.	No Serpentuator application
S047 Stellar Refraction Density Measurement	Experiment is to test a technique for determining atmospheric structure by measuring the refraction of light from occulting stars, and to supply information on background radiance and starlight attenuation. Experimental method consists of tracking a preselected star during occulation using a two gimbal gyro stabilized star tracker. Spacecraft attitude must be maintained within ± 1/2 degree during (Continued)	Experiment equipment activated 30 minutes prior to entering dark side of orbit. After entering dark side of orbit, the spacecraft is maneuvered so that the desired star is within the sensor field of view. The star tracker is uncaged, and automatically tracks star and measures desired parameters. Time must be known to ± 1 millisecond. Approximately 5 minutes is required for the acquisition and tracking (Continued)	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S047 (Continued)	tracking mode to prevent star tracker from hitting gimbal stops. Angular motion of the star must be resolved to 2 arc-sec. Data is recorded for telemetry or later recovery.	procedure. Four or five stars will be observed per dark side traversal. Experiment will be repeated 2 to 4 times.	
S048 UHF Species Detection	Experiment is to detect and measure UHF emissions from cumulus clouds and thunderstorms. Experiment equipment consists of an antenna system, UHF receiver, signal processing unit, data tape recorder, and a control panel. The spacecraft must be oriented so the astronaut can observe the target clouds. The acquisition antenna must simultaneously illuminate the area under consideration. Spacecraft attitude must be held within 5 degrees. System very susceptible to RF noise entering through antenna. Care must be taken in the integration of the antenna system to minimize response to noise originating inside the spacecraft.	Observing period will last 20 to 30 minutes, to allow the spacecraft to pass from the radio horizon, over the region of interest, and to the other radio horizon. During the observing period astronaut 1. Turns equipment from standby to on. 2. Marks indication of visual observation. 3. Marks occurence of visible lightning. 4. Turns equipment from on to standby. Astronaut makes visual observations or receives ground notification of storms over which data should be taken. Data is recorded on magnetic tape for later analysis. Experiment is repeated 20 times.	No Serpentuator activity. Experiment requires visual observation by astronaut.
S057 Multi-Channel Radiometer	Experiment is to measure the temperature structure of the atmosphere from ground to a height of 50 KM with a (Continued)	Astronaut will activate the system, monitor displays several times daily, and perform calibration by over- (Continued)	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
S057 (Continued)	vertical resolution of 10 KM and a horizontal resolution of 150 KM. The sensor is coarse pointed to the earth along a vertical line. There is no requirement for controlling attitude rates.	riding the automatic system. The experiment will run continuously for the duration of the mission.	
S061 Potato Respiration	Experiment measures the sprouting rhythm oxygen consumption of a potato in zero-g and compares it to the same function of the potato in one-g. A life support system will supply the potato's thermal, barometric, gaseous and nutritional requirements and will accumulate oxygen consumption data.	Experiment is self contained and is placed in CSM. Four observations per day are required of crewman.	No Serpentuator application
S073 Gegenschein/ Zodiacal Light	Experiment measures surface brightness and polarization of the night sky light and with sunlight on the spacecraft to determine extent and nature of spacecraft corona. The data is taken by a self contained camera and photometry unit.	The experiment package is stored in the MDA and set up and connected in the MDA Airlock. The package is $\approx$ to 0.3 ft^3. The package is stored in the CM for return following the experiment.	No Serpentuator application
T002 Manual Navigation Sightings	Experiment is to evaluate the ability of an astronaut to measure the angle between various celestial bodies from on-board a spacecraft using a simple hand-held sextant.	Astronaut will measure the angle to 15 selected celestial bodies in one orbital period, using the hand-held sextant. The experiment will be repeated on each of 58 orbits.	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
T003 In-Flight Nephelometer	Experiment is to measure the particle concentration and size distribution inside the spacecraft, and to collect particles for post-flight analysis. Air is drawn into the nephelometer, passes through an illuminated area where any particles present scatter the incident light in all directions. The particles are then deposited on a membrane filter. The scattered light is focused on a photomultiplier tube, which is used to determine the particle size and concentration.	Astronaut removes nephelometer from storage location. Measurements are taken in CM, MDA, AM, and OWS. Astronaut required to record readings of particle size and concentration from instrument. Experiment will be repeated 14 times. The nephelometer is returned to earth for analysis of collected particles.	No Serpentuator application
T004 Frog Otolith Function	Two frogs are located in fixed, self contained, life support capsules which will provide a 0.5 g spin acceleration to the frogs. Control equipment is in CM and the capsule is in the SM. Experiment is conducted through first 72 hours of flight and can be extended.	Experiment requires crewman in CM to select and initiate test by pressing button. Test is run for 44 times at 8 minutes each time during 72 hours.	No Serpentuator application
T013 Crew Vehicle Disturbance	Experiment is to measure the effects of various crew motions on the dynamics of manned spacecraft. Partial and total astronaut motion will be measured by body instrumentation and by motion picture photography. Resulting vehicle motion will be (Continued)	Three astronauts required for performance of experiment. Astronauts will operationally check the experiment equipment and position cameras for photographing of motion sequences. Astronaut in CM will perform a 6 minute motion sequence. Then one astronaut in OWS will (Continued)	No Serpentuator application

