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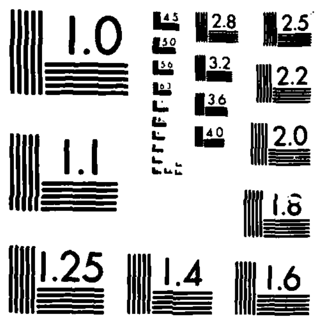

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The flying qualities of this Interim Rescue Vehicle (IRV) were simulated using an existing NASA spaceflight simulation computer program. The results showed that the Manned Maneuvering Unit's control system was capable of limiting uncommanded rotations to within the control law's deadbands during all simulated maneuvers and in all control modes, except during transverse translations in the Backup control mode. The IRV's increased mass and increased center-of-mass/center-of-thrust offset significantly degraded acceleration capability and specific propellant consumption. Thruster plume impingement upon the attached Personnel Rescue Enclosure, however, was found to cause only minor additional performance degradation. The Satellite Stabilization control mode was found to have significant rotational-to-translational coupling which made it undesireable for IRV use.

Finally, procedures were outlined for using the IRV in an orbiter-to-orbiter rescue scenario.

A PROPOSED DESIGN FOR AN INTERIM SPACE RESCUE FERRY VEHICLE

THESIS

James D. Halsell, Jr., Captain, USAF

AFIT/GSO/ENY/85D-2

AFIT/GSO/ENY/85D-2

A PROPOSED DESIGN FOR AN INTERIM SPACE RESCUE FERRY VEHICLE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Space Operations

James D. Halsell, Jr., B.S.

Captain, USAF

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James D. Halsell, Jr.

Table of Contents

List of Acronyms

AAH	Automatic Attitude Hold
ACD	Apogee Kick Motor Capture Device
CEA	Control Electronics Assembly
EVA	Extravehicular Activity
FSS	Flight Support Station
JSC	Johnson Space Center
IRV	Interim Space Rescue Ferry Vehicle
MILMU	Man-In-The-Loop Maneuvering Unit
MMU	Manned Maneuvering Unit
NASA	National Aeronautics and Space Administration
PRE	Personnel Rescue Enclosure
TPAD	Trunnion Pin Attachment Device

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Abstract

This investigation proposed a method of connecting the Personnel Rescue Enclosure to the Manned Maneuvering Unit using a modified flight-qualified hardware item, the Apogee Kick Motor Capture Device. The resulting configuration is an immediately available but non-optimum vehicle for transferring stranded astronauts, housed within Personnel Rescue Enclosures, from a rotating stranded spacecraft to a nearby rescue spacecraft.

The flying qualities of this Interim Rescue Vehicle (IRV) were simulated using an existing NASA spaceflight simulation computer program. The results showed that the Manned Maneuvering Unit's control system was capable of limiting uncommanded IRV rotations to within the control law deadbands during all simulated maneuvers and in all control modes, except during transverse translations in the Backup control mode. The IRV's increased mass and increased center-of-mass/center-of-thrust offset significantly degraded acceleration capability and specific propellant consumption. Plume impingement, however, was found to be of minor importance. The Satellite Stabilization mode was found to have significant rotational-to-translational coupling which made it undesireable for IRV use.

Finally, procedures were outlined for using the IRV in an orbiter-to-orbiter rescue scenario.

A PROPOSED DESIGN FOR AN INTERIM SPACE RESCUE FERRY VEHICLE

I. Introduction

Overview

Currently, U. S. astronauts and U.S.S.R. cosmonauts conduct routine space operations without the "safety net" of a tested and ready space rescue plan. Realizing this deficiency, in July 1984, during a speech to the Conference on U. S.-Soviet Exchange, President Reagan proposed that the two countries conduct a joint space mission to demonstrate the capability of rescuing stranded astronauts and cosmonauts (24:16). Later that same year, the President signed Senate Joint Resolution 236, which directed the Administration to work toward more cooperative East-West ventures in space, including a joint simulated rescue mission (33). These overtures were subsequently curbed by a downward swing in the cycle of detente; however, recent press reports indicate that the political climate is again ripening for the approval of a joint mission (8:15).

The National Aeronautics and Space Administration (NASA) is not currently officially preparing for a joint space rescue mission. However, space rescue planning is important for the following reasons:

1. Should the political environment indeed improve, the joint space rescue demonstration mission will probably be scheduled on a "last-minute" basis. Planning accomplished now will allow a timely response to a Presidential directive to proceed.

2. Regardless of whether a joint U. S.-Soviet space rescue mission is ever flown, the need exists to develop and test the hardware and procedures necessary for rescuing the crew of a space shuttle orbiter stranded in orbit. As of now, neither hardware nor procedures are completely developed.

This thesis, while motivated by the prospect of a joint U.S.-U.S.S.R. demonstration mission, directly contributes to the development of a NASA space rescue contingency plan. It proposes an Interim Space Rescue Ferry Vehicle (IRV) consisting only of current or soon-to-be-available hardware, and which under emergency conditions could be made ready for launch in less than twelve hours. The flying qualities of this vehicle are explored, and procedures proposed for its use.

Because it is limited to off-the-shelf hardware not originally intended for this purpose, the IRV suffers obvious performance deficiencies and will no doubt be followed by a more capable version specifically designed for the rescue mission. However, the IRV presented in this thesis provides an immediate "stop-gap" rescue capability until a more ambitious follow-on version is designed and built.

Background and Literature Review

Space rescue is defined as rendezvousing with a disabled spacecraft, transferring the crew members to the rescue vehicle, and returning them safely to earth. During the early 1960's, NASA conducted analyses to determine rescue requirements and capabilities for the Mercury, Gemini, and Apollo programs. Development was not pursued, however, because planners realized successful space rescue requires an ambulance spacecraft that is available for almost immediate launching, and maintaining such a capability was deemed impracticable at that time (32).

Today, this lack of a rescue vehicle is being resolved by the increasing space shuttle flight rate. The fourth orbiter made its first flight in October of this year, and the larger shuttle fleet plus expedited turnaround servicing procedures will, by 1990, allow NASA to launch a shuttle every two weeks (22). Such a flight frequency will permit each shuttle mission to serve as the standby rescue vehicle for the flight immediately preceding it.

Space rescue in the shuttle era is complicated by the lack of two capabilities taken for granted in preceding U.S. spacecraft. First, unlike the Apollo capsule, current shuttle orbiters cannot dock with other spacecraft; therefore, victims must conduct extra-vehicular activity (EVA, or

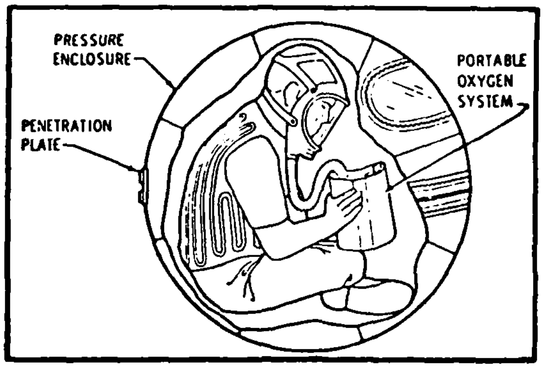


Figure 1.1. The Personnel Rescue Enclosure (1:198)

"spacewalk") to transfer to the rescue vehicle (1:197). This shortcoming will be partially alleviated within the next decade when a docking module is built to allow the orbiter to mate with the space station. However, orbiters not destined to the space station will not carry this payload-reducing module, and therefore will still rely on the rescue procedures discussed in this report (6).

Second, weight and volume constraints dictate that only two spacesuits be carried on all shuttle missions, even though the crew usually numbers between five and eight astronauts (20:A1-101). Accordingly, some mechanism is necessary for transferring unprotected astronauts across the open void between the two spacecraft.

Anticipating this requirement, NASA developed the Personnel Rescue Enclosure (PRE) in 1975. This device, illustrated in Figure 1.1, is an inflatable life-support sphere which provides a thermally protected, puncture-resistant, pressurized environment within which a non-space-

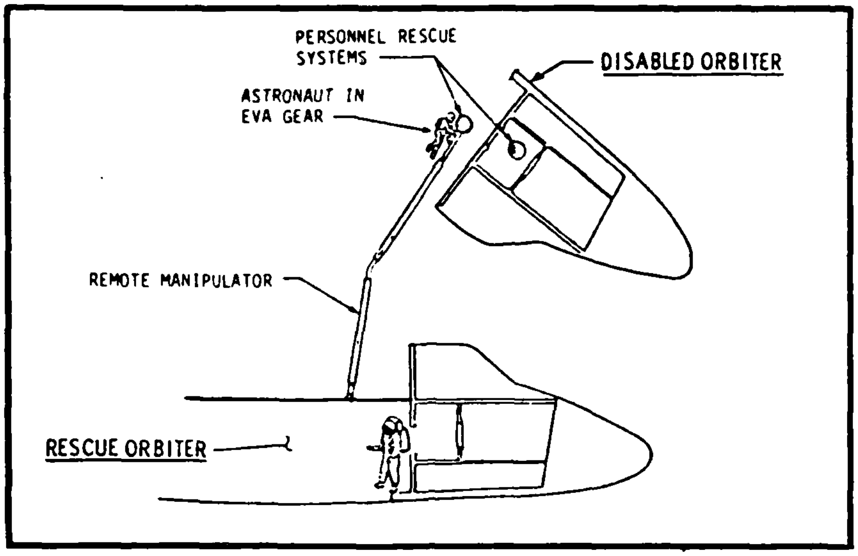


Figure 1.2. PRE Transfer via Remote Manipulator Arm (1:202)

suited astronaut can survive for about one hour--long enough to be transported to the rescue orbiter. Three potential PRE transfer techniques were identified by Brown in 1977 (1:202-03):

1. Remote Manipulator Arm. Standard orbiter configuration includes a 50-foot long remote manipulator arm which is electromechanically operated by an operator located inside the cabin. Figure 1.2 shows how a rescuing orbiter could maneuver into very close formation with the disabled spacecraft and the remote manipulator arm used to pluck PRE spheres from the airlock door of the stranded vehicle. A rescue crewman, attached to the manipulator arm by foot restraints, would ride on the end of the arm and grasp the PRE by one of its handles. The arm operator, viewing the work area through the aft

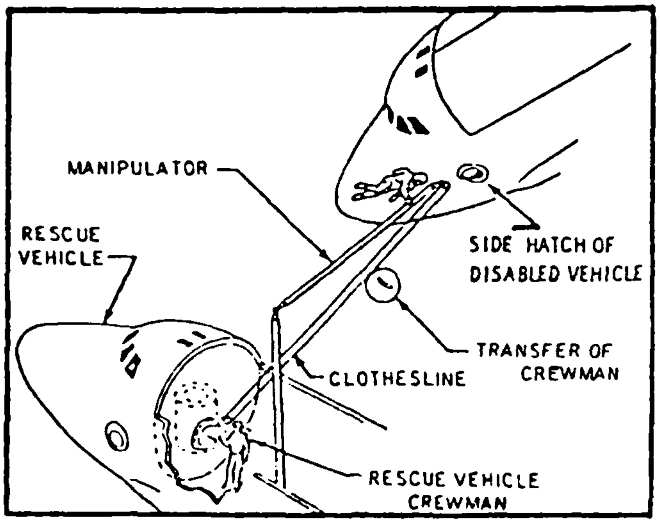


Figure 1.3. PRE Transfer via Clothesline Trolley (1:203)

cabin windows and by remote television camera, would then swing the EVA astronaut, with PRE in tow, to the rescue vehicle's airlock door. Here the PRE would be handed off to a waiting rescue astronaut for insertion into the airlock. The sequence would be repeated until all PRE's were transferred. The spacesuited stranded astronauts would transfer to the rescue vehicle by riding the manipulator arm's foot restraints.

2. Clothesline Trolley. An adaptation of the manipulator arm transfer method is illustrated in Figure 1.3. Here, the shuttle is again maneuvered into close formation with the disabled vehicle and the end of the manipulator arm positioned at the side hatch or airlock hatch. However, the arm then remains stationary and

serves as the supporting structure for a continuous wire loop trolley on which the PRE's are attached and translated to the rescue vehicle. Two rescue astronauts, one positioned at each orbiter's hatch, serve to attach and disconnect the PRE's, and to provide the locomotive force for the trolley. As before, the spacesuited stranded astronauts would ride the manipulator arm to safety.

3. Ferry Vehicle. Both versions of the remote manipulator arm transfer method assume a stable (i.e., non-tumbling) disabled orbiter. However, if the disabled vehicle had uncontrollable rotation rates, the rescue orbiter would not be able to fly in close enough proximity for the arm to reach the airlock door. A smaller, more maneuverable ferry vehicle would be required which was capable of rendezvousing with the tumbling target vehicle and matching it's rotational rates so that no relative motion exists. Figure 1.4 depicts the Manned Maneuvering Unit (MMU) accomplishing PRE rescue under these difficult conditions. The MMU is an operational one-man "jetpack" allowing a spacesuited astronaut to make untethered excursions from the orbiter. An astronaut piloting an MMU equipped with a PRE attachment device would fly over to the tumbling spacecraft, match its rotational rates, and maneuver to the airlock hatch. A PRE would then be attached and transported to

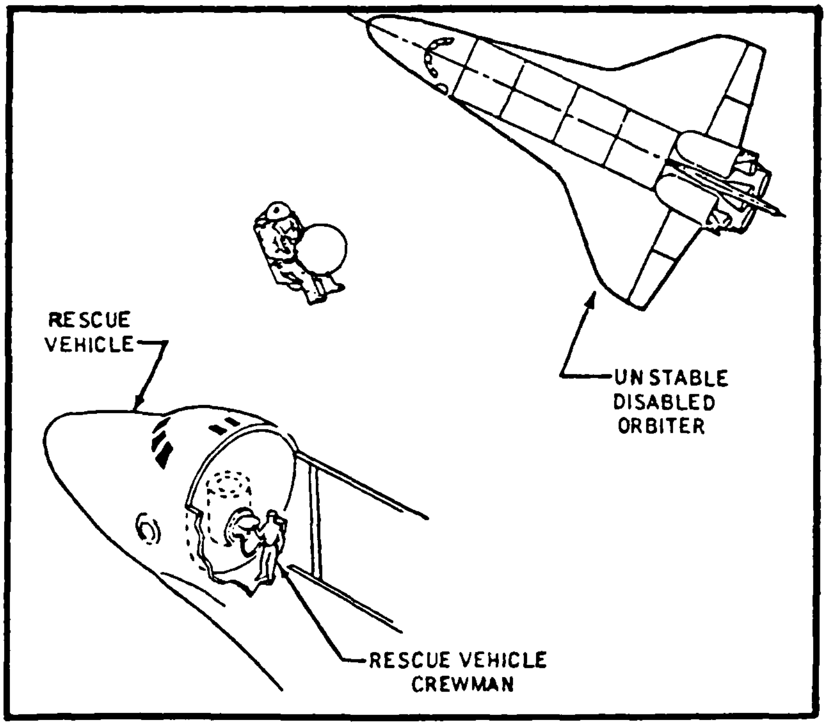


Figure 1.4. PRE Transfer via MMU (1:203)

the rescue vehicle. The procedure would be repeated until all victims had been transferred.

Rogers reports that the Martin Marietta Corporation has recently completed preliminary simulations of a conceptual MMU/PRE combined vehicle which indicate the MMU/PRE retains adequate performance and stability for use in a space rescue scenario (26:8).

Problem Statement

This thesis develops the ferry vehicle transfer method by answering three research questions:

1. What is a mechanically and operationally sound method

of attaching the PRE to the MMU, using only minimally modified and available flight-qualified hardware, to arrive at an Interim Rescue Vehicle (IRV)?

2. What is the stability and performance of the resulting IRV? The term "stability" refers to the ability of the MMU's control system to limit the IRV's dynamic response to maneuvers commanded by the pilot. The term "performance" refers to the IRV's translational and rotational acceleration capabilities, and the fuel expended to achieve these accelerations.

3. What procedures will the stranded and rescue crews follow to conduct a successful save using the IRV?

Assumptions and Scope

This thesis does not delve into the types of emergencies which would strand an orbiter and its crew and require a space rescue mission--it simply assumes that such a mission is necessary. This thesis also assumes that the disabled orbiter, although stranded in orbit, still has functioning life support systems, and that the remaining consumables provide the necessary time (at least three days) to prepare and launch a rescue mission.

The intent of this project was to propose a design which offers an immediately available "stop-gap" rescue capability which can be fielded in a matter of hours after notification of the rescue requirement. Therefore, only currently available or soon-to-be-available flight qualified hardware was considered for use.

While the performance and stability of the proposed design were examined, this report does not venture a subjective opinion concerning the overall acceptability of the determined flight characteristics. However, the results have been made available to NASA for such use.

Approach and Presentation

Answering research question 1 (i.e., a suitable MMU/PRS connection device) first required a review of the design and capabilities of the PRE and MMU. This is presented in Chapter II. Chapter III lists the requirements for an acceptable MMU/PRE connecting device and presents the proposed device which meets most of the criteria. The resulting MMU/PRE combined vehicle is referred to as the IRV.

Obtaining the answer to research question 2 (i.e., IRV performance and stability) was accomplished using an existing NASA spaceflight simulation program. This computer program and the determination of required inputs concerning IRV mass properties and plume impingement are explained in Chapter IV. The actual simulation runs, their results, and the analysis are presented in Chapter V.

Research Question 3 is answered in Chapter VI, which proposes procedures for using the IRV to rescue the crew of a stranded orbiter. Finally, Chapter VII presents the conclusions and recommendations.

II. PRE and MMU Design Review

Chapter Overview

The proposed IRV consists of three major components: the MMU and its pilot, the PRE and its victim, and the as-yet-undefined device connecting the PRE to the MMU. This chapter reviews the design and operation of the PRE and the MMU so that a suitable connecting device and realistic procedures for use can be proposed in later chapters.

The Personnel Rescue Enclosure

PRE Design. Figure 2.1 presents a detailed drawing of the PRE. The PRE is a puncture-resistant Kevlar pressure sphere with a diameter of 34 inches--small enough to fit through the airlock doors and orbiter side hatch.

Connectors penetrate the sphere which provide for attaching an air umbilical (for inflation and also for additional victim breathing oxygen) and a communication line. The sphere is also equipped with a pressure gauge, a small viewing window, and a pressure relief valve which limits maximum PRE pressure to 5.25 psia (28:1-4).

Two external carrying loops are positioned on opposite sides for ease of handling. A waist restraint belt is attached inside the sphere to prevent relative movement of the crewman and the PRE. Entry is through a zipper which cuts across one hemisphere, and can be operated from both inside and outside the PRE.

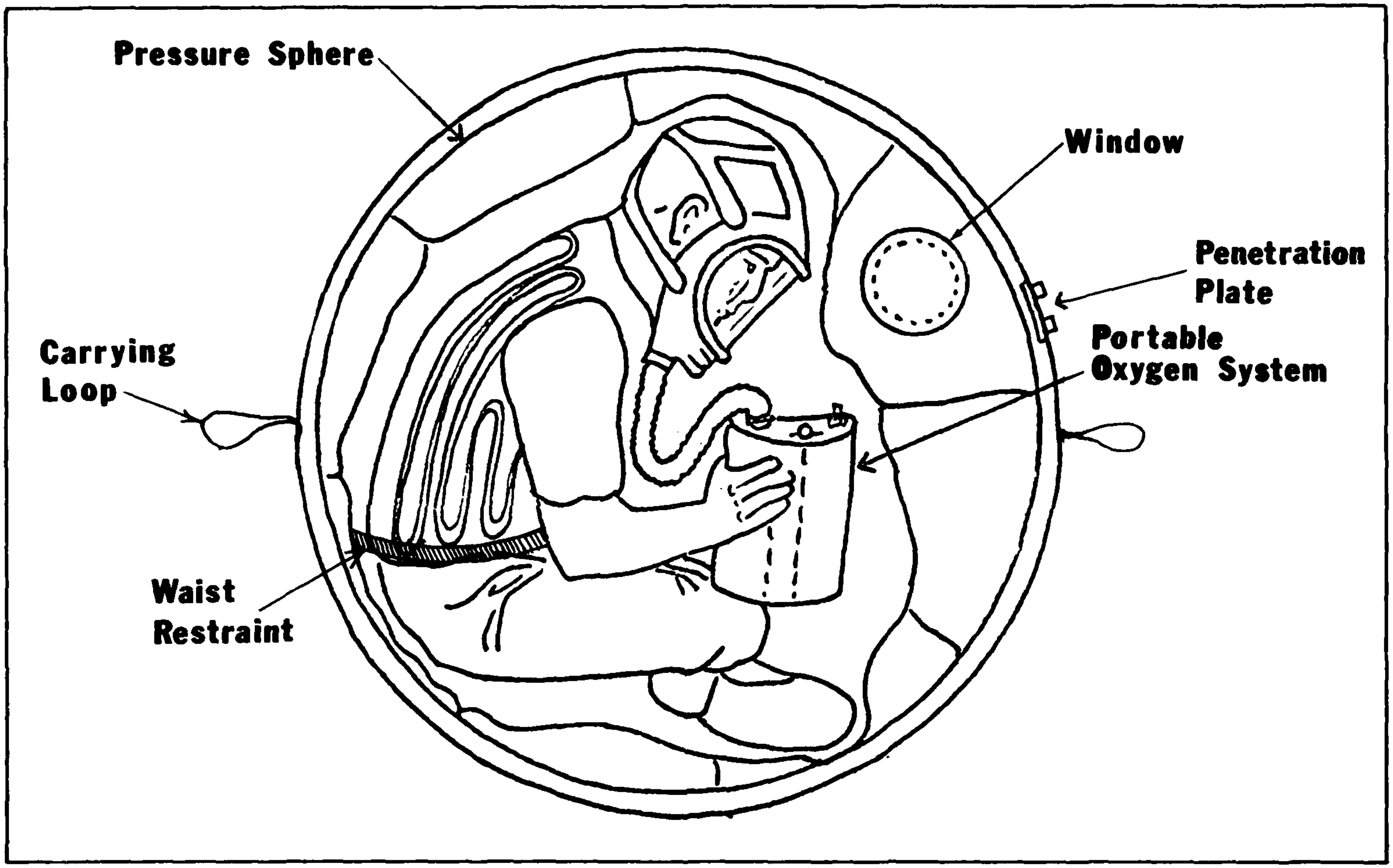


Figure 2.1 Personnel Rescue Enclosure (PRE) (28:8)

A one-hour supply of breathing air is furnished by a portable oxygen system currently under development by Johnson Space Center's Crew Systems Division. The portable oxygen system is carried inside the PRE, nestled in the lap of the victim. The air is fed to the victim by a hose and mask. Additional breathing air can be supplied through the aforementioned air umbilical connector. This allows orbiter-furnished oxygen to be consumed, thus conserving the limited supply available from the portable oxygen system. The astronaut's exhalation products are dumped into the sphere to make up for slow leakage through the zipper, so that the desired 5.0 psia atmosphere is maintained (29).

PRE Use. Figure 2.2 depicts PRE entry and use. The PRE is designed to fold up and be stored in a small volume. When required, it is unstowed, unzipped, and the crewmember enters and fastens the restraint belt. Next, he positions the portable oxygen system between his legs and connects the bottle's regulator to the air umbilical connector. Finally, he dons the oxygen mask and insures a positive oxygen flow, then another astronaut helps close the zipper, sealing the PRE.

As already mentioned, two of the stranded astronauts are allocated spacesuits. After his fellow crewmember is sealed inside the PRE, one of these two astronauts connects the PRE's air umbilical connector to an air umbilical, two of which are available in the airlock. This umbilical provides compressed air at 900 psi to quickly inflate the

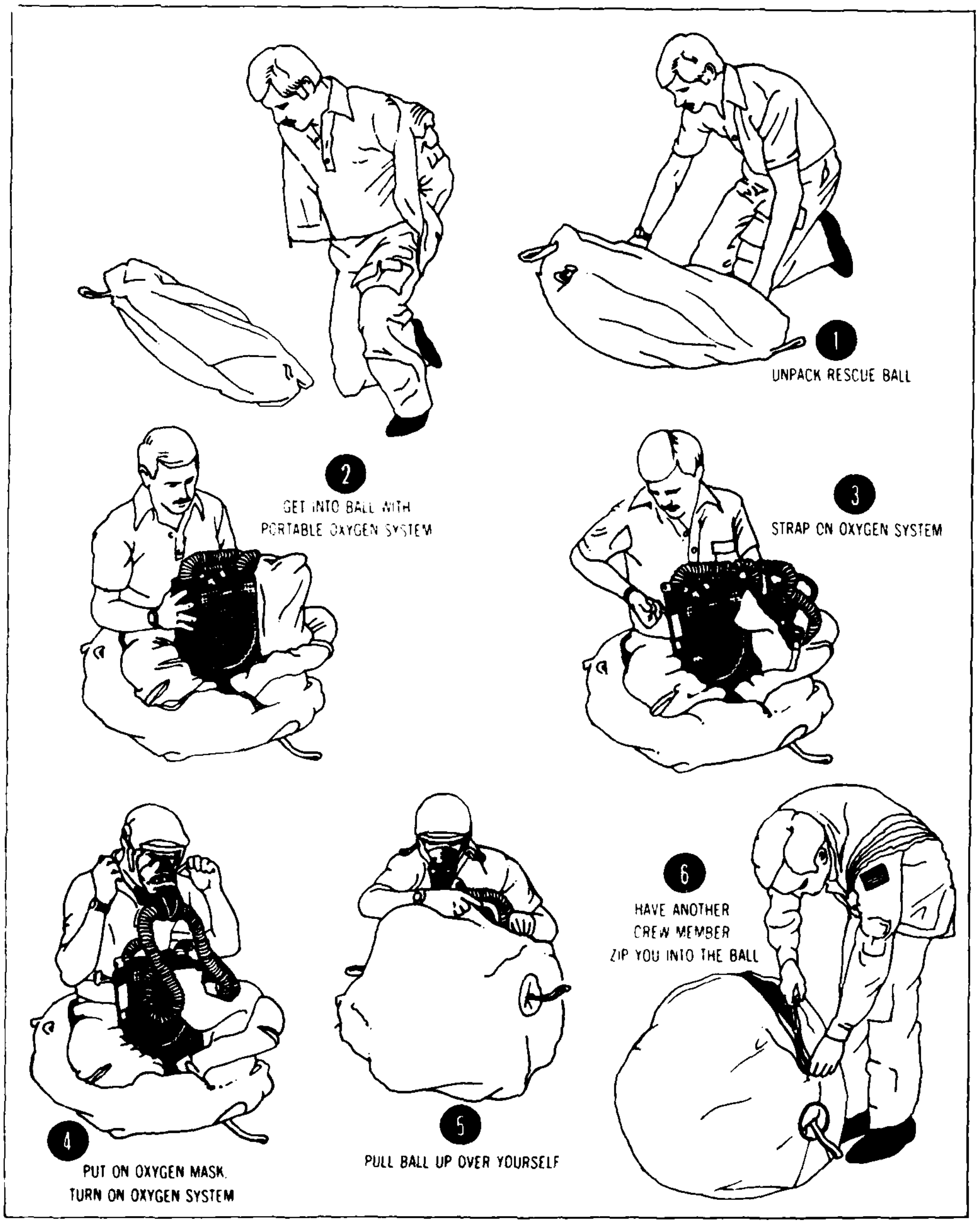


Figure 2.2. PRE Entry (7:4.7)

sphere to 5.0 psia. Thereafter, the umbilical remains connected for as long as possible (optimally until just before PRE transfer) to provide breathing oxygen directly to the mask (though stepped down to the proper pressure by the portable oxygen system's regulator) so as to avoid depletion of the one-hour supply in the portable bottle (18:2.3-20).

Two PREs can be placed in the airlock and undergo the three-minute depressurization simultaneously; however, there is not enough room for an accompanying astronaut. Therefore, a spacesuited astronaut must already be waiting in the payload bay to disconnect the air umbilicals, remove the PREs, and close the airlock hatch (19).

Upon successful transfer to the rescue vehicle's airlock but before repressurization, another air umbilical can be connected if the one-hour oxygen supply in the air bottle is approaching exhaustion. Following airlock repressurization, the crewman exits the PRE. Total time of enclosure cannot exceed three hours because temperature and humidity inside the PRE begin to exceed habitability limits (29).

PRE Development Status. After two prototype models were built and extensively tested (but not man-rated) in 1976, PRE development halted because it was realized that the old nemesis of space rescue--lack of a rescue vehicle--would continue for another decade until the space shuttle fleet became fully operational. That has now occurred; therefore, ten new PREs are currently being built by Johnson Space Center's Crew Systems Division, and will be man-rated

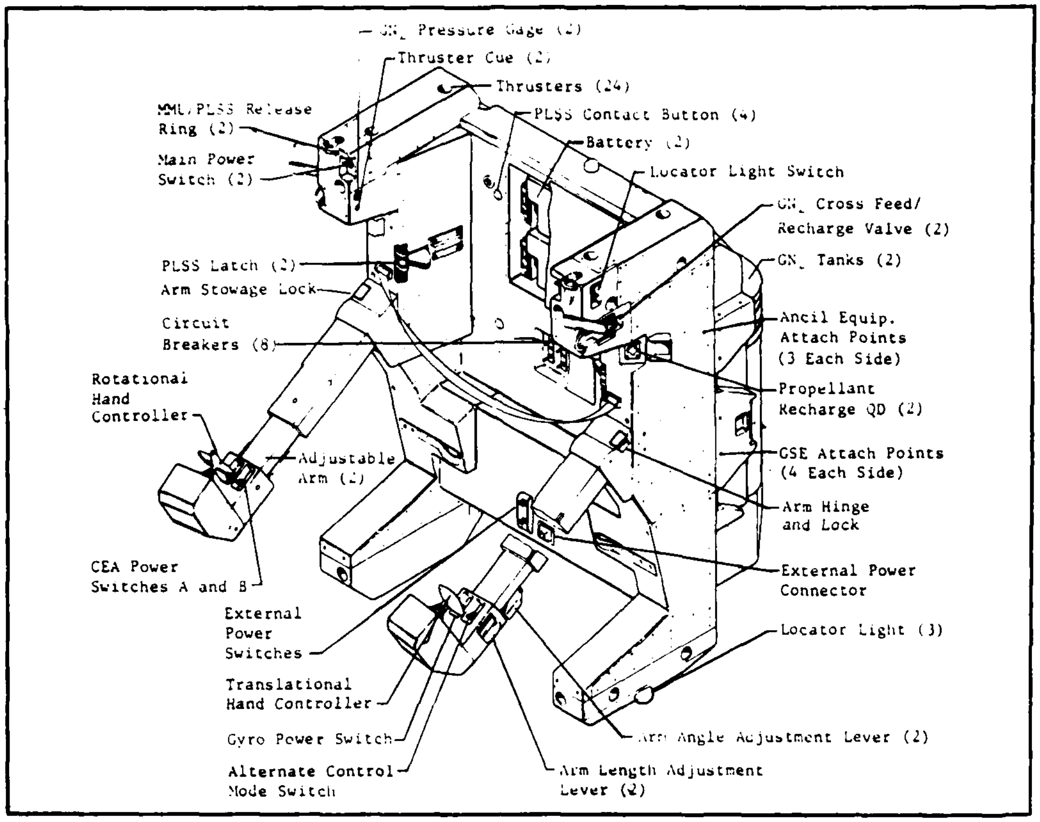


Figure 2.3. The Manned Maneuvering Unit (MMU) (9:1-14)

and manifested on future space shuttle flights (29).

The Manned Maneuvering Unit

MMU Design. The MMU concept was born out of a recognized need to furnish EVA astronauts with a personal propulsion system allowing untethered excursions of up to several hundred feet away from the orbiter.

Figure 2.3 details the MMU design. The MMU is a one-man propulsive backpack which attaches to the standard NASA spacesuit. Completely redundant propulsion, electrical, and

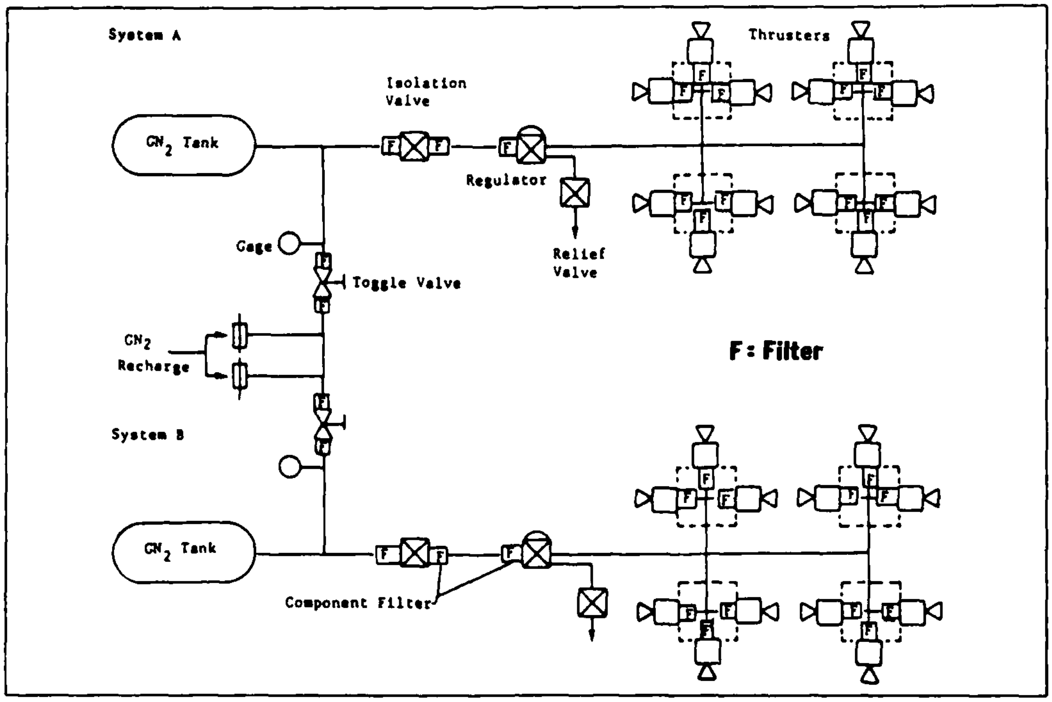


Figure 2.4. MMU Propellant System (9:1-20)

control subsystems insure that no single credible failure can disable the unit. This redundancy permits the MMU to be flown untethered and completely free of the mother ship.

The primary structure consists of an aluminum frame covered by aluminum skins, and is built using aircraft-type semimonocoque construction techniques. The basic configuration consists of two vertical towers connected by a backplate, and two control arms protruding forward from the midsection of each tower. Two propellant tanks attach to the rear of the backplate (9:2.26).

Figure 2.4 portrays a simplified schematic of the MMU propulsion system. Two 1630 in^3 pressure bottles contain the propellant (gaseous nitrogen) at an initial pressure of 3000 psia. Each bottle supplies an identical, completely independent propulsion subsystem capable of providing translational forces and rotational moments. Each subsystem consists of an isolation valve which permits emergency shutdown, a regulator which reduces the gas pressure to a working pressure of 212 psia, and tubing which carries the gaseous nitrogen to four triads of cold jet nozzles located on the corners of the towers. There are a total of twenty-four thrusters. If required, the two propellant bottles can be interconnected via two toggle valves to insure that all nitrogen is made available for use. Upon command from the Central Electronics Assembly, solenoids open the appropriate thruster valve(s) and expel the gaseous nitrogen to produce 1.7 lbs of force per thruster (9:2-79).

Two 16.8 Volt potassium hydroxide batteries are enclosed within the backplate and provide six hours of electrical power before requiring recharge or replacement. These batteries supply two completely independent and redundant electrical systems which insure electrical power is supplied to all MMU systems (9:1-16).

Two hand controllers are located at the end of the adjustable arms and provide full six degrees-of-freedom maneuvering capability. These arms can be rotated downward while in flight to allow closer access to the worksite (9:4-1).

The hand controller commands are interpreted by dual redundant Control Electronics Assemblies (CEA), which are also located in the backplate, beneath the batteries. The CEAs contain gyros, control logic, and amplifiers which deliver drive voltages to the thruster solenoids to open the thrusters required for the commanded maneuvers (9:1-12). The CEA and hand controllers are further explained in a latter section.

Presently, there are only two types of instruments on the MMU. The first consists of two thruster cues--one each located at eye-level on the inside upper section of the both towers--which illuminate when their respective propulsion system is firing. The second type of instrumentation consists of two fuel gauges (one for each propulsion tank), one mounted on each tower directly above the thruster cue (9:1-15).

MMU Performance. Thruster force is 1.7 lbs per thruster, and specific impulse is approximately 66 seconds. The two propellant tanks provide 23.2 lbs. of useable gaseous nitrogen, meaning a total impulse of approximately 1531 lb-sec is available (9:1-16). Assuming an average MMU mass (with astronaut attached) of 737 lbs., that implies a translational acceleration capability of .3 ft/sec^2 and a total velocity change capability of approximately 67 ft/sec. For this configuration, the thrusters provide yaw, pitch, and roll accelerations of between 7.5 and 9.0 deg/sec^2 (9:1-44).