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
T013 (Continued)	recorded by rate and position sensing devices in the spacecraft. Data will be telemetered to earth to check the validity of information obtained from ground simulations, and to determine the effects of astronaut motion on attitude and control systems.	perform a predefined motion sequence. Third astronaut assists in set up and checkout of experiment equipment. During the performance of a motion sequence, other astronauts must remain as motionless as possible.	
T018 Precision Optical Tracking	Experiment is to establish accuracies of state-of-the-art laser tracking system by tracking vehicle from lift-off through the first 50 seconds of flight. Only equipments mounted on vehicle are two passive reflectors.	No astronaut participation required. Experiment is performed from ground tracking station.	No Serpentuator application
T020 Jet Shoes	Experiment is to obtain experimental design data and to determine the feasibility of the Jet-Shoe concept for EVA locomotion.	Astronaut donns Jet-Shoe equipment and performs a series of translational and rotational maneuvers.	The Serpentuator could not be used in the evaluation of the Jet-Shoes. The use of the Serpentuator as an aid to or elimination of EVA would negate the need for Jet Shoes.
T025 Coronagraph Contamination Measurements	Experiment is to perform an engineering measurement to determine; a) the presence of an induced atmosphere about the spacecraft during flight, b) changes in the induced atmosphere due to thruster firings, waste dumps, and vehicle orientation, c) the nature and extent of the F- (Continued)	Astronaut required to secure the canister in the MDA scientific airlock, assemble the boom, and extend the boom through the pressure seal in the canister. When the sun is occulted, the astronaut sets the camera focus, aperture, and shutter speed, and begins exposing (Continued)	No Serpentuator application. Occulting discs require fine alignment with camera. Extension rod is integral part of experiment equipment.

EXPERIMENT NO. and TITLE	EXPERIMENT SUMMARY	EXPERIMENT ACTIVATION	COMMENTS
T025 (Continued)	corona. Experiment equipment consists of three basic assemblies; the coronograph canister, boom, and a Hasselblad camera. The canister contains three occulting disks which are extended out from the spacecraft by the boom. The canister is to be pointed at the sun.	film. The number of exposures may exceed 30 per orbit. Experiment will be repeated 4 times. At the conclusion of the experiment the film is stowed for return to earth.	
T027 ATM Contamination Measurement	Experiment is to measure the sky brightness background caused by solar illumination of contamination particles about a spacecraft, and to measure the change in optical properties of various lenses, mirrors, and gratings as a result of surface contamination deposits. Experiment has two basic assemblies; a photometer system which provides electrical and photographic data to measure sky brightness, and a sample array canister, containing optical surfaces which are uncovered to expose them for various intervals to collect contamination deposits. Both assemblies operate from the MDA scientific airlock.	Astronaut installs sample array canister in MDA scientific airlock and deploys canister. Automatic sequence of samples is taken. Canister is then removed from airlock and photometer is deployed through the airlock. At conclusion of experiment photometer is retracted. Film and sample array returned to earth.	No Serpentuator application

APPENDIX B

Detail Joint Design Recommendations

Included here are the detailed recommendations to flight qualify the existing Serpentuator roll and elbow joints. The recommendations are given for explicit MSFC drawings.