In frictionless space, propellant consumption is directly proportional to the translational and rotational rates commanded by the pilot. Therefore, as long as time is not a critical factor, there is a strong incentive for fuel-conscious pilots to use translation rates of less than 1 ft/sec, and rotation rates of not more than 5 deg/sec (11:7).

The proposed IRV has a mass of approximately 1040 lbs; therefore, its predicted translational and rotational accelerations are significantly less than those of the solo MMU, as reported in Chapter V.

MMU Operation. Up to two MMUs are stored on the port and starboard sidewalls of the forward payload bay, attached to Flight Support Stations as shown in Figure 2.5. The Flight Support Station not only carries the MMU, but also provides foot restraints and handrails to assist the crewmember in servicing and donning/doffing the MMU. Connections between the MMU and Flight Support Station provide electrical power for MMU thermal control heaters and MMU propellant refueling.

To conduct a MMU flight, the pilot dons his spacesuit and undergoes depressurization in the orbiter airlock. He then opens the airlock door, exits into the payload bay, and translates via handrails to the Flight Support Station, where he faces the MMU and prepares it for flight. When ready, he turns to face away from the MMU, and backs into it so that latch receptacles on his life support backpack engage latch mechanisms on the MMU. Pulling rearward on two release handles frees the MMU from the Flight Support Station and the pilot flies away.

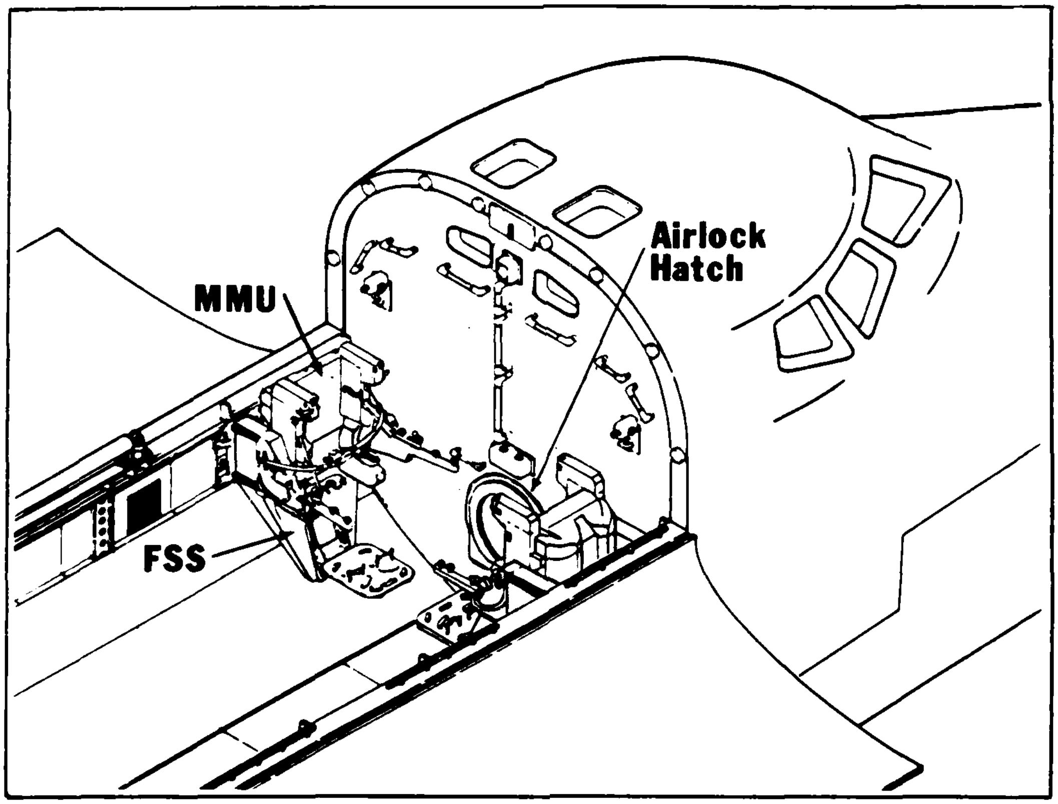


Figure 2.5. Manned Maneuvering Units (MMU) Mounted in Flight Support Stations (FSS) (26:2)

At mission termination, the MMU pilot "lands" on the FSS foot platform and doffs the MMU by performing the reverse of the donning procedure. Before entering the airlock, he prepares the MMU for its next flight by replacing the batteries and charging the propellant bottles (9:4-18--4-24).

Pilot control inputs are via the two hand controllers. The right hand controller inputs three degrees-of-freedom rotational commands and the left hand controller inputs three degrees-of-freedom translational commands. Figure 2.6

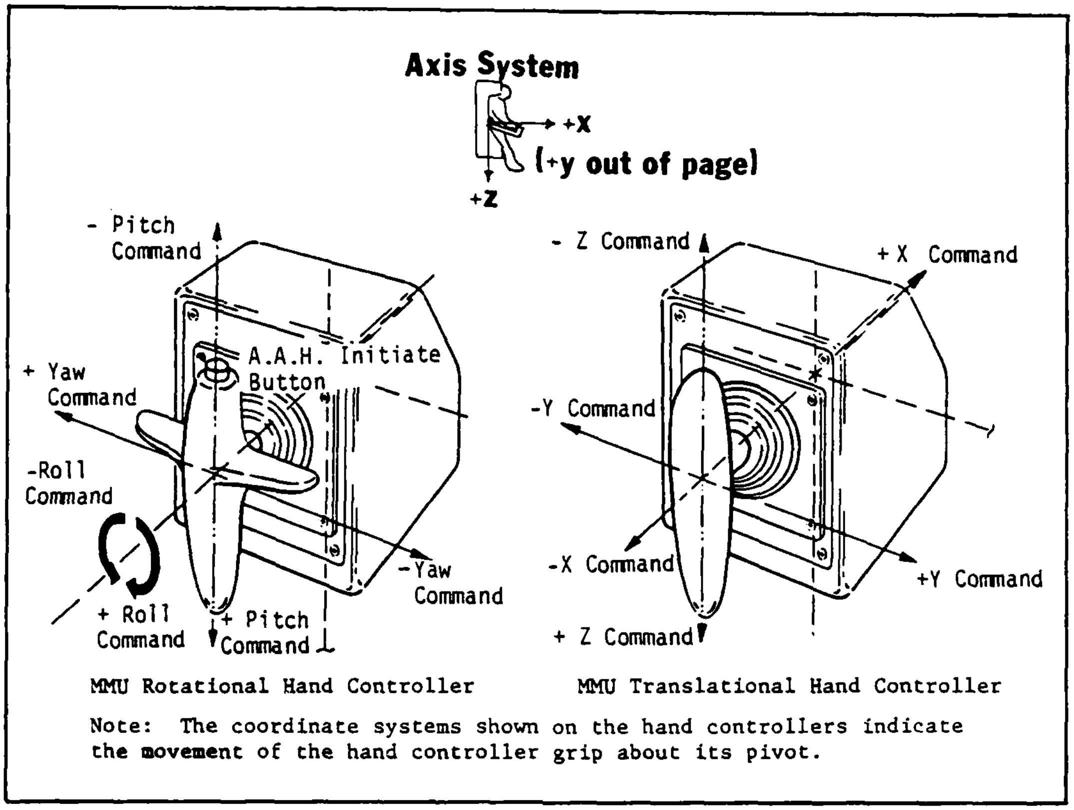


Figure 2.6. MMU Hand Controllers (12:36)

illustrates the pilot inputs required for the various translations and rotations, and the MMU body coordinate system used throughout this report. Commands can be enacted singly or in combination. Deflecting either hand controller fully opens the valves of the appropriate 1.7-pound thrusters, and the valves remain full open for as long as the hand controller remains deflected from the null position.

The Control Electronics Assembly fires the correct thrusters by matching the received hand controller inputs against Primary tabulated thruster select logic and sending drive voltages to the designated thruster solenoids. Should an in-flight failure of the propulsion, electrical, or control systems reduce the MMU to operating on only one of the two propulsion subsystems (and therefore on only half of its thrusters), the Control Electronics Assembly reverts to a Backup thruster select logic table which uses only thrusters of the remaining propulsion subsystem to maintain translational and rotational control authority.

Also, the Control Electronics Assembly has a third, pilot-selectable thruster logic table designed for zeroing out rotation rates when the MMU is attached to large payloads. Called the Satellite Stabilization control mode, it decreases thruster plume impingement on the payload by avoiding as much as possible the use of forward-firing jets, and increases control moments by firing more thrusters or by firing thrusters with longer moment arms from the combined vehicle's displaced center of mass. Satellite Stabilization mode was designed to permit the MMU to stop the rotation of a connected disabled satellite and allow subsequent capture by the orbiter's remote manipulator arm, and is not optimized for translational motion.

Appendix A presents the thruster select tables for the Primary, Backup, and Satellite Stabilization control modes, and a diagram showing the thruster labeling scheme used throughout this report (9:1-12).

By pushing a button on top of the right hand controller, the MMU pilot can implement the automatic attitude hold

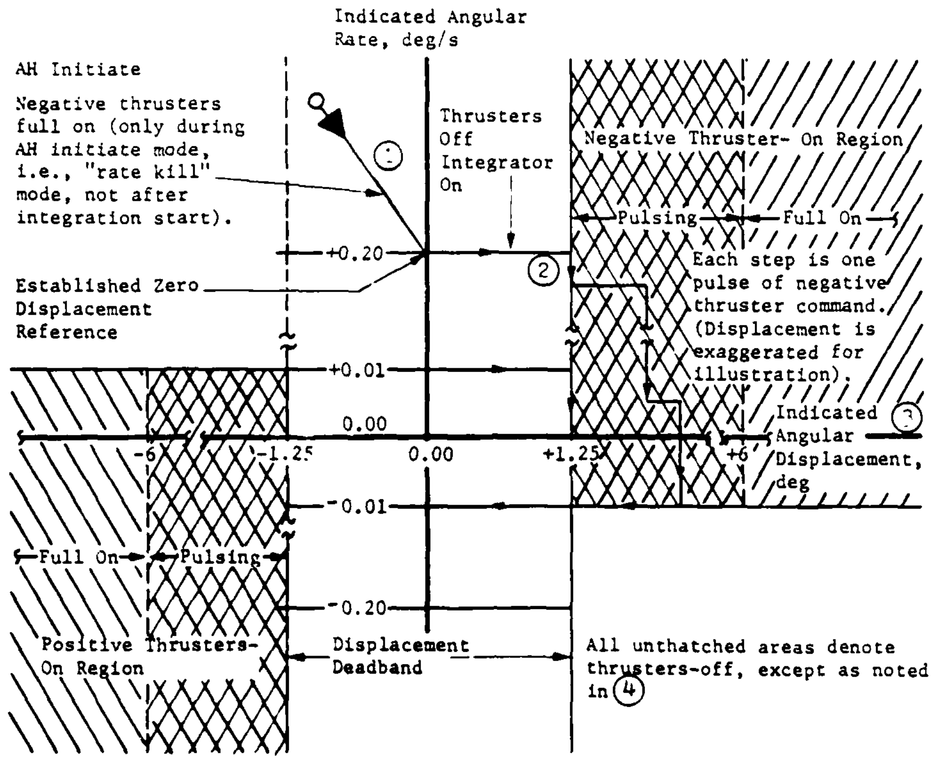


Figure 2.7. Automatic Attitude Hold System Control Logic (9:2-35)

(AAH) feature of the Control Electronics Assembly, which stops all MMU rotation and holds the vehicle in the resulting attitude. Subsequent rotational commands issued by the pilot are heeded but AAH is lost in that axis of rotation until the AAH button is again depressed. Those axes not manually commanded continue in AAH.

Figure 2.7 is a phase plane plot which depicts AAH operation. The horizontal axis measures the MMU's attitude error (in degrees) from the desired attitude. The vertical axis measures the rate error (in deg/sec) at which the MMU is rotating away from or toward the desired attitude. The origin of the axes represents that situation where the MMU is at the desired attitude and is not rotating. Figure 2.7 is simplified in that it only presents information for one of the three axes. The circled numbers in the following discussion correspond to the circled numbers in the figure.

(1) Upon activation, AAH uses rate feedback from the CEA gyros to fire the proper thrusters full on so that the MMU rotation is automatically nulled to only .2 deg/sec. The correct thrusters are selected by referring to the thruster select logic tables currently designated for use by the pilot (Primary, Backup, or Sat Stab). After nulling the rotation rate to only .2 deg/sec, the thrusters are turned off and the orientation at that instant is designated as the desired attitude.

(2) The .2 deg/sec residual rate takes the MMU away from the desired orientation. When gyro attitude feedback senses that the attitude error exceeds the +/-1.25 degree deadband, the CEA pulses the proper thrusters three times per second, 10.6 milliseconds per pulse, to bring MMU attitude back within the deadband. The restoring pulses are stopped when gyro feedback senses that the MMU is converging back toward the desired attitude at a rate of at least .01 deg/sec. The procedure is repeated when the attitude deadband is violated on the opposite side, hence the MMU continues to slowly oscillate within +/-1.25 deg of the desired attitude.

(3) Should a persistent torque overwhelm the corrective moments of the pulsed thrusters and continue to drive the MMU away from the desired attitude, the thrusters are turned full on when gyro feedback senses that the MMU has rotated six degrees away from the desired attitude.

(4) During translation commands, an additional +/-.2 deg/sec rate limit is imposed, which may cause thruster firings even when the MMU is within the attitude deadband. The purpose of this limit is to prevent excessive attitude excursions which could be caused by the overwhelming moments created by the full-on thrusters during translations in certain MMU configurations. If, after the translation burn, the original attitude deadband has been exceeded, corrective burns will be made as explained in 2 and 3 (9:2-34--36).

Figure 2.7 does not reflect the effects of a limb motion filter, which briefly delays AAH response to transgressions of the +/-1.25 deg attitude deadband. This time delay reduces propellant wasted on temporary deadband violations caused by MMU pilot limb motions. The principle of angular momentum conservation tells us if, for example, the pilot moves his hand from the hand controller up to the tower (to activate a switch, perhaps), that the MMU will move to a new stationary attitude. Likewise, when the pilot moves his hand back to its original position, the MMU will assume its original attitude. *In other words*, attitude displacements caused by pilot motion are inherently self-correcting. The limb motion filter allows a short time for this self-correction to occur before AAH enters the pulsed thruster mode (27).

AAH serves three useful purposes. First, it provides an easy and accurate way for the pilot to quickly null all rotation rates and to maintain the MMU in the resulting orientation. Second, AAH counteracts the rotations induced when pure translations are attempted with a MMU configuration that has the center of mass offset from the geometric center of thrust. Without the +/-.2 deg/sec rate limit explained in 4, above, translational commands would also cause such a configuration to spin out of control. Third, AAH limits uncommanded rotations due to non-zero products of inertia. The principal axes of the MMU typically do not align with MMU body coordinate system; therefore, dynamics theory tells us that thruster firings intended to produce rotations about only one axis actually result in coupled rotational components about all three axes. AAH provides corrective thrusts when uncommanded rotations exceed the +/- 1.25 deg and +/- 6.0 deg deadbands. As the proposed IRV suffers from a significant offset between the center of thrust and center of mass, and also features principal axes not aligned with the MMU body coordinate system, the AAH system will be highlighted in Chapter V.

<u>MMU Development Status</u>. Two MMUs are fully operational

and stored ready for flight at Martin Marietta Aerospace Corporation in Denver CO. To date, they have been flown a total of seven times, including spectacular saves of two disabled communication satellites (34).

Chapter Summary

This chapter has summarized the knowledge base concerning the PRE and MMU which was required before conducting the research described in the following chapters. The next chapter describes the device proposed for connecting the PRE to the MMU.

III. MMU/PRE Connection Device

Overview

This chapter lists requirements for a suitable MMU/PRE connecting device, proposes an advantageous design for a MMU/PRE connecting mechanism, presents the resulting IRV, and then compares the proposed design to the requirements to determine acceptability.

Requirements

The objective of this project was to propose an immediately available space rescue rescue ferry vehicle. Research indicated that achieving this goal necessitated that the MMU/PRE connection device satisfy the following requirements:

1. Off-the-Shelf. Only currently available or soon-to-be-available hardware be considered for use.

2. Visibility. The IRV pilot must have adequate visibility with the PRE connected to allow him to safely maneuver the IRV to the rescue vehicle.

3. Ease of Use. The connection device should be easy to use by a spacesuited astronaut. All controls should be within the IRV pilot's reach.

4. Stowage. The connecting device should be capable of being stowed in the orbiter's payload bay using currently available payload mounting hardware.

5. Critical Fits. Critical fits should be avoided.

On Mission 41C, the MMU was tasked to dock with and stabilize the failed Solar Maximum Satellite. The MMU carried a Trunnion Pin Attachment Device (TPAD) designed to automatically clamp over a pin protruding from the satellite. The approach failed, however, because an undocumented grommet stopped the TPAD one inch short of its intended travel, thus failing to trigger the automatic clamp. A manual jaws trigger should have been available to allow the MMU pilot to complete the connection (5).

6. Quick Response. The proposed IRV must be ready for flight within several hours of notification of an impending rescue mission. Therefore, all hardware modifications must be permissible in advance or achievable in minimum time.

7. Safety. Redundant systems should back up critical components so that foreseeable possible failures do not prevent completion of the rescue mission or cause injury to crewmembers.

8. Stability and Performance. The terms "stability" and "performance" were defined in Chapter I. The proposed IRV will exhibit improved stability and performance if the connecting device meets the following five sub-requirements:

a. Minimum Mass. Increases in mass will decrease the IRV's translational acceleration and total velocity change capabilities. The MMU/PRE connection device should be as light as possible.

b. Minimum Center of Mass Shift. Connecting the

PRE to the MMU will unavoidably shift the center of mass away from the geometric center of the MMU's thrusters, thus increasing the coupled rotations experienced during translational burns, as discussed in Chapter 2. Minimizing this shift by reducing the distance between the PRE and MMU will minimize the degradation to IRV performance and stability. In other words, the MMU/PRE connection device should be short.

c. Minimum Moments of Inertia. A short connection device of low mass will also achieve a related criterion: minimally increased moments of inertia. Moments of inertia measure a spinning body's resistance to changes in its rotation rates; consequently, achieving this goal will maximize the IRV's rotational acceleration capability.

d. Rigid Connection. The device should provide a rigid connection between the MMU and the PRE. A flexible connection would allow the IRV's center of mass and moments of inertia to vary with time, thereby possibly degrading stability below an acceptable level.

e. Plume Impingement. If the gas plumes expelled from the MMU's thrusters impinge upon the PRE or the connection device, moments and forces will be created which, in general, will create undesired translational and rotational accelerations, thus degrading the IRV's stability and performance. The connection device should position the PRE so that plume impingement is prevented or, where unavoidable, such that opposite jets are equally degraded so that symmetry of thrust is preserved.

Proposed Connecting Device

Apogee Kick Motor Capture Device. Tests conducted by this researcher at the Johnson Space Center, Houston TX, 23 Jun-3 Jul 85, revealed that an existing piece of flight-qualified hardware, the Apogee Kick Motor Capture Device (ACD), can be modified to adequately meet most of the above criteria, and serve as the MMU/PRE connection device.

The ACD was originally built to allow the MMU to capture and stabilize two stranded Hughes 376 satellites. This was successfully accomplished in November 1984 during Mission 51D, when the Palapa B and Westar satellites were retrieved and returned to earth for repair. Figure 3.1 illustrates the MMU, with ACD attached to the controller arms, docking with a satellite.

ACD Design and Operation. Figure 3.2 details the ACD. It consists of four subassemblies: toggle finger, control box, structure, and grapple device.

The toggle finger subassembly was initially streamlined for insertion into the target nozzle. After insertion, the MMU pilot pulled on a lever located on top of the control box subassembly to extend three toggle fingers that trapped the probe inside the thrust chamber. By then turning a flywheel located on the aft end of the control box, the MMU pilot translated the toggle fingers toward him until they came to rest against the nozzle throat. Further tightening

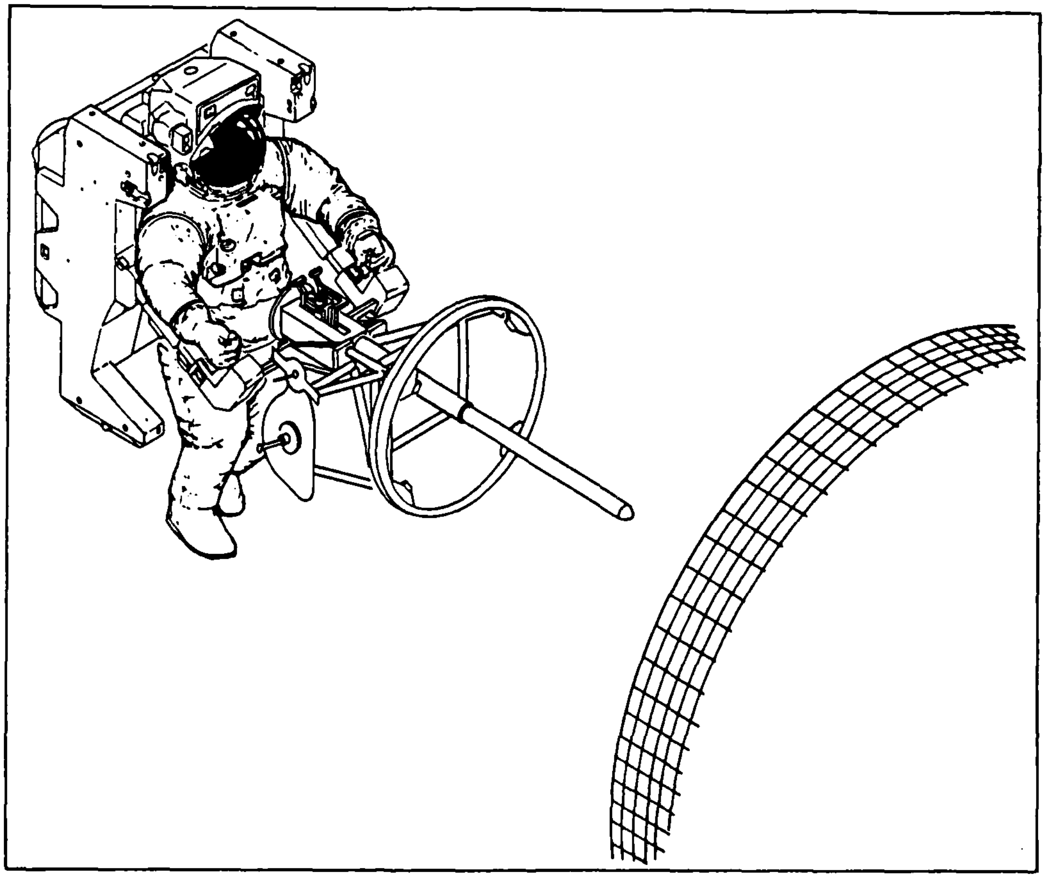


Figure 3.1. Hughes 376 Rescue (5)

of the flywheel caused the satellite and MMU/ACD to translate toward each other until the satellite's nozzle bell came to rest against the ACD's structure subassembly ring, thus making a rigid connection. The MMU pilot then activated the automatic attitude hold feature of the MMU control system to zero out all rotation rates. After stabilization, the orbiter attached its remote manipulator arm to the grapple device subassembly. The MMU pilot then disconnected the MMU from the ACD, and the arm operator positioned the

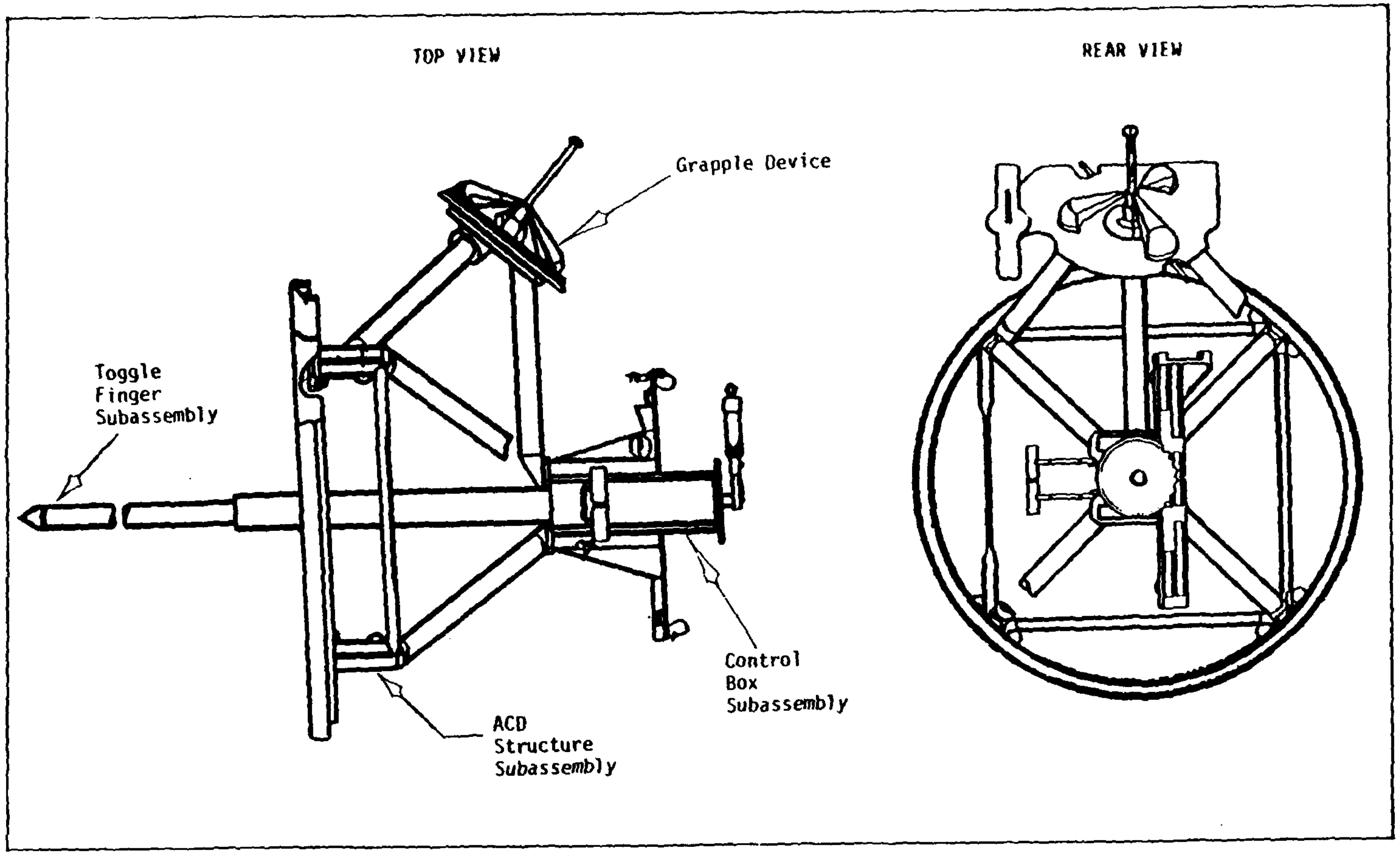


Figure 3.2. Apogee Kick Motor Capture Device (ACD) (30:3-4)

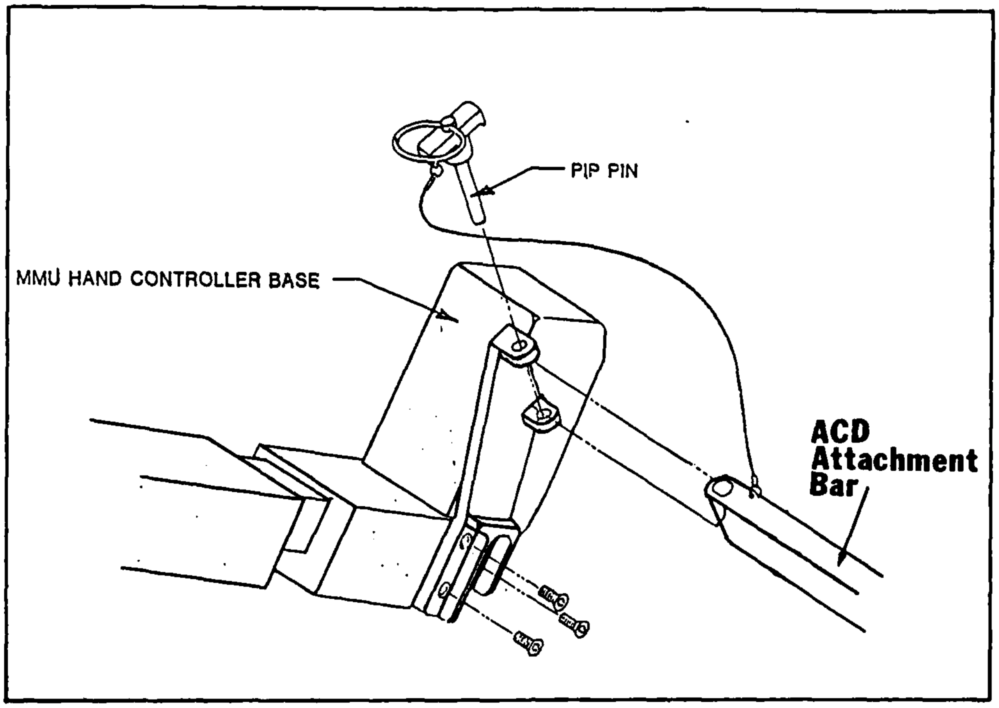


Figure 3.3. Detail of MMU/ACD Attachment

remaining assemblage (ACD and satellite) inside the orbiter's payload bay (11).

MMU/ACD Attachment. The ACD connected to the MMU controller arms as illustrated in Figure 3.3. An attachment bar mounted on the rear of the ACD's control box interfaced with two mounting brackets, one each located on the inside of a hand controller box. Drop-in pins locked the attachment bar into the mounting brackets.

ACD Status. Two flight ACDs were built and used on Mission 51D. One of these is currently in storage in Building 7A at the Johnson Space Center, and the other is on display at the National Air and Space Museum in Washington

D.C. A third flight-quality unit was built for engineering qualification tests and served as the backup for the two flight units on Mission 51D. It, too, is stored at the Johnson Space Center and could be called into operational use if required.

Modified ACD. Measurements indicated that the ACD's structure subassembly was the correct size and shape to serve as a "basket" within which a attached PRE could be securely carried. The following modifications were proposed to remove all ACD components which interfered with the use of the structure subassembly for this purpose:

1. Remove the guide ring, part number SDD39117409-001, from the structure subassembly.

2. Remove the entire toggle finger subassembly, part number SED39117128-301.

3. Remove the entire control box subassembly, part number SED39117360-301.

4. Remove the entire grapple fixture assembly (part number 10169-20400-01) and its three supporting struts (part numbers SDD 39117211-001 through -003).

The resulting modified ACD is shown in Figure 3.4.

The Interim Rescue Vehicle (IRV)

Fit Test. During tests at the Johnson Space Center during 25-27 Sep 85, this researcher modified a full-size

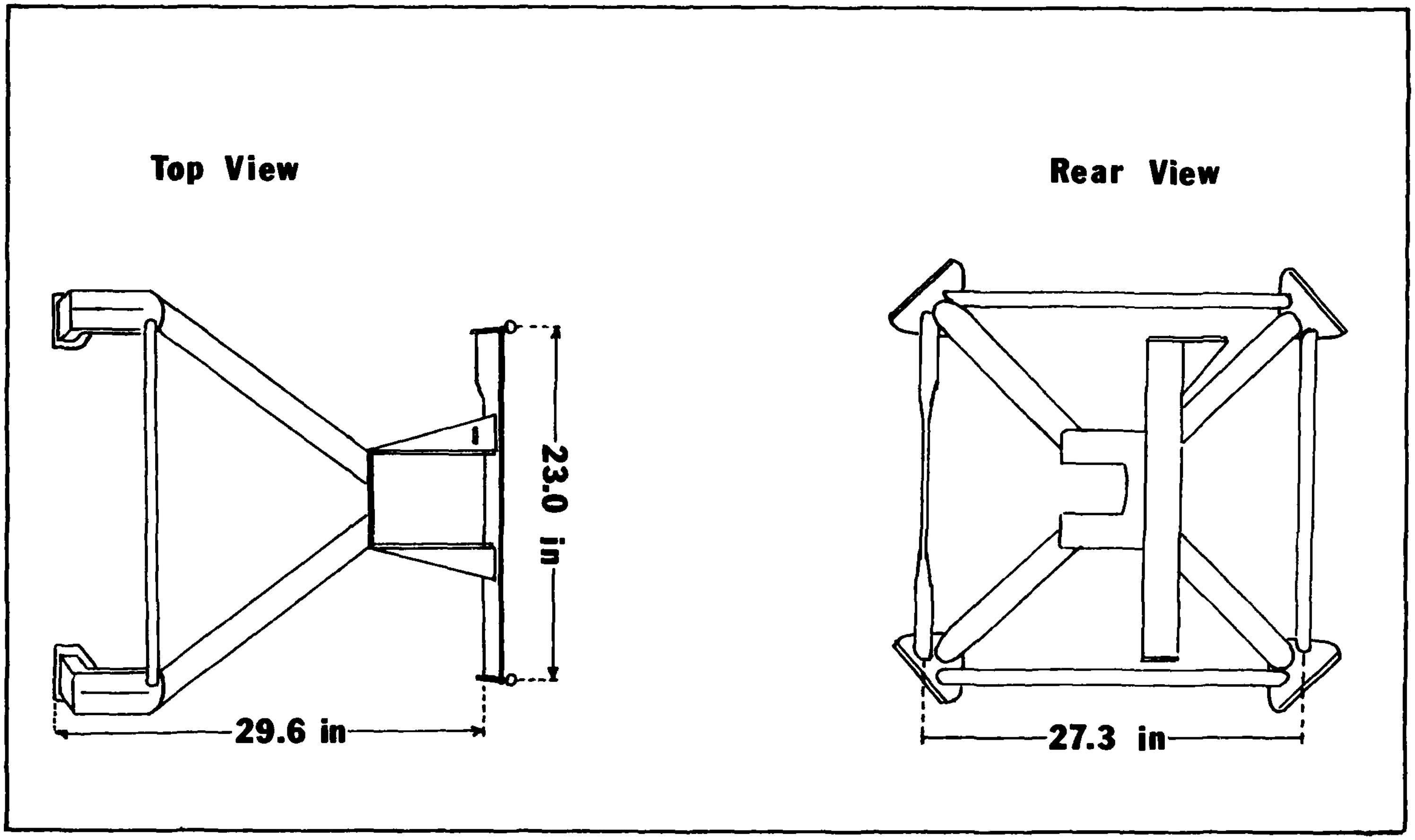


Figure 3.4. Proposed Modified ACD

engineering model ACD according to the four steps listed above. The modified ACD was then attached to a full-size mockup MMU and a prototype PRE to arrive at the proposed Interim Space Rescue Ferry Vehicle (IRV). The IRV is presented in Figure 3.5.

IRV Design. Figure 3.5 shows how the modified ACD structure forms a "basket" within which the PRE neatly fits. The modified ACD contacts the PRE at eight points: midway along the four cross support struts and at the four foot pads. These multi-points of contact insure that the PRE Kevlar shell is not punctured due to overstress at any single location.

The PRE is rigidly held against the points of contact by tension provided by two tethers connected to the PRE carrying strap. The primary tether consists of a standard adjustable wrist tether with it's other end hooked to one of two waist attachment rings located on the front torso of the pilot's spacesuit. The secondary tether is the four-foot (maximum extension) adjustable self-reeling tether that is an integral part of the Mini-Work Station carried on the pilot's chest. In addition to anchoring the tether, the Mini-Work Station also carries up to four tool caddies, each carrying two EVA tools. The adjustable wrist tether and Mini-Work Station are standard, flight-tested EVA equipment, and details concerning their design and operation are in Appendix B.