On Drawing No. 500218:

1. Change all hardware (screws, retaining rings, etc.) to NASA approved parts per MSFC-PPD-600.

2. Replace all "O" rings with omniseals, made from a compound consisting of 80% teflon (TFE), 15% glass fiber and 5% moly disulphate. This filled teflon material is rated at -400°F to 500°F, is self lubricating, and is one of the better polymers available for use in vacuum environments. It is, however, affected by U.V. radiation, but in this application the locations of all these seals are well shielded by the aluminum structure. It would be desirable to build and test this item for the expected environmental conditions.

3. Enlarge the outside diameter of item 25 (500207-7 spacer) and add "O" ring groove to inside diameter, such that an omniseal would seal against the outside diameter of item 28 (500207-9 sleeve, shaft).

4. Replace item 24 with larger seal having sealing material of filled teflon, or design a new seal using a rotary omniseal and a face-type omniseal in its flange.

5. Consider putting an electrical connector through wall of item 46 instead of potting cable through wall.

6. Secure all fasteners with lockwire or other approved locking methods.

7. Possibly install heating blanket around O.D. of flex-spline in the area of torque motor and brake. This would control low temperature to within rated range of the motor, brake, and lubricant.

The above mentioned omniseals are a product of Aeroquip Corporation, Jackson, Michigan. They are a "C" shape cross-section containing a flat helical garter spring. The material is basically teflon and the spring may be either beryllium copper or 17-7 PH Cres. In this application the 17-7 PH Cress would be used. When installed, the open side of the "C" is exposed to the higher pressure side of the gland or joint, thereby allowing pressure to aid in seating the seal.

If heaters are not desirable at the motor locations, or insulating the Serpentuator is not desirable, special motors might be obtained and dry lubricants should be considered. To increase confidence in this type of lubrication, a test joint (base-roll and elbow) should be built, treated, and tested.

On Drawing No. 500226:

1. Change all hardware (screws, retaining rings, etc.) to NASA approved parts per MSFC-PPD-600.

2. Install heating blanket around drive motor housing and on I.D. of item 1. This would control low temperature to within rated range of motor, brake, and lubricant.

3. Replace items 22, 23, and 35 with a metal bellows and adapters as required. The bellows design for the elbow joint would consist of approximately 50 ripple, nested, convolutions of .005 thickness 347 cres material, with outside diameter of 9.50 inches and inside diameter of 8.50 inches. The bellows assembly has a spacer midway in its length similar to the original design. The calculated spring rate is 10.5 lb/in. Its maximum internal operating pressure is 15 lb/in^2. The calculated squirm pressure is 19 psi.

The following changes relative to the base roll are recommended. These changes are illustrated in Figure B-1:

1. Replace "O" ring No. 2-269 with an omniseal No. AR10105-269P1H.

2. Change P/N 500217 to a three piece assembly as shown plus two omniseals No. AR10110-447P1H with the seals and two clamp rings being retained by a bolt circle of eight 6-32 flat head screws. These omniseals replace the No. 2-272 "O" rings.