Despite the major changes, the modified ACD rigidly

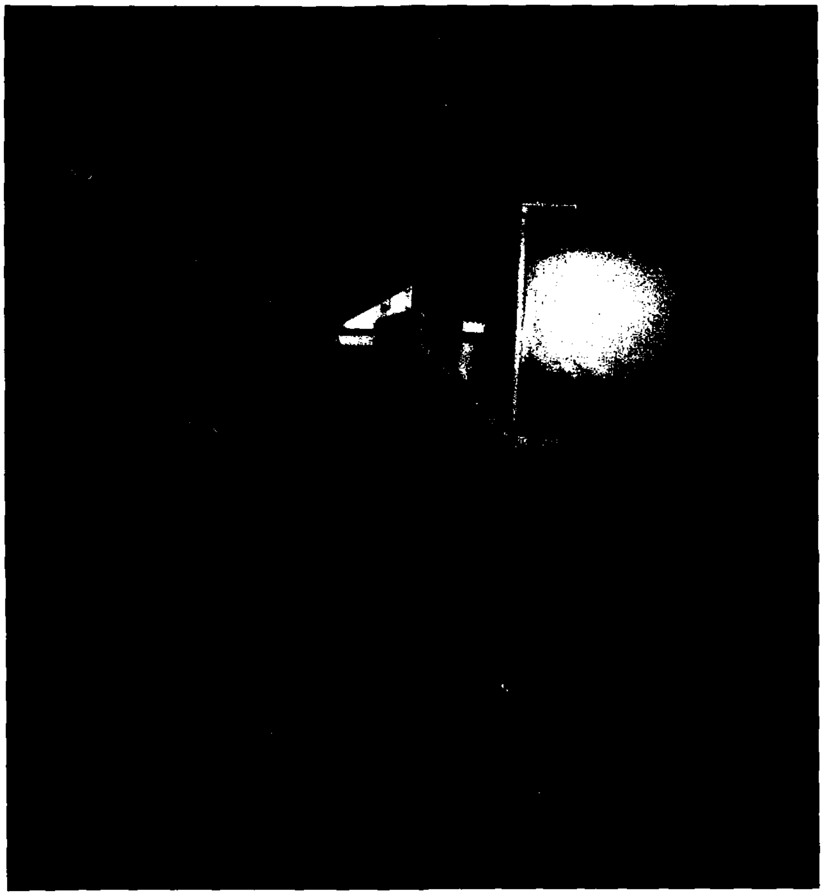


Figure 3.5. Mockup Interim Space Rescue Ferry Vehicle (IRV)

attaches to the MMU controller arms in the same manner as the unmodified ACD.

Requirements Achievement

This section assesses the degree to which the proposed modified ACD satisfies the requirements listed at the beginning of this chapter.

1. Off-the-Shelf. This requirement is fully satisfied.

2. Visibility. This requirement is adequately satisfied. The IRV pilot's horizontal line of sight lies 2-7/8 inches above the top of the PRE. This corresponds to a look-down angle of 3.34 degrees. The answer to the question, "Is this enough?" was obtained from experimental data and an astronaut interview.

Visibility Experiment. The IRV simulator shown in Figure 3.6 was constructed by the AFIT Fabrication Shop. It duplicated the obstruction to vision caused by the PRE with a 34-inch diameter styrofoam disc mounted 49.25 inches in front of the test subject "pilot." The disc height was adjustable by the test subject. The test subjects "flew" the simulator by pushing the castor-mounted disc in front of them.

Twenty-two USAF pilots were tested. Each was instructed to "fly" toward and "dock" with a space shuttle airlock hatch silhouette located on the wall, and to adjust the styrofoam disc to the tallest height which still permitted

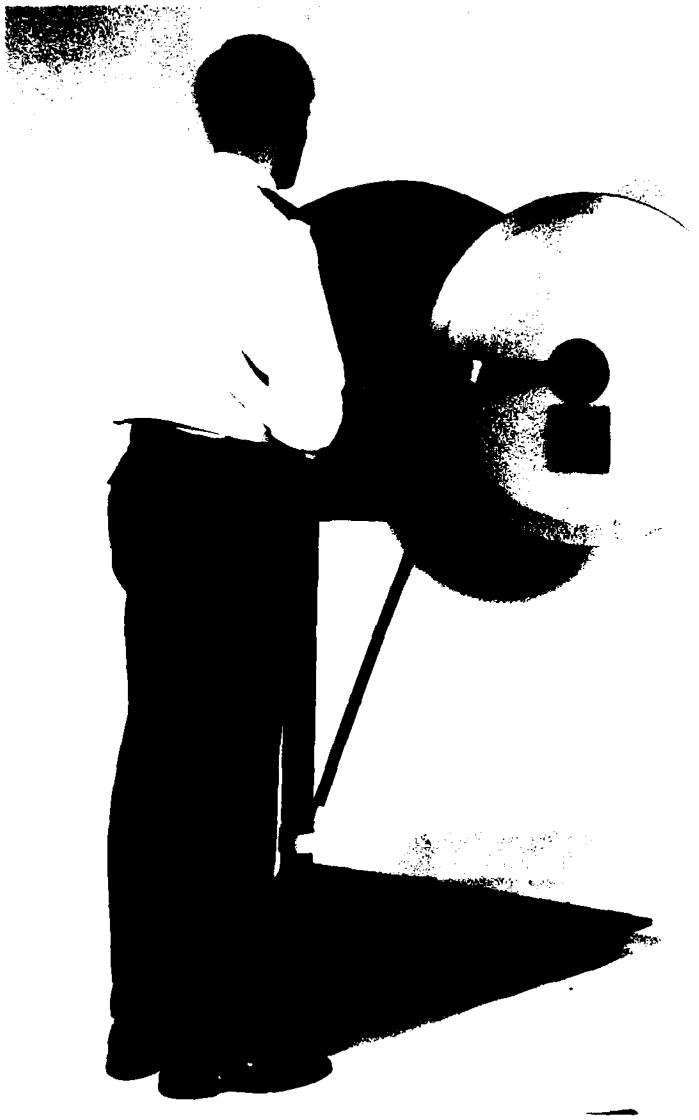


Figure 3.6. IRV Visibility Test Apparatus

adequate visibility to complete the task.

Appendix C presents the experimental results and the calculations of the statistical measures of the results. The mean look-down angle required by the 22 subjects was .43 degrees, with a standard deviation of 1.02 degrees. Therefore, it can be said with greater than 99 percent confidence that the 3.34 degree look-down angle afforded by the proposed IRV is a statistically significant improvement over the average required by the test subjects (16:213).

Astronaut Interview. Astronaut Bruce McCandless, a designer of the MMU and pilot during its first flight, was interviewed at Martin Marietta Aerospace, Denver CO, 5 Sep 85. He expressed the opinion that ". . . only a couple of degrees look-down should be required. . ." to provide adequate visibility (13). He also pointed out that the IRV pilot always had the capability of improving his forward visibility by pitching the IRV down and thus moving the PRE further below his line of sight to the target (13).

While IRV pilots would no doubt appreciate more visibility, the aforementioned research indicates that the afforded 3.34 degrees is adequate.

3. Ease of Use. The fit test revealed one significant shortcoming in the proposed design. With the PRE nestled in position, the carrying handle falls eight inches short of the MMU pilot's reach; therefore, he cannot grasp the carrying handle and attach the two tethers. Two measures were proposed to alleviate this problem:

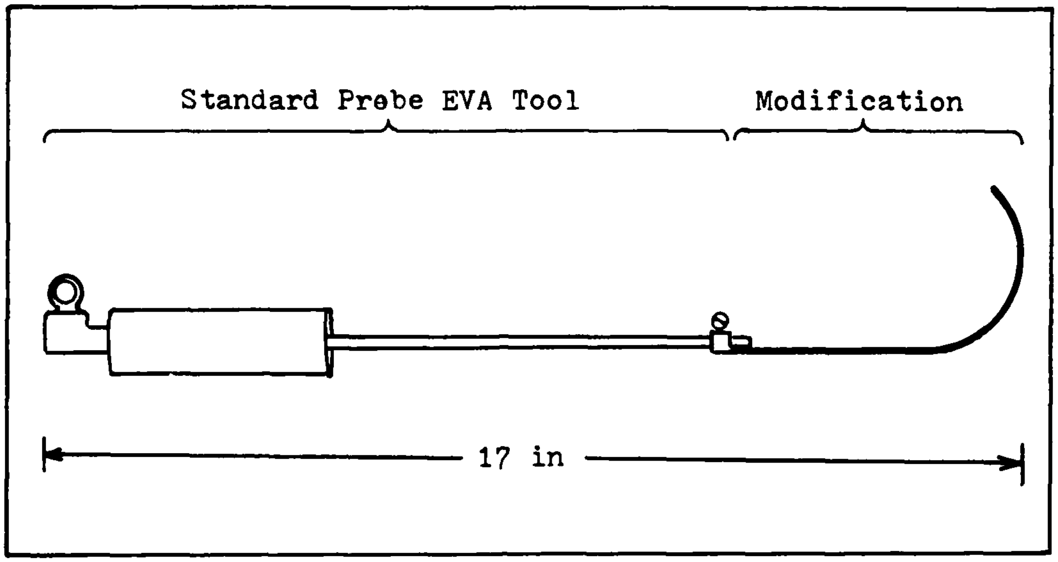


Figure 3.7. Hook Tool.

1. Lengthen the PRE carrying handles from their current six inches to twenty inches. This can be quickly done by attaching fourteen-inch extender loops to the present straps.

2. The aforementioned lengthening will not insure that the PRE carrying strap always projects into the arc of the MMU pilot's reach. Therefore, provide him with a hook tool, depicted in Figure 3.7, which extends his reach by allowing him to hook the carrying strap and to pull it to within his grasp. This tool could result from a simple and quick modification to a standard EVA tool, the Probe (see Appendix B). The modified probe would be carried in a tool caddy affixed to the Mini-Work Station.

With the above two modifications, the Ease of Use requirement is fully satisfied. All pilot-operated items are current or slightly modified EVA support equipment pieces; therefore, little or no additional crew training would be necessary prior to mission execution.

4. Stowage. This requirement is fully satisfied. Despite the major modifications, the proposed connection device can still be carried on the same bracket used to stow the original ACDs in the orbiter payload bay during Mission 51D. This was confirmed by attaching a modified ACD to a full-size engineering model of the carrying bracket. The resulting configuration is illustrated in Figure 3.8.

During Mission 51D, two carrying brackets were attached to the side wall of a payload bay pallet. The pallet was required on that mission to serve as a berthing platform for the two salvaged satellites; however, during a rescue mission the pallet would serve no such additional purpose. As the pallet is large, heavy, and takes long to install in the orbiter payload bay, it is recommended for the rescue mission that two modified ACDs and their carrying brackets be mounted on two Get-Away Special Beams, attached in the normal fashion on the payload bay sidewalls (34).

The Get-Away Special Beam is described and illustrated in Appendix B. It is a standard flight hardware item which was originally designed to serve as a mounting platform for Get-Away Special Experiment Cans. The beam can be mounted in thirty different locations around the periphery of the

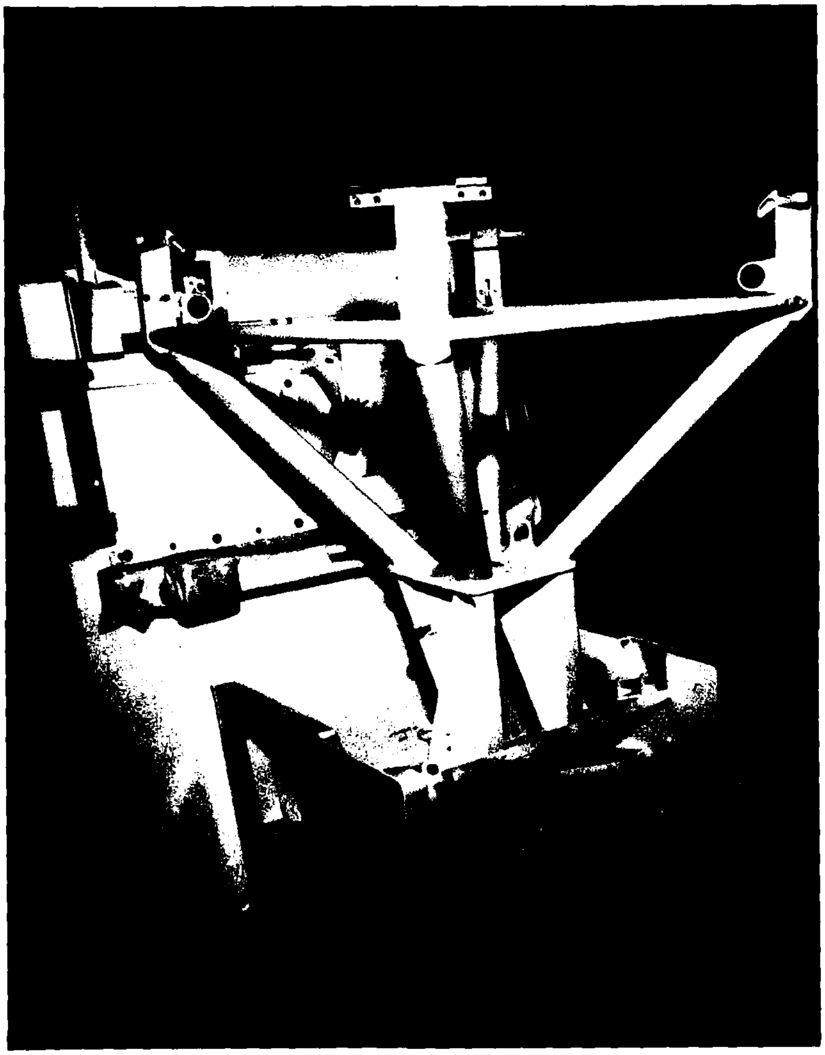


Figure 3.8. Modified ACD Attached to Unmodified Carrying Bracket

payload bay, and is capable of withstanding the loads and moments imposed by the attached modified ACD (20:B3-107). Mounting the ACD carrying brackets on the Get-Away Special Beams will require the drilling of several holes in each of the beams to match the already-existing mounting holes in the carrying brackets.

5. Critical Fits. This requirement is fully satisfied.

6. Quick Response. This requirement is fully satisfied. The modifications to the ACD took two man-hours, and it's estimated that modifications to two EVA Probe tools, twelve PRE carrying straps (six PREs), and two Get-Away Special Beams would total an additional 36-48 man-hours, provided the required materials were already on hand. Even if no modifications were performed in advance as a precautionary measure, a Johnson Space Center crisis action team could perform the work and have the equipment items on their way to Kennedy Space Center for installation in the rescue orbiter within half a day.

7. Safety. This requirement is fully satisfied. All hardware is flight-qualified. The two tethers and two PRE carrying straps provide redundant connection capability between the MMU and PRE, and the loads on both tethers and straps are only a fraction of their maximum rated strength.

8. Stability and Performance. The definitive answer to this requirement must await the results of the research explained in Chapter V; however, it can immediately be said

that the proposed IRV does not represent an optimum design. This is because the ACD was originally designed to satisfy the requirements of a completely different mission.

a. Minimum Mass. This requirement is not satisfied. The modified ACD weighs 36.41 pounds, while a MMU/PRE attachment device designed from scratch would weigh only 10-15 pounds (27). The excess mass of the modified ACD is attributable to the requirement for the original ACD to be able to withstand the loads induced if the orbiter's remote manipulator arm experienced a runaway condition with the MMU and Hughes 376 satellite attached (5).

b. Minimum Center of Mass Shift. This requirement is not satisfied. With the controller arms sized for the 50th percentile male astronaut (position "E"), the modified ACD positions the center of the attached PRE 4.74 feet away from the MMU's geometric center of thrust. A shorter attachment device specifically designed for this purpose could reduce this separation by about 18 inches.

c. Minimum Moments of Inertia. As requirements 8a. and 8b. were not achieved, it can be reasoned that such must also be the case with this requirement. The IRV's response to rotational commands can be expected to suffer because of higher than necessary moments of inertia.

d. Rigid Connection. This requirement is fully satisfied. Both the adjustable wrist tether and the Mini-Work Station tether are capable of maintaining enough tension on the PRE carrying strap so that the sphere is rigidly held against the modified ACD structure. Also, as previously mentioned, the modified ACD rigidly attaches to the MMU in the same manner as the unmodified ACD.

e. Plume Impingement. This requirement is adequately satisfied. The modified ACD positions the PRE so that only the four forward firing thrusters impinge on the sphere, and it holds the sphere just 1.25 inches above the center of thrust, so that the four jets impinge about equally, nearly preserving symmetry of thrust. However, as mentioned in paragraph 8a., the modified ACD is bulkier than necessary. It therefore presents a greater surface area for impingement than would an optimum MMU/PRE connection device.

Chapter Summary

This chapter has answered Research Question 1 by listing requirements for a suitable MMU/PRE attachment device, and proposing modifications to the Apogee Kick Motor Capture Device (ACD) and prototype PRE which produce an interim space rescue ferry vehicle. The modified ACD adequately satisfies all requirements with the possible exceptions of performance and stability. The next two chapters investigate performance and stability of the proposed IRV.

IV. Simulation Inputs

Chapter Overview

An existing MMU flight simulation program, Man-in-the-Loop Maneuvering Unit (MILMU), was utilized to simulate the flying qualities and performance of the proposed IRV. This chapter describes MILMU and explains the determination of the required inputs concerning the IRV's mass properties and plume impingement. The next chapter will explain the simulation runs and the analysis of the results.

MILMU

MILMU is an adaptation of NASA's Desk Top Flight Simulator, which has been used for several years by JSC's Mission Planning and Analysis Division to plan space shuttle flights. TRW's Systems Engineering and Applications Division modified the program so that it models the flying qualities and performance of the MMU (37). The program was validated by its acceptable performance during the planning for the Westar and Palapa B rescue mission (38:3).

The program allows the user to specify the mass properties, initial translational state vector (which describes the orbit and the beginning location on that orbit), and initial rotational state vector (which describes the beginning attitude and angular rates) of both the MMU and a nearby freeflying satellite. In addition, plume impingement effects information can be entered. The program's primary output is a near real time graphical presentation of the MMU pilot's view of space and the satellite.

Before simulation, MILMU uses the inputs concerning mass properties and plume impingement in a mechanics algorithm to develop a table of the ideal translational and rotational accelerations imparted to the MMU by each of the 24 thrusters. During simulation, the program uses a point-slope method to integrate the differential equations of motion of both the MMU and the satellite. At the end of each integration step, the new translational and rotational state vectors for the MMU and satellite are differenced and the satellite's relative position and attitude graphically portrayed on the screen.

Translational and rotational commands are generated either by the user (entered through the keyboard) or by MILMU's duplication of the MMU's automatic attitude hold control law. Just as in the actual MMU, MILMU interprets the commands by referencing the appropriate thruster select table and firing the designated jets. It then updates the translational and rotational state vectors to reflect the accelerations imposed by the thruster firings and uses these new state vectors in the next integration step.

MILMU automatically outputs a digital printout of the MMU and satellite initial and final state vectors. The final state vector printout also specifies the amount of propellant consumed during the simulation run. Upon request, MILMU draws a phase plane plot describing the MMU's control response (21).

To simplify the simulation, MILMU departs from the real-world case in two ways: it assumes that the MMU/payload combination is a rigid body, and it does not model the time delay introduced by the limb motion filter (explained in Chapter III). The rigid body assumption is valid for IRV simulation if the victim remains motionless inside the PRE and if he holds the portable oxygen system stationary. The fit tests described in Chapter III confirmed that all other IRV component attachments are very nearly rigid, at least under the light acceleration loads imposed by the MMU's thrusters. The lack of limb motion filter modeling causes the MILMU-produced phase plane plots to be slightly "tighter" about the axes origin than actually experienced, but not enough to negate the usefulness of the results (36).