3. Change 500212-1 and 4 to accommodate the inside diameter of the AR10110-447P1H omniseals.

4. Modify the 5.00 inch diameter tubular portion of P/N 500211-1 to clear the clamp rings on P/N 500212-4.

5. Incorporate new spacer/seal using one each AR10105-022P1H and AR10104-003P1H omniseals.

6. Add groove for AR10105-010P1H omniseal to P/N 500207-5 shaft.

7. Add groove to inside diameter of P/N 500207-9 sleeve shaft for AR10105-017P1H omniseal.

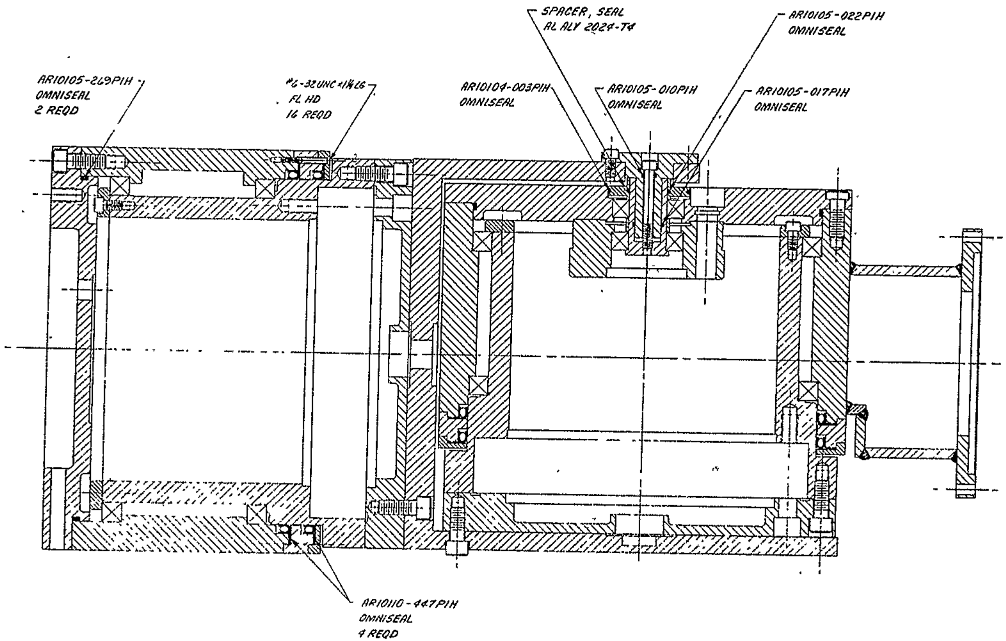


Figure B-1 Modified Base Roll and Yaw Assembly

8. Add groove to each of the six .531 diameter bolt holes in P/N 500215-1 end plate to accommodate AR10105-014P1H omniseals.

The following recommended changes, relative to the elbow joint design are shown in Figure B-2:

1. Change the material of the P/N's 500223-3 hinge support, 500225-4 housing, 500225-2 tube, 500225-3 housing, and 500223-2 hinge from aluminum allow to 304 corrosion resistant steel.

2. On the P/N 500223-3 hinge support, increase inside diameter to 5.750 inches to reduce weight. Add the 7.063 diameter bellows adapter ring as shown. Reduce chamfer on inside diameter of the flange to .03 x 45° maximum.

3. Increase the inside diameter at one end of the P/N 500225-4 housing as shown to 5.750 inches to reduce the weight. Change 5.00 dimension to 5.125.

4. Change thickness of plate portion of P/N 500223-2 hinge from 3/8 to 1/4 stock to reduce weight.

5. On the P/N 500225-3 housing increase inside diameter at one end, as shown, to 5.750 inches to reduce weight. Reduce chamfer on inside diameter of the flange to .03 x 45° maximum.

6. Fabricate bellows ring adapter and weld to P/N 500221-1 actuator housing assembly as shown.

7. Add groove for AR10205-163P1H omniseal to flange of P/N 500221-2 and -3 spacer tube and reduce chamfer on inside diameter of flange to .03 x 45° maximum.

APPENDIX C

STRUCTURAL CONSIDERATIONS

1. Serpentuator Joints

3.1.1.2.1.1 Stand-By Time - One condition to examine would be the possibility of moisture freezing externally on the bellows, however this condition should disappear long before operation of the Serpentuator. Moisture freezing internally on the moving parts should be prevented by the hermetic seals and presumably dry nitrogen pressure.