Using MILMU to simulate the stability and performance of the proposed IRV required the determination of inputs concerning mass properties and plume impingement. The remainder of this chapter details the work done to arrive at these inputs.

Mass Properties

The end products of this section are the weight of the IRV, the location of its center of mass, and the moments and products of inertia which describe how its mass is distributed about the center of mass. This information is referred to as the IRV mass properties. The reader is reminded that weight (units = pounds) is not a direct measure of mass, but rather of the force imposed on a body by gravity. Nevertheless, MILMU uses weight as its measure of component mass by assuming that all weight measurements were taken at the surface of the earth, where acceleration due to gravity is 32.2 ft/sec^2. MILMU converts the inputted weight into mass (units = slugs) by dividing by 32.2 ft/sec^2.

The moments of inertia are defined as:

$$Ixx = \int_m (y^2 + z^2)\,dm$$

$$Iyy = \int_m (x^2 + z^2)\,dm$$

$$Izz = \int_m (x^2 + y^2)\,dm$$

and the products of inertia are defined as:

$$Pxy = +\int_m xy\ dm$$

$$Pxz = +\int_m xz\ dm$$

$$Pyz = +\int_m yz\ dm \quad (3:86) \qquad (1)$$

where x,y, and z are the coordinates of incremental mass dm. The moments and products of inertia can conveniently be represented in an inertia matrix, the entries of which are:

$$\begin{bmatrix} Ixx & -Pxy & -Pxz \\ -Pxy & Iyy & -Pyz \\ -Pxz & -Pyz & Izz \end{bmatrix} \quad (35:8) \qquad (2)$$

The following methodology was employed to arrive at the desired mass properties information:

1. The vehicle was segmented into five components and mass properties information collected or, where necessary, generated for each part.

2. The collected mass properties information was manipulated to reflect the orientations and positions of the components in the IRV.

3. The weights of the five components were summed to arrive at the weight of the complete IRV.

4. The center of mass for the complete IRV was determined.

5. The Parallel Axes Theorem was employed to obtain the inertia matrix describing each component's mass distribution about the IRV's center of mass.

6. The component inertia matrices were summed to yield one inertia matrix explaining the distribution of the complete vehicle's mass about its center of mass.

Coordinate Systems. The IRV and its important dimensions are depicted in Figure 4.1. Also shown is the MMU body coordinate system. Its origin is at the geometric center of the MMU's twenty-four thrusters; the X-axis points forward, the Y-axis out the right side, and the Z-axis points down. The axes are fixed with respect to the MMU (10:6).

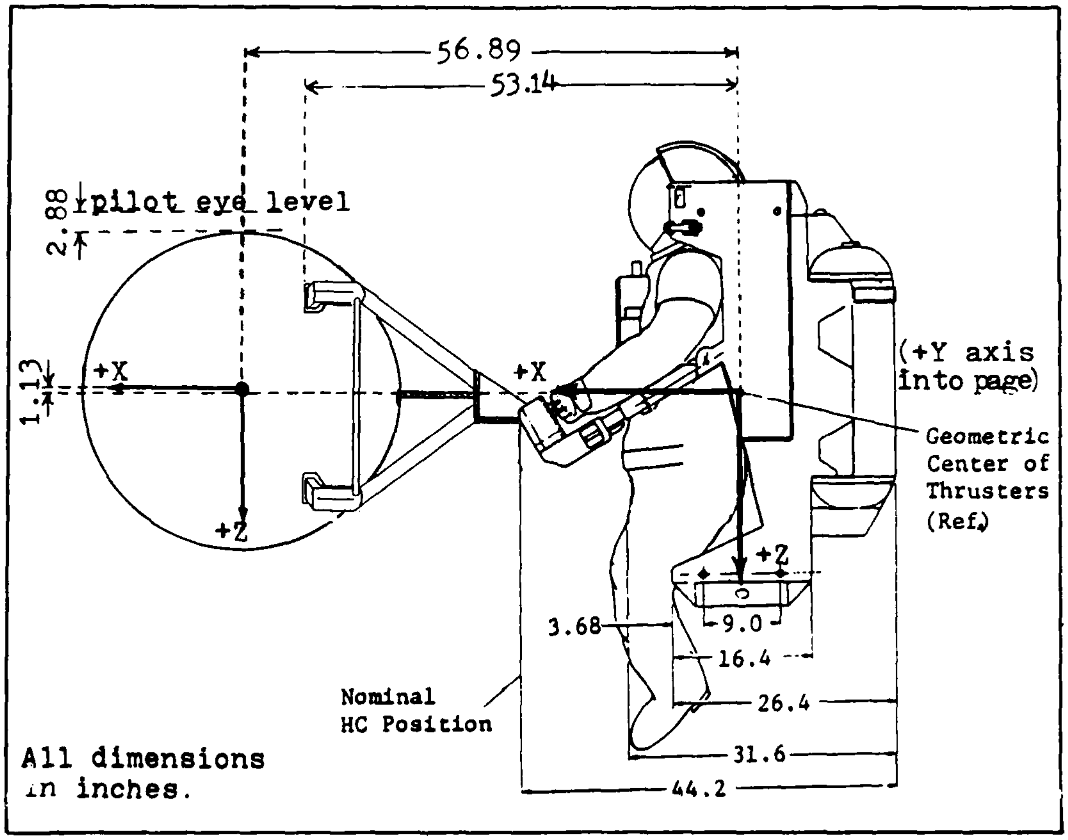


Figure 4.1 IRV Dimensions and Coordinate Systems (18:2.4-154)

This axis system is used by MILMU as the "master" coordinate system--the one in which the location of all component mass centers are expressed. Also, MILMU requires that all component inertia matrices be defined about an axes system originating at the component mass center with axes parallel to the MMU body frame. Also shown in Figure 4.1 is a coordinate frame originating at the geometric center of the PRE with axes parallel to the MMU body frame. This coordinate system was used during some intermediate mass properties calculations.

Finally, each component also has its own coordinate system originating at its center of mass with axes oriented such that the component inertia matrix simplifies to:

$$I = \begin{bmatrix} Ixx & 0 & 0 \\ 0 & Iyy & 0 \\ 0 & 0 & Izz \end{bmatrix} \quad (35:12) \qquad (3)$$

Such an axes frame is called the principal coordinate frame for that component. Much of the mass properties raw data was defined about such axes systems. Generally, the axes were oriented differently for each component, and not aligned with the MMU body coordinate frame.

One comment is necessary to avoid confusion. Even though the +Z axis of the MMU body coordinate system points down in Figure 4.1, the terms "up" and "down," or "above" and "below," will be used as would be by the MMU pilot. Hence "down," for example, means in the +Z direction.

Component Mass Properties Data. For the purposes of determining the mass properties of the IRV, the vehicle was broken into the following five components and mass properties information obtained for each.

MMU and Pilot. The mass properties of the solo MMU, with pilot attached, have been calculated by the Martin Marietta Corporation and validated by actual flight experience. The collected information is for a MMU with full propellant tanks, piloted by a 50th percentile male astronaut, hand controller arms adjusted to the "E" (average)

Table I

MMU/Pilot Mass Properties (27)

Weight (lbs)	Center of Mass in MMU Body Coordinate System (inches)	Inertia Matrix About MMU Center of Mass ($slug-ft^2$)*
794.50	X = 0.55 Y = -0.05 Z = -2.54	Ixx = 37.2100 Iyy = 40.0800 Izz = 26.1200 Pxy = .0600 Pxz = 2.5900 Pyz = .0100

*About an axes system parallel to the MMU body coordinate frame.

length, and with the helmet television camera, helmet lights, and Mini-Work station attached. Table I lists the mass properties.

Modified ACD. The Lockheed Engineering and Management Services Co., of Houston TX, was contracted by NASA to determine the mass properties of the modified ACD. They used a computer program and data base originally produced to determine the mass properties of the unmodified ACD in preparation for the Westar and Palapa B satellite rescues on Mission 51D. The program and data base were validated during development by comparing its output to experimentally determined mass properties, and found to be accurate (30:iii). The mass properties of the modified ACD were

Table II

Modified Capture Device Mass Properties (31)

Weight (lbs)	Center of Mass in MMU Body Coordinate System (inches)	Inertia Matrix About Capture Device Center of Mass ($slug\text{-}ft^2$)*
36.41	X = 41.13 Y = 0.15 Z = - 1.05	Ixx = 1.9897 Iyy = 1.9630 Izz = 2.3732 Pxy = -0.0184 Pxz = 0.0459 Pyz = -0.0231

*About an axes system parallel to the MMU body coordinate frame.

obtained by deleting from the data base the part numbers of the removed components, and having the program recompute the mass properties of the remaining structure. The results are listed in Table II.

PRE. No documentation on PRE mass properties could be found; therefore, experimental and analytical techniques were used to generate the required information.

Weight. A prototype PRE was weighed by personnel of the Crew Systems Division, Johnson Space Center, Houston TX. It weighed 11.5 pounds.

Inertia Matrix. The PRE closely approximates a 34-inch diameter, homogeneous, hollow sphere. The small viewing window, two carrying straps, and umbilical interfaces slightly disturb this approximation, but not enough to make it invalid. Noting that the inside and outside radii of the PRE sphere are approximately equal (i.e., the PRE's skin is thin compared to the radius of the sphere), the equations for the principal moments of inertia about a spherical shell's center of mass are:

$$Ixx = Iyy = Izz = (2/3)\ m\ r^2 \quad (15:472) \tag{4}$$

and, by definition

$$Pxy = Pxz = Pyz = 0 \tag{5}$$

where m is mass and r is the radius of the sphere. Because a sphere is symmetric about any axes system originating at its center, the principal axes can be oriented in any convenient direction. Therefore, as shown in Figure 4.2, they were aligned parallel with the MMU body coordinate system to lessen subsequent computational difficulty.

Applying Eqns (4) and (5) to the PRE:

$$Ixx = Iyy = Izz = (2/3)\ (11.5\ lbs/(32.2\ ft/sec^2))\ (1.4167\ ft)^2$$

$$= .4778\ slug\text{-}ft^2 \tag{6}$$

and

$$Pxy = Pxz = Pyz = 0 \tag{7}$$

PRE mass properties are summarized in Table III.

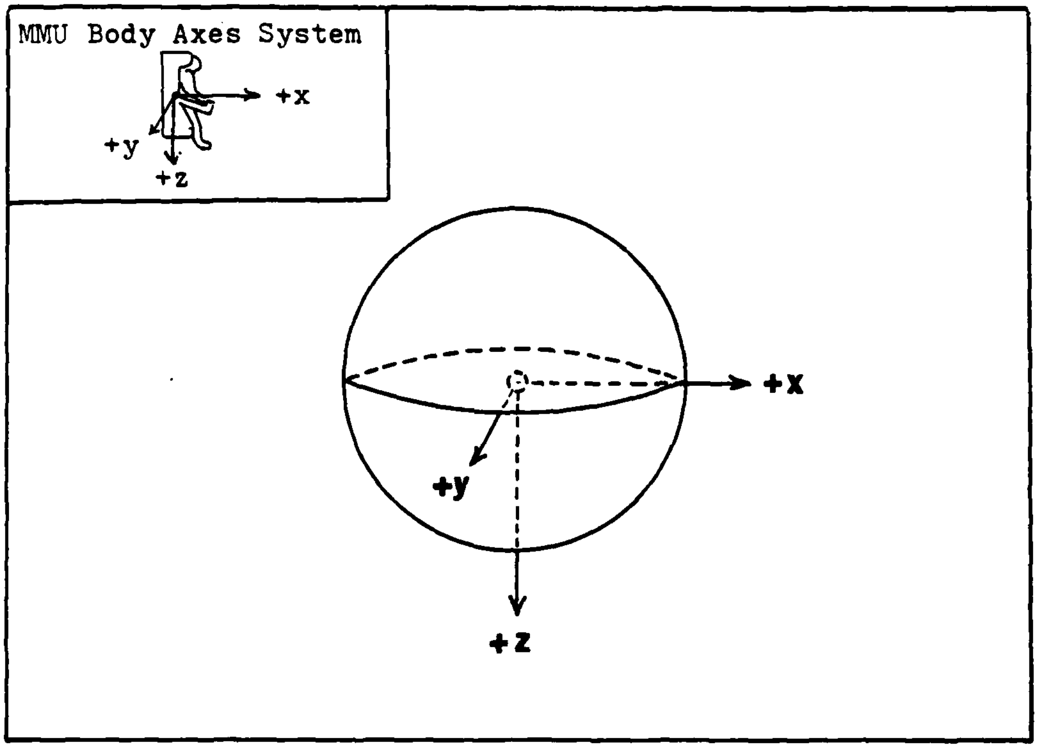


Figure 4.2. PRE Principal Axes

Table III

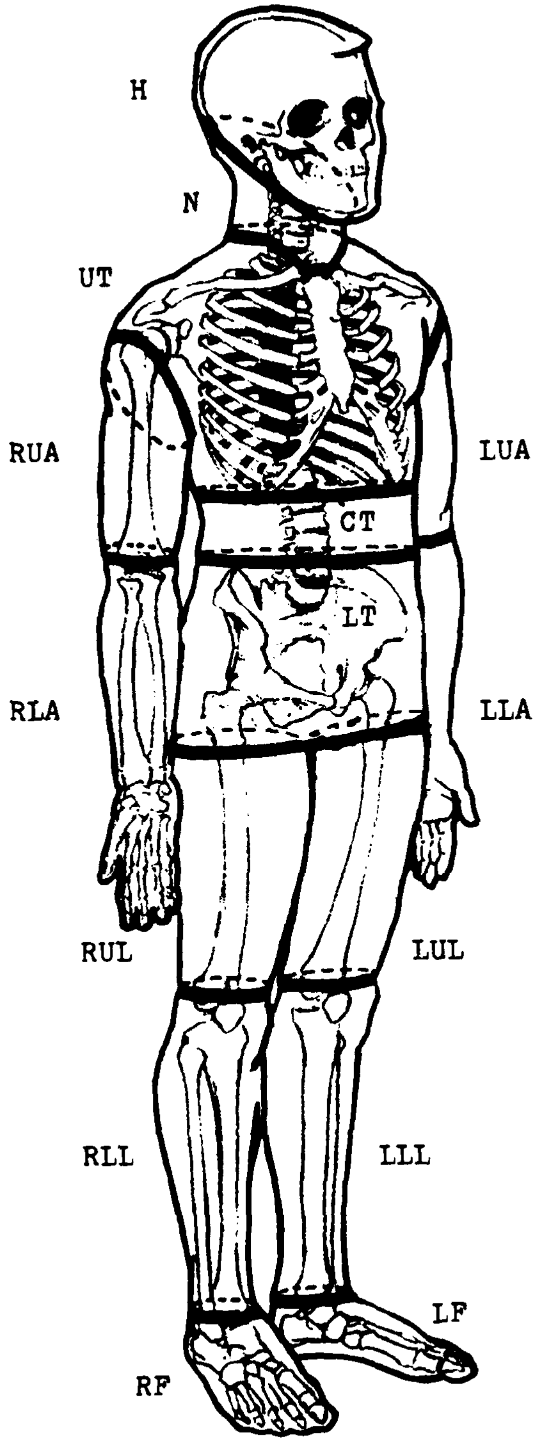
PRE Mass Properties

Weight (lbs)	Center of Mass in MMU Body Coordinate System (inches)	Inertia Matrix About PRE Center of Mass ($slug-ft^2$)*
11.5	X = 56.89	Ixx = 0.4778
	Y = 0.00	Iyy = 0.4778
	Z = - 1.125	Izz = 0.4778
		Pxy = 0.0000
		Pxz = 0.0000
		Pyz = 0.0000

*About an axes system parallel to the MMU body coordinate frame.

Victim. The PRE houses a victim in a squatting position. Although the victim position within the PRE is fixed by the waist restraint belt, some manipulation of IRV mass properties was possible because the PRE can be attached to the modified ACD by either of its two carrying straps and at any roll angle about an axis parallel to the MMU's X axis. The choice of orientations was settled by referring to criterion 8a, in Chap III, which required that the shift of the IRV's mass center away from the MMU geometric center of thrusters be minimized. This was achieved by orienting the victim with his head down and his back toward the MMU. However, the mass properties data to follow was collected with respect to the head-up orientation. This inconsistency will be remedied following disclosure of the remaining mass properties information.

The victim defied mass properties modeling using one or two simple geometric shapes; therefore, the Air Force Aerospace Medical Research Laboratory's (AFAMRL) Articulated Total Body Model computer program was used to produce the required information. The Articulated Total Body Model was developed jointly by AFAMRL and the Department of Transportation and has successfully been used to model bioengineering problems ranging from automobile crashes to aircraft ejections. The data base includes the mass properties of the fifteen major body segments of the fiftieth percentile male Air Force pilot. The segmentation scheme is depicted in Figure 4.3.



Key

H....Head
N....Neck
UT...Upper Torso
CT...Center Torso
LT...Lower Torso
RUA..Right Upper Arm
RLA..Right Lower Arm
RUL..Right Upper Leg
RLL..Right Lower Leg
RF...Right Foot
LUA..Left Upper Arm
LLA..Left Lower Arm
LUL..Left Upper Leg
LLL..Left Lower Leg
LF...Left Foot

Figure 4.3. Articulated Total Body Model Segmentation Scheme (14:12)

A subroutine allows the user to designate the positions and orientations of these fifteen body segments with respect to a user-defined coordinate system, and the resulting body position is presented on a graphics terminal. The program then computes the center of mass of the entire body with respect to the defined coordinate system by the equation:

$$\bar{r}_{\text{mass center}} = (1/m) \sum m_i \bar{r}_i \quad (3:49) \qquad (8)$$

where m_i is the mass of the i^{th} component, $\bar{r}_i$ is the position vector of the i^{th} component, and $m = \Sigma m_i$. The program also outputs a list of the weights, principal moments of inertia, and Euler angles (3-2-1 rotation order) from the user-defined coordinate system to the principal axes for each of the fifteen body parts.

The Articulated Total Body Model was used to curve the spine and fold the arms and legs of the body model until all body segments fell within the 34-inch diameter sphere. An iterative process taking advantage of the graphics capability of the program was used to insure that a natural body position was designated. The victim was oriented with his head up (with respect to the MMU pilot) and with his back to the MMU. The resulting orientation is shown in Figure 4.4. The program printouts giving the mass properties and orientation angles of the body segments, and the location of the center of mass of the entire body, are reproduced in Table IV. Note that the reference system used for this program was centered at the geometric center of the PRE, with axes

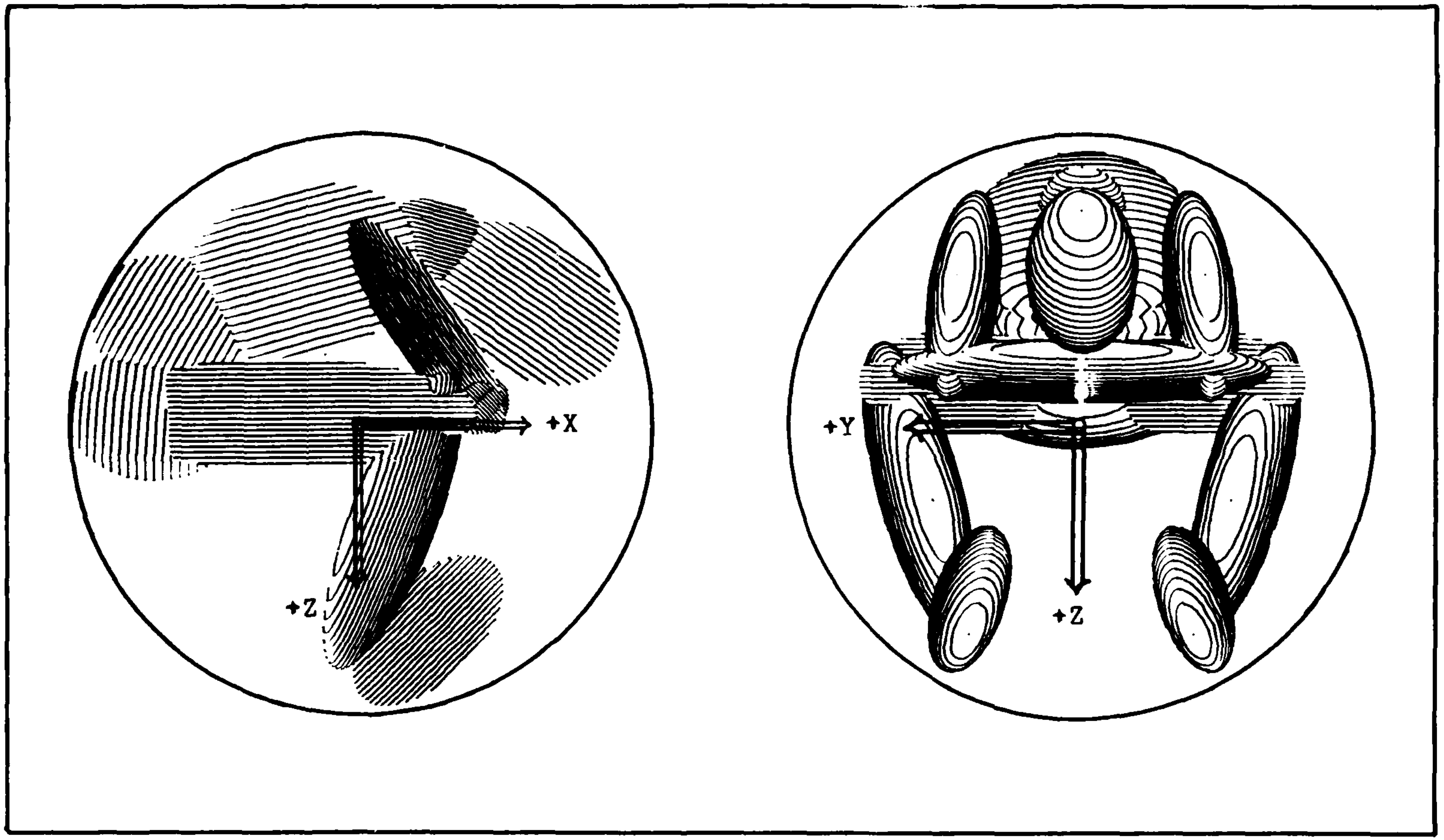


Figure 4.4. Victim Head-Up Orientation in PRE

Table IV

Victim Mass Properties Information

SEGMENT		(INERTIAL) ANGULAR ROTATION (DEG) YAW	PITCH	ROLL
1	LT	0.0000	-5.0000	0.0000
2	CT	0.0000	-30.0000	0.0000
3	UT	0.0000	-75.0000	0.0000
4	N	0.0000	-105.0000	0.0000
5	H	0.0000	-125.0000	0.0000
6	RUL	25.0000	90.0000	0.0000
7	RLL	-20.0000	-15.0000	20.0000
8	RF	0.0000	135.0000	15.0000
9	LUL	-25.0000	90.0000	0.0000
10	LLL	20.0000	-15.0000	-20.0000
11	LF	0.0000	135.0000	-15.0000
12	RUA	10.0000	35.0000	0.0000
13	RLA	180.0000	-45.0000	-90.0000
14	LUA	-10.0000	35.0000	0.0000
15	LLA	180.0000	-45.0000	90.0000

SEGMENT		(INERTIAL) LINEAR POSITION (IN.) X	Y	Z
1	LT	-11.5000	0.0000	-2.0000
2	CT	-10.4167	0.0000	-7.0122
3	UT	-3.7785	0.0000	-9.9109
4	N	4.2237	0.0000	-11.7252
5	H	9.4997	0.0000	-8.3016
6	RUL	-4.1920	6.6621	-2.1395
7	RLL	1.9367	9.0266	3.7786
8	RF	2.9317	6.5636	10.5331
9	LUL	-4.1920	-6.6621	-2.1395
10	LLL	1.9367	-9.0266	3.7786
11	LF	2.9317	-6.5636	10.5331
12	RUA	3.8060	6.5430	-6.9937
13	RLA	6.6981	-0.7121	-2.7996
14	LUA	3.8060	-6.5430	-6.9937
15	LLA	6.6981	0.7121	-2.7996

Table IV (cont)

SEGMENT I	SYM	PLOT	WEIGHT (LB.)	PRINCIPAL MOMENTS OF INERTIA (LB.-SEC.**2- IN.) X	Y	Z
1	LT	1	28.834	1.1859	0.7297	1.2733
2	CT	2	10.463	0.2795	0.1544	0.3914
3	UT	3	43.946	2.4619	1.9614	1.5497
4	N	4	2.940	0.0229	0.0229	0.0176
5	H	5	11.425	0.2470	0.2517	0.1464
6	RUL	6	16.320	1.3955	1.3955	0.1770
7	RLL	7	8.155	0.3636	0.3635	0.0459
8	RF	8	1.734	0.0329	0.0313	0.0042
9	LUL	9	16.320	1.3955	1.3955	0.1770
10	LLL	A	8.155	0.3636	0.3636	0.0459
11	LF	B	1.734	0.0329	0.0315	0.0042
12	RUA	C	4.613	0.1290	0.1290	0.0186
13	RLA	D	5.065	0.2567	0.2563	0.0163
14	LUA	E	4.613	0.1290	0.1290	0.0186
15	LLA	F	5.065	0.2567	0.2563	0.0163

CENTER OF GRAVITY
(IN.)

X	Y	Z
-2.849	0.000	-4.420

parallel to the MMU body coordinate frame.

The fifteen body segment principal inertia matrices in Table IV are defined about individual principal axes systems which generally differ in orientation from each other and from the MMU body coordinate system. Therefore, inertia matrices were obtained describing the mass distribution of each segment about an axes system originating at the segment's mass center but oriented parallel to MMU body coordinate system. This was done using:

$$I^{a} = (R^{a\ to\ b})^{-1}\ I^{b}\ R^{a\ to\ b} \qquad (35:13) \qquad (9)$$

where I^{a} is the inertia matrix about orthogonal axes with the desired orientation, I^{b} is the inertia matrix about the given axis system, and $R^{a\ to\ b}$ is the transformation matrix representing the rotation from the desired to the known orientation. Applying Eqn (9) to the present situation:

$$I^{body\ segment\ expressed\ in\ mmu\ axes\ system} = (R^{from\ mmu\ to\ body\ principal\ axis\ system})^{-1}\ I^{body\ segment\ expressed\ in\ principal\ axis\ system}\ R^{from\ mmu\ to\ body\ principal\ axis\ system} \qquad (10)$$

A utility subroutine within the Articulated Total Body Model program generated the rotation matrix required in Eqn (10) for each of the fifteen different body segments, using as input the orientation angles listed in Table IV. The subroutine's accuracy was checked by manually computing several of the rotation matrices and confirming identical results. Eqn (10) was then implemented on AFIT's UNIX system using a matrix multiplication algorithm, and applied to each of the fifteen body segment principal inertia matrices. The rotation matrix and resulting inertia matrix after applying Eqn (10) are shown for each body segment in Table V.

The Parallel Axes Theorem was used to combine the inertia matrices of the fifteen body segments to obtain the inertia matrix of the entire victim defined about a coordinate system originating at the victim's center of the mass and parallel to the MMU body frame. The Parallel Axes Theorem states that, given an inertia matrix defined about an orthogonal coordinate system originating at the center of mass of a rigid body, an inertia matrix defined about an offset but parallel coordinate system can be found according to:

$$I2 = Ic + m \begin{bmatrix} b^2+c^2 & -ab & -ac \\ -ab & c^2+a^2 & -bc \\ -ac & -bc & a^2+b^2 \end{bmatrix} \quad (3:89) \qquad (11)$$

where I_2 is the desired inertia matrix; I_c is the given inertia matrix defined about a parallel axis system located

Table V

Body Segment Inertia Matrix Rotations into Alignment with MMU Body Coordinate System

Segment	Rotation Angles (deg) and Rotation Matrix			Resulting Inertia Matrix* (slug-in^2)		
	Yaw	Pitch	Roll			
LT	0.0000	-5.0000	0.0000	1.190	0.000	-0.007
				0.000	0.730	0.000
	0.99619	0.00000	0.03716	-0.007	0.000	1.272
	0.00000	1.00000	0.00000			
	-0.08716	0.00000	0.99619			
CT	0.0000	-30.0000	0.0000	0.307	0.000	-0.480
				0.000	0.154	0.000
	0.86603	0.00000	0.50000	-0.048	0.000	0.363
	0.00000	1.00000	0.00000			
	-0.50000	0.00000	0.86603			
UT	0.0000	-75.0000	0.0000	1.704	0.000	0.203
				0.000	1.981	0.000
	0.25882	0.00000	0.96593	0.203	0.000	2.408
	0.00000	1.00000	0.00000			
	-0.96593	0.00000	0.25882			

*Defined about an axis system originating at the segment center of mass and with axes parallel to MMU body coordinate system.

Table V (cont)

Segment	Rotation Angles (deg) and Rotation Matrix Yaw	Pitch	Roll	Resulting Inertia Matrix (slug-in^2)		
N	0.0000	-105.0000	0.0000	0.018	0.000	-0.001
				0.000	0.023	0.000
	-0.25882	0.00000	0.96593	-0.001	0.000	0.023
	0.00000	1.00000	0.00000			
	-0.96593	0.00000	-0.25882			
H	0.0000	-125.0000	0.0000	0.179	0.000	-0.047
				0.000	0.282	0.000
	-0.57358	0.00000	0.81915	-0.047	0.000	0.214
	0.00000	1.00000	0.00000			
	-0.81915	0.00000	-0.57358			
RUL	25.0000	90.0000	0.0000	0.395	-0.467	0.000
				-0.467	1.178	0.000
	0.00000	0.00000	-1.00000	0.000	0.000	1.395
	-0.42262	0.90631	0.00000			
	0.90631	0.42262	0.00000			
RLL	-20.0000	-15.0000	20.0000	0.326	-0.026	0.100
				-0.026	0.346	0.069
	0.90767	-0.33037	0.25882	0.100	0.069	0.102
	0.23821	0.91330	0.33037			
	-0.34552	-0.23821	0.90767			

Table V (cont)

Segment	Rotation Angles (deg) and Rotation Matrix			Resulting Inertia Matrix (slug-in^2)		
	Yaw	Pitch	Roll			
RF	0.0000	135.0000	15.0000			
				0.019	0.005	0.013
	-0.70711	0.00000	-0.70711	0.005	0.030	-0.005
	0.18301	0.96593	-0.18301	0.013	-0.005	0.019
	0.68301	-0.25882	-0.68301			
LUL	-25.0000	90.0000	0.0000			
				0.395	0.467	0.000
	0.00000	0.00000	-1.00000	0.467	1.178	0.000
	0.42262	0.90631	0.00000	0.000	0.000	1.395
	0.90631	-0.42262	0.00000			
LLL	20.0000	-15.0000	-20.0000			
				0.326	0.026	0.100
	0.90767	0.33037	0.25882	0.026	0.346	-0.069
	-0.23821	0.91330	-0.33037	0.100	-0.069	0.102
	-0.34552	0.23821	0.90767			
LF	0.0000	135.0000	-15.0000			
				0.019	-0.005	0.013
	-0.70711	0.00000	-0.70711	-0.005	0.030	0.005
	-0.18301	0.96593	0.18301	0.013	0.005	0.019
	0.68301	0.25882	-0.68301			

Table V (cont)

Segment	Rotation Angles (deg) and Rotation Matrix			Resulting Inertia Matrix (slug-in²)		
	Yaw	Pitch	Roll			
RUA	10.0000	35.0000	0.0000	0.094	-0.006	-0.051
	0.80671	0.14224	-0.57358	-0.006	0.128	-0.009
	-0.17365	0.98431	0.00000	-0.051	-0.009	0.055
	0.56486	0.09960	0.81915			
RLA	-180.0000	-45.0000	-90.0000	0.256	0.000	0.000
	-0.70711	0.00000	0.70711	0.000	0.016	0.000
	-0.70711	0.00000	-0.70711	0.000	0.000	0.256
	0.00000	-1.00000	0.00000			
LUA	-10.0000	35.0000	0.0000	0.094	0.006	-0.051
	0.80671	-0.14224	-0.57358	0.006	0.128	0.009
	0.17365	0.98481	0.00000	-0.051	0.009	0.055
	0.56486	-0.09960	0.81915			
LLA	180.0000	-45.0000	90.0000	0.256	0.000	0.000
	-0.70711	0.00000	0.70711	0.000	0.016	0.000
	0.70711	0.00000	0.70711	0.000	0.000	0.256
	0.00000	1.00000	0.00000			

at the segment's center of mass; and a, b, and c are the x, y, and z distances, respectively, from the new coordinate system origin to the center of mass of the segment.

Eqn (11) was applied to obtain inertia matrices describing the mass distribution of the fifteen body segments about the victim center of mass. The calculations were accomplished by a mass properties subroutine within MILMU, using as input the inertia matrices listed in Table V (converted into units of slug-ft^2) and the weights and offset distances from the PRE geometric center in Table IV. The results were checked manually to confirm accuracy. The resulting matrices were then summed to obtain an inertia matrix defining the entire victim's mass distribution. The mass properties of the victim are summarized in Table VI.

Portable Oxygen System. As explained in Chapter II, the victim carries with him a portable oxygen system containing a one-hour supply of oxygen. This system is in the preliminary design phase and specific mass properties information was unavailable; therefore, this component was modeled as a 25-pound hollow cylinder eighteen inches long and six inches in diameter, with flat circular end disks. It was assumed that the head-up victim would position the bottle between his legs at a pitch angle of -52.5 degrees from the MMU body frame. Figure 4.5 depicts the oxygen system parts, their principal axes, and their orientation with respect to the MMU body frame.

Table VI

Victim Mass Properties--Head Up Orientation

Weight (lbs)	Center of Mass in PRE Frame System (inches)[1]	Inertia Matrix About Victim Center of Mass ($slug\text{-}ft^2$)[2]
173.54	X = -2.85	Ixx = 1.6807
	Y = 0.00	Iyy = 2.3576
	Z = -4.20	Izz = 2.2339
		Pxy = 0.0000
		Pxz = -0.0077
		Pyz = 0.0000

[1]Axes system originating at the PRE center with axes parallel to the MMU body coordinate frame.

[2]About an axes system originating at the victim's center of mass and with axes parallel to the MMU body coordinate frame.

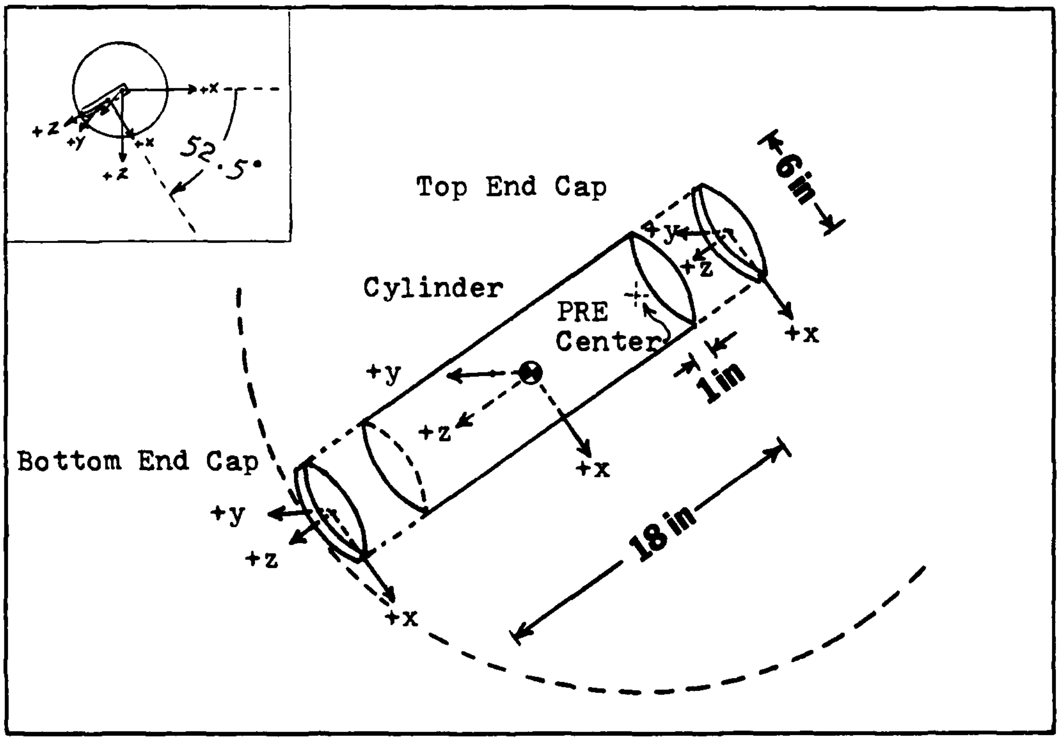


Figure 4.5. Portable Oxygen System Components and Principal Axes

Assuming the inside and outside radii are approximately equal (i.e., the walls of the bottle are thin compared to its radius) the equations for the principal moments of inertia of a hollow cylinder are:

$$Ixx = Iyy = (1/2)\ m\ r^2 + (1/12)\ m\ l^2$$

and

$$Izz = m\ r^2 \quad (15:471) \tag{12}$$

and the equations for the principal moments of inertia of a thin circular disk are:

$$Ixx = Iyy = (1/4)\ m\ r^2$$

and

$$Izz = (1/2)\ m\ r^2 \quad (14:498) \tag{13}$$

where m is mass, l is length, and r is the radius of the cylinder. Applying Eqn (12) to the oxygen bottle cylinder:

$$Ixx = Iyy = (1/2)\ (21.450\ lbs/(32.2\ ft/sec^2))\ (.25\ ft)^2$$

$$+ (1/12)\ (21.450\ lbs/(32.2\ ft/sec^2))\ (1.5\ ft)^2$$

$$= .1457\ slug\text{-}ft^2$$

and

$$Izz = (21.450\ lbs/(32.2\ ft/sec^2))\ (.25\ ft)^2$$

$$= .0416\ slug\text{-}ft^2 \tag{14}$$

Applying Eqn (13) to the end disks:

$$I_{xx} = I_{yy} = (1/4)\ (1.775\ \text{lbs}/(32.2\ \text{ft/sec}^2))\ (.25\ \text{ft})^2$$

$$= .0009\ \text{slug-ft}^2$$

and

$$I_{zz} = (1/2)\ (1.775\ \text{lbs}/(32.2\ \text{ft/sec}))\ (.25\ \text{ft})^2$$

$$= .0017\ \text{slug-ft}^2 \qquad (15)$$

In Eqns (14) and (15), mass was attributed to the cylinder and end caps in proportion to the ratio of their respective areas to the total area of the portable oxygen system.