3.1.1.2.4 Prelaunch Loads - Since the present joint mechanism is compact, dense, and tight fitting, it should not be vulnerable to normal handling conditions, Conceivably, a bellows could be damaged by dropping on a hard surface, necessitating repair or replacement. See 3.1.2.4.1, 3.1.2.8.3.

3.1.1.2.5 Flight Loads - (3.1.2.8.1)(3.1.2.8.2)(10.1) - The environment table for shock and vibration lists 3000 g at 2000 cps external to the MDA. This may or may not be directly applicable to the Serpentuator, depending on the mounting arrangement during launch. The ball screw and the bellows should be checked for resonance at this frequency and all ball bearings should be checked for non-brinelling capability at this g level. The acoustical environment should not be critical since no large panels are involved, (see 3.1.2.4.2). This does not appear to be a problem area but testing of a prototype design for these conditions would be desirable.

3.1.1.2.5.1 Operational Loads - There are no apparent static loads on the Serpentuator. In order to consider the Serpentuator as a massless cantilever spring supporting an end load, it is approximately correct to add one fourth of the Serpentuator weight (assumed 425 lb, 3.3.1.2) to the nominal tip weight (500 lb). This results in a total of 606 lb. The Serpentuator is basically a 6.0-inch diameter aluminum alloy (assumed 6061ST6) tube with .065 inch wall. It is conservatively assumed to be 40 feet long and straight. From

$$I = \pi R^3 t = \pi 3^3 \times .065 = 5.5 \text{ in}^4$$

$$E = 10^7$$

$$k = \frac{3EI}{3} = \frac{3 \times 5.5 \times 10^7}{480^3} = 1.49 \text{ lb/inch of tip deflection}$$

It is required (3.1.2.8.2.5) that the tip mass be accelerated to a maximum of $\pm$ .025 ft/sec^2. From

$$F = Ma$$

$$F = \frac{606}{32.2} \times .025 = .47 \text{ lb}$$

The moment at the base is 480 x .47 = 226 in-lb.

The tube wall stress is then

$$\sigma = \frac{MR}{I} = \frac{226 \times 3}{5.5} = 123 \text{ psi, which is negligible}$$

The line of action of the ball screw is about 4.5 inches from the joint pivot. The screw load is then

$$P = \frac{M}{d} = \frac{226}{4.5} = 50 \text{ lb}$$

Even with a yield load factor of 1.10 and a conservative dynamic load factor of 2.0 these loads are negligible. The entire Serpentuator is considerably overstrength for this application. It is marginally rigid, however, as discussed later.

Vibration and shock during operation should only arise from rough operation of the motor and brakes or astronaut activity, since collisions are to be avoided (3.1.1.2.8.2.1). See also 3.1.2.4.2. and 3.1.2.4.3.

In the light of the tip speed restriction, it may be desirable to select smaller motors, brakes, and ball jacks to provide less excess torque capability. Paragraphs 3.1.1.2.6.2.1 through 3.1.1.2.6.2.3, which deal with the joint motors, gears, and brakes, appear to require that these items differ for each joint. Also, paragraph 3.1.1.2.8.4 requires a "controlled stop at the specified maximum rate of deceleration." This may require gradual brake application rather than simply on-off action.

3.1.1.2.8.2 Oscillation Damping - Hysteresis damping of the links in bending is negligible. Mechanical damping can be supplied by clutch slippage or brake in the power-off condition. Electrical damping is possible by not applying the brake in the power-off condition. Motion of the link would then rotate the joint, driving the motor as a generator. Related to these effects, but not strictly damping, are the modifications of the mechanical disturbances by gradual application of the motor and brake.

The common objection to all these concepts is the degradation of platform positioning accuracy (3.1.1.2.8.2.4) implicit in all unprogrammed motion of the joint. It is recommended for now that brake and clutch slippage be permitted only as required to prevent damage to the Serpentuator joints and links due to inadvertent overload, and that electrical damping not be used (see 3.1.1.2.6.2.3). Gradual onset of motor and brake torque should be employed to the maximum extent compatible with positioning accuracy. Oscillation control is further discussed under Serpentuator assembly comments.

3.1.1.2.8.2.5 Platform Positioning Response Speed - This section defines the power requirements and the reduction gear ratios required at each joint. As noted above, the present design considerably exceeds these requirements. Note that the maximum tip speed of .5 ft/sec conflicts with 4 ft/sec given in 3.1.1.2.5.1.

3.1.2.2 Maintainability - It appears that differences in joints can be limited to the reduction gears. For maximum interchangeability and minimum spare parts, it would be desirable that the design allow replacement of at least the motor and gears without disturbing the bellows or other welded joints.

3.1.2.2.1 Maintenance Requirements - All mechanisms must be self-lubricating and sealed to require no maintenance in space. However it must be possible to adjust the joints (or the controls) to permit compensation for docking errors (3.1.1.2.8.2.3).

3.1.2.4.1 Ground Environment - The joints are compatible with the ground environment either because of their construction (see 3.1.1.2.4), because other environments are more stringent, or because they are sealed when exposed.

3.1.2.4.2 Flight Environments - Due to their metallic construction the joints and links are insensitive to vacuum and radiation. Non-structural items such as seals and lubricants are discussed elsewhere. Because of their small size and the screening they receive from the sun shield, solar panels, AAP cluster, and the earth, the joints and links stand little chance of being struck by meteoroids. The .065 inch wall thickness of the links and the corrugated shape of the bellows offer a good deal of protection against penetration in event of an impact. A detailed analysis of the exposure based on projected use of the Serpentuator would be required to calculate the probability of puncture.

3.1.2.4.3 Thermal - The joint mechanisms and structure of the links have enough freedom to deflect so that thermal shock should produce no high stresses. Furthermore, the largely aluminum structure should rapidly even out temperature differences. The effects of internal heat sources such as motors and brakes, and the operating temperature limits of motors, lubricants and seals are being considered along with typical exposures to external sources and sinks in selecting surface finishes and paints and possible insulations.

3.3.1 General Design Features - Since it has been shown that the present design is vastly overstrength, and that each joint in the space qualified item will differ from the others, we do not recommend further structural analysis on the present design at this time. Our studies show that stiffness is much more critical than strength. This point is discussed in some detail, under section 2 of this Appendix.

3.3.1.2 Weight - If the Serpentuator assembly is considered as basically a 6" diameter aluminum tube with .065 inch wall thickness, 480 inches long, its weight is

$$W = \pi \times 6 \times .065 \times 480 \times .10 = 59 \text{ lb.}$$

If this weight is doubled to allow for bolts and flanges, and doubled again to account for mechanism weight, the result is

$$W = 4 \times 59 = 236 \text{ lb.}$$

This is less than 56% of the allowable weight of 425 lb, and thus it appears that the weight restriction can be rather easily met.

2. Serpentuator Assembly

3.1.1.2.1.1 Standby Time - If the stowed Serpentuator is in fact exposed to cryogenic vapors during propellant loading, moisture could freeze on the mechanisms which hold and release the Serpentuator. However, we assume that this would evaporate in space before the Serpentuator is deployed. Since automatic deployment is planned, this item should be examined in detail.

3.1.1.2.1.2 Checkout - The Serpentuator cannot be checked functionally or structurally without a large air-bearing facility. Continuity and logic checks could possibly be made electrically.

3.1.1.2.2 External Profile - This should include handrails (3.1.2.6. and stowage attachment points.

3.1.1.2.4 Prelaunch Loads - 3.1.1.2.5 Flight Loads - These paragraphs define the requirements for Serpentuator attachment to the ATM structure for stowage. (See 3.1.2.4.1, 3.1.2.4.2, 3.1.2.8.1, 3.1.2.8.2, 3.1.2.8.3.

3.1.1.2.5.1 Operational Loads - In the previous comments it was shown that the present design is overstrength for this application, and that the tip velocity of 4 ft/sec specified here conflicts with .5 ft/sec in (3.1.1.2.8.2.5).

3.1.1.2.6.1 Serpentuator Movement,- 3.1.1.2.8.2.2 Oscillation Damping, 3.1.1.2.8.2.3 Docking Error Adjustment, 3.1.1.2.8.3.3 Docking Tolerance Provisions, 3.1.1.2.8.2.4 Platform Positioning Accuracy, 3.1.1.2.8.3.1.1 "Jogging" Control", 3.1.2.4.2 Thermal - The following comments are pertinent to all of these headings. The actual shape of the Serpentuator in use varies widely and includes considerably curvature. Because of the low natural frequencies in the system, it is possible that several of the lower modes in both bending and torsion can be excited by astronaut movement and controls. However, considering the Serpentuator as a straight cantilever massless beam, with a tip mass as described in the joints comments under paragraph 3.1.1.2.5.1, reduces the problem to a one-degree-of-freedom spring mass system. This concept serves to highlight the behavior of the Serpentuator in operation.

As shown previously,

effective tip weight $W = 606$ lb.

length $= 480$ inches

spring constant $k = 1.49$ lb/inch

static deflection $d_{ST} = 407$ inches

$$p^2 = \frac{g}{d_{ST}} = \frac{12 \times 32.2}{407} = .949 \text{ sec}^{-2}$$

$$p = .974 \text{ sec}^{-1}$$

frequency $$f = \frac{p}{2\pi} = .155 \text{ cps}$$

$$\tau = \frac{1}{f} = 6.45 \text{ seconds/cycle}$$

From elementary theory,

$$x = x_o \cos pt + \frac{v_o}{p} \sin pt$$

where x is the displacement of the tip mass after being given an initial displacement x_o and an initial velocity v_o and allowed to oscillate. It has been shown previously that the tip force required to produce a tip acceleration of .025 ft/sec^2 is 0.47 lb. If applied suddenly, this could produce a displacement of about 2 x 0.47/1.49 or 0.63 inches. By the above equation, as cospt varies from 1.0 to -1.0, the tip mass would sway ± 0.63 inches.

If the tip mass were moving at a constant rate of 4 fps and the Serpentuator stopped while straight (so that $x_o = 0$) the tip would displace

$$x = \frac{v_o}{p} = \frac{4 \times 12}{.974} = 49.4 \text{ inches, assuming no damping by brakes.}$$

If the tip velocity were only 0.5 fps, as seems more likely, the displacement would be

$$x = \frac{.5 \times 12}{.974} = 6.2 \text{ inches.}$$

It is not possible, without a lengthly consideration of the exposure of the Serpentuator to the heat sources and sinks within its view during orbital operation, to define the temperature distribution at any given time. But it is not difficult to see that this could be fairly large and subject to large fluctuations. The resulting curvature of the Serpentuator assembly would not have to be very great to produce a tip displacement of several inches.

These considerations lead to the following conclusions:

1. For the present design and tip mass requirement, tip speed should be limited to .5 fps, not 4 fps.

2. It is probably not feasible to specify platform positioning accuracy tolerances to the accuracy prescribed for the current design, since these are subject to motions and displacements which cannot be controlled. It may be desirable to specify tolerances on angular accuracy of the joints instead.

3. A "jogging" type of control is potentially dangerous and perhaps useless since it could easily be applied at the resonant frequency of the system, or possibly of the Serpentuator boom alone, causing increasing amplitude of vibration or whipping.

3.1.1.2.6.3 Cargo Rack/Control Station

d. See immediately above.
e. The astronaut cannot face the direction of motion both coming and going.
f. As shown, the CR/CS does not protect the astronaut from injury to meteoroid impact.

3.1.2.1.1 Failure Effects Analysis - A failure of the Serpentuator attachment to the ATM rack structure during boost could cause the Serpentuator, under the action of 7-g boost acceleration, to cause serious damage to the SLA. This might prevent continuation of the mission, or worse.

3.1.2.5 Transportability (See also 3.1.2.8.3) -It appears practical to ship the Serpentuator disassembled into individual links, and to assemble it in the installed position on the ATM rack. Handling loads are small and do not affect the design.

APPENDIX D

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