Just as with the victim body segments, Eqn (10) was applied to transform the three oxygen system component inertia matrices from their principal axes systems to coordinate systems parallel to the MMU body coordinate system. Table VII presents the results of these calculations. Eqn (11) was then applied to translate the inertia matrices to the center of mass of the portable oxygen system, and the resulting matrices summed to obtain the complete oxygen system's mass properties, which are summarized in Table VIII.

Mass Properties Correction. As already noted, the mass properties information for the victim and portable oxygen system was collected for the head-up victim orientation, but the desired victim orientation is head down. Before consolidating the mass properties information for the IRV, this inconsistency was corrected by combining the PRE, victim, and portable oxygen system into a single mass entity which

Table VII

Oxygen System Component Inertia Matrix Rotations into Alignment with MMU Body Coordinate System

Segment	Rotation Angles (deg) and Rotation Matrix: Yaw	Pitch	Roll	Resulting Inertia Matrix (slug-in)		
Cylinder	0.00	-52.50	0.00			
	.609	.000	.793	11.5498	0.0000	7.2387
	.000	1.000	.000	0.0000	20.9836	0.0000
	-.793	.000	.609	7.2387	0.0000	15.4289
End Caps	same as cylinder			0.2021	0.0000	-0.0600
				0.0000	0.1240	0.0000
				-0.0600	0.0000	0.1700

Table VIII

Portable Oxygen System Mass Properties
Head Up Orientation

Weight (lbs)	Center of Mass in PRE Frame (inches)[1]	Inertia Matrix About Oxygen System Center of Mass ($slug\text{-}in^2$)[2]
25.00	X = -6.35 Y = 0.00 Z = 4.87	Ixx = 0.1060 Iyy = 0.2095 Izz = 0.1486 Pxy = 0.0000 Pxz = -0.0794 Pyz = 0.0000

[1]An axes system originating at the PRE center and with axes parallel to the MMU body coordinate frame.

[2]About an axes system originating at the victim's center of mass and with axes parallel to the MMU body coordinate frame.

was then rotated 180 degrees to the desired orientation.

First, the center of mass of the PRE, head-up victim, and portable oxygen system with respect to the center of the PRE was determined by applying Eqn (8):

$$\bar{r}_{head\ up} = (1/210.038\ lbs)[(11.50\ lbs)(0.0i + 0.0j + 0.0k) + (173.538\ lbs)(-2.85i + 0j - 4.42k) + (25.00\ lbs)(-6.35i + 0j + 4.87k)] = -3.11i + 0j - 3.07k \text{ inches} \quad (16)$$

Table IX

Mass Properties--Combined PRE/Victim/Oxygen Bottle System

(Victim Oriented Head Up)

Weight (lbs)	Center of Mass in PRE Frame (inches)[1]	Inertia Matrix About System Center of Mass ($slug\text{-}ft^2$)[2]
210.04	X = -3.11 Y = 0.00 Z = -3.07	Ixx = 2.6965 Iyy = 3.5600 Izz = 2.9434 Pxy = 0.0000 Pxz = -0.2153 Pyz = 0.0000

[1]An axes system originating at the PRE center and with axes parallel to the MMU body coordinate frame.

[2]About an axes system originating at the combined system's center of mass and with axes parallel to the MMU body coordinate frame.

Next, the MILMU mass properties subroutine was used to apply Eqn (11) to translate the head-up inertia matrices for the PRE, victim, and oxygen system to the head-up center of mass. Summing the matrices yielded the total inertia matrix for this combination, the mass properties of which are summarized in Table IX.

It was determined by inspection that rotating the PRE and its contents 180 degrees about the X-axis resulted in the system mass center moving to -3.11i + 0j + 3.07k inches (relative to the PRE frame). Eqn (9) was then applied to

Table X

Mass Properties--Combined PRE/Victim/Oxygen Bottle System

(Victim Oriented Head Down)

Weight (lbs)	Center of Mass in PRE Frame (inches)[1]	Inertia Matrix About System Center of Mass (slug-in^2)[2]
210.04	X = -3.11	Ixx = 2.6965
	Y = 0.00	Iyy = 3.5600
	Z = 3.07	Izz = 2.9434
		Pxy = 0.0000
		Pxz = 0.2153
		Pyz = 0.0000

[1] An axes system originating at the PRE center and with axes parallel to the MMU body coordinate frame.

[2] About an axes system originating at the combined system's center of mass and with axes parallel to the MMU body coordinate frame.

rotate the inertia matrix for the PRE/Head-Up Victim/Oxygen Bottle system to obtain the inertia matrix for the PRE/Head-Down Victim/Oxygen Bottle system, the inertia properties of which are summarized in Table X.

Mass Properties Consolidation. The mass properties of the MMU/Pilot, modified ACD, and PRE/Head-Down Victim/Oxygen System were consolidated into one IRV mass entity as follows.

Weight. The IRV's weight was found by summing the weights of its components:

$$W_{IRV} = 794.50 \text{ lbs} + 36.41 \text{ lbs} + 210.04 \text{ lbs}$$
$$= 1040.95 \text{ lbs} \qquad (17)$$

Mass Center Location. The PRE/Head-Down Victim/ Oxygen Bottle System mass center location was transformed into the MMU body coordinate system, then Eqn (8) was applied to determine the mass center of the entire IRV:

$$\bar{r}_{IRV} = (1/1040.95 \text{ lbs})[(794.50 \text{ lbs})(.55i - .05j - 2.54k)$$
$$+ (36.41 \text{ lbs})(41.130i + .150j - 1.05k)$$
$$+ (210.04 \text{ lbs})\ (53.78i + 0j + 1.95k)]$$
$$= 12.71i - .03j - 1.58k \text{ inches} \qquad (18)$$

Inertia Matrix. The MILMU mass properties subroutine was used to apply Eqn (11) to translate the inertia matrices for the MMU/Pilot, modified ACD, and PRE/Head-Down Victim/Oxygen System to the IRV's mass center. Summing the matrices yielded the total inertia matrix for the IRV, the mass properties of which are summarized in Table XI. This information was used by MILMU simulate the response of the IRV to MMU thruster firings.

Table XI

IRV Mass Properties

Weight (lbs)	Center of Mass in MMU Body Coordinate System (inches)	Inertia Matrix About IRV Center of Mass (slug-ft^2)*
1040.95	X = 12.71	Ixx = 42.6209
	Y = - 0.03	Iyy = 154.5021
	Z = - 1.58	Izz = 139.6117
		Pxy = 0.1794
		Pxz = 11.5398
		Pyz = - 0.0042

*About an axes system parallel to the MMU body coordinate frame.

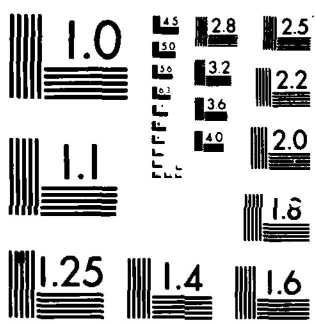
Plume Impingement

Table XII lists the forces created by each of the MMU's 24 thrusters. An identical table is used by MILMU to determine the accelerations produced by thruster firings. However, this table was inappropriate for modeling the IRV because the attached PRE lies within the exhaust plume region of the MMU's four forward-firing thrusters. The impingement of the nitrogen gas against the PRE sphere produces forces and moments which change the effective forces and moments created by the four forward-firing jets.

The Martin Marietta Corporation provided a table of the moments and forces caused by impingement of the MMU's four forward-firing thruster plumes upon the PRE. The table is

AD-A164 039 A PROPOSED DESIGN FOR AN INTERIM SPACE RESCUE FERRY VEHICLE(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING J D HALSELL DEC 85 2/3

UNCLASSIFIED AFIT/GSO/ENY/85D-2 F/G 22/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

Table XII

BASIC JET FORCE TABLE

THRUSTER NO.	ID*	****** FORCE (LB) ****** X	Y	Z	EFFECTIVE LOCATION (IN) STA	BL	WL	C (FT)
1	B1A	-1.700	0.000	0.000	-4.50	13.45	21.00	0.000
2	D1A	0.000	0.000	1.700	-4.50	13.45	21.00	0.000
3	L1A	0.000	-1.700	0.000	-4.50	13.45	21.00	0.000
4	D2A	0.000	0.000	1.700	4.50	-13.45	21.00	0.000
5	F2A	1.700	0.000	0.000	4.50	-13.45	21.00	0.000
6	R2A	0.000	1.700	0.000	4.50	-13.45	21.00	0.000
7	F3A	1.700	0.000	0.000	4.50	13.45	-21.00	0.000
8	L3A	0.000	-1.700	0.000	4.50	13.45	-21.00	0.000
9	U3A	0.000	0.000	-1.700	4.50	13.45	-21.00	0.000
10	B4A	-1.700	0.000	0.000	-4.50	-13.45	-21.00	0.000
11	R4A	0.000	1.700	0.000	-4.50	-13.45	-21.00	0.000
12	U4A	0.000	0.000	-1.700	-4.50	-13.45	-21.00	0.000
13	D1B	0.000	0.000	1.700	4.50	13.45	21.00	0.000
14	F1B	1.700	0.000	0.000	4.50	13.45	21.00	0.000
15	L1B	0.000	-1.700	0.000	4.50	13.45	21.00	0.000
16	B2B	-1.700	0.000	0.000	-4.50	-13.45	21.00	0.000
17	D2B	0.000	0.000	1.700	-4.50	-13.45	21.00	0.000
18	R2B	0.000	1.700	0.000	-4.50	-13.45	21.00	0.000
19	B3B	-1.700	0.000	0.000	-4.50	13.45	-21.00	0.000
20	L3B	0.000	-1.700	0.000	-4.50	13.45	-21.00	0.000
21	U3B	0.000	0.000	-1.700	-4.50	13.45	-21.00	0.000
22	F4B	1.700	0.000	0.000	4.50	-13.45	-21.00	0.000
23	R4B	0.000	1.700	0.000	4.50	-13.45	-21.00	0.000
24	U4B	0.000	0.000	-1.700	4.50	-13.45	-21.00	0.000

* Thruster identification code explained in Appendix A.

reproduced in Table XIII. It was produced by a Fortran 77 implementation of the McDonnell Douglas Technical Services Corporation's Plume Impingement Model, which was originally designed to calculate the effects of orbiter reaction control system jet firings on nearby free-flying satellites. The model was modified to reflect the location, thrust, and firing direction of the MMU's jets. Additional inputs included the size of the PRE sphere, and its location with respect to the MMU body coordinate system. Two simplifying assumptions were made:

Table XIII (17)

PRE IMPINGEMENT EFFECTS TABLE

THRUSTER NO.	ID*	*** DELTA FORCE (LB) *** X	Y	Z	** DELTA MOMENT (LB-FT) ** rol	pch	yaw
1	B1A	0.173	-0.083	0.122	-0.007	-0.595	-0.391
2	D1A	0.000	0.000	0.000	0.000	0.000	0.000
3	L1A	0.000	0.000	0.000	0.000	0.000	0.000
4	D2A	0.000	0.000	0.000	0.000	0.000	0.000
5	F2A	0.000	0.000	0.000	0.000	0.000	0.000
6	R2A	0.000	0.000	0.000	0.000	0.000	0.000
7	F3A	0.000	0.000	0.000	0.000	0.000	0.000
8	L3A	0.000	0.000	0.000	0.000	0.000	0.000
9	U3A	0.000	0.000	0.000	0.000	0.000	0.000
10	B4A	0.144	0.070	-0.115	0.006	0.531	0.331
11	R4A	0.000	0.000	0.000	0.000	0.000	0.000
12	U4A	0.000	0.000	0.000	0.000	0.000	0.000
13	D1B	0.000	0.000	0.000	0.000	0.000	0.000
14	F1B	0.000	0.000	0.000	0.000	0.000	0.000
15	L1B	0.000	0.000	0.000	0.000	0.000	0.000
16	B2B	0.173	0.083	0.122	0.007	-0.595	0.391
17	D2B	0.000	0.000	0.000	0.000	0.000	0.000
18	R2B	0.000	0.000	0.000	0.000	0.000	0.000
19	B3B	0.144	-0.070	-0.115	-0.007	0.531	-0.331
20	L3B	0.000	0.000	0.000	0.000	0.000	0.000
21	U3B	0.000	0.000	0.000	0.000	0.000	0.000
22	F4B	0.000	0.000	0.000	0.000	0.000	0.000
23	R4B	0.000	0.000	0.000	0.000	0.000	0.000
24	U4B	0.000	0.000	0.000	0.000	0.000	0.000

* Thruster identification code explained in Appendix A.

1. Only the four forward-firing thrusters impinge on the PRE. The modified ACD holds the PRE well in front of the MMU and out of the plume impingement fields of all but the forward-firing thrusters; therefore, this is a valid assumption (25).

2. The modified ACD was not modeled so as to simplify implementation. This assumption appears reasonable because only the "basket" portion of the

modified ACD (that part closest to the PRE) lies within a region of significant plume dynamic pressure (approximately .1 lb/ft^2) (25). It was reasoned that impingement which would actually be incurred by the ACD structure would be closely approximated in the model by the additional impingement experienced by unshadowed portions of PRE lying directly behind the modified ACD.

The Plume Impingement Model integrated the local dynamic pressure of each of the MMU's forward-firing thrusters over the surface area of the PRE sphere, arriving at a resultant force vector due to impingement from that thruster. The vector was resolved into components in the MMU body coordinate system to arrive at the X, Y, and Z components of force due to impingement from that thruster. The resultant force vector was also crossed with its moment arm from the MMU's geometric center of thrusters, and the resulting vector resolved into components in the MMU body coordinate system to arrive at the moments about the X, Y, and Z axes due to impingement (2).

MILMU added the forces due to impingement (Table XII) to the basic forces caused by the thrusters (Table XIII) to arrive at the net effective forces for each thruster to be used in the simulation. These effective forces are listed in Table XIV.

Table XIV.

(PRE) JET FORCE TABLE

THRUSTER NO.	ID*	****** FORCE (LB) ****** X	Y	Z	EFFECTIVE LOCATION (IN) STA	BL	WL	C (FT)
1	B1A	-1.527	-0.083	0.122	-4.72	12.16	19.08	-0.001
2	D1A	0.000	0.000	1.700	-4.50	13.45	21.00	0.000
3	L1A	0.000	-1.700	0.000	-4.50	13.45	21.00	0.000
4	D2A	0.000	0.000	1.700	4.50	-13.45	21.00	0.000
5	F2A	1.700	0.000	0.000	4.50	-13.45	21.00	0.000
6	R2A	0.000	1.700	0.000	4.50	-13.45	21.00	0.000
7	F3A	1.700	0.000	0.000	4.50	13.45	-21.00	0.000
8	L3A	0.000	-1.700	0.000	4.50	13.45	-21.00	0.000
9	U3A	0.000	0.000	-1.700	4.50	13.45	-21.00	0.000
10	B4A	-1.556	0.070	-0.115	-4.68	-12.35	-19.19	0.000
11	R4A	0.000	1.700	0.000	-4.50	-13.45	-21.00	0.000
12	U4A	0.000	0.000	-1.700	-4.50	-13.45	-21.00	0.000
13	D1B	0.000	0.000	1.700	4.50	13.45	21.00	0.000
14	F1B	1.700	0.000	0.000	4.50	13.45	21.00	0.000
15	L1B	0.000	-1.700	0.000	4.50	13.45	21.00	0.000
16	B2B	-1.527	0.083	0.122	-4.72	-12.16	19.08	0.001
17	D2B	0.000	0.000	1.700	-4.50	-13.45	21.00	0.000
18	R2B	0.000	1.700	0.000	-4.50	-13.45	21.00	0.000
19	B3B	-1.556	-0.070	-0.115	-4.68	12.35	-19.19	0.000
20	L3B	0.000	-1.700	0.000	-4.50	13.45	-21.00	0.000
21	U3B	0.000	0.000	-1.700	-4.50	13.45	-21.00	0.000
22	F4B	1.700	0.000	0.000	4.50	-13.45	-21.00	0.000
23	R4B	0.000	1.700	0.000	4.50	-13.45	-21.00	0.000
24	U4B	0.000	0.000	-1.700	4.50	-13.45	-21.00	0.000

* Thruster identification code explained in Appendix A.

Chapter Summary

This chapter introduced the MILMU computer program which was used to analyze the IRV's performance and stability, and presented the determination of the required inputs concerning IRV mass properties and plume impingement. The next chapter explains the simulation runs and their results.

scribed in Chapter II. They graphically describe the automatic attitude hold (AAH) control system's success or failure at limiting undesired rotations due to the presence of non-zero products of inertia, plume impingement, and the offset between the center of mass and center of thrust.

5. Items 1. through 4. while operating in the Backup control mode. As described in Chapter II, the Backup mode allows continued operation after a malfunction has disabled one of the two propulsion subsystems. The results will indicate if stability and performance would allow an IRV forced to operate in this mode to complete its return trip to the rescue orbiter, maintaining the PRE in tow.

6. Items 1. through 4. while operating in the Satellite Stabilization control mode. As described in Chapter III, the Satellite Stabilization mode was designed to reduce plume impingement and increase control authority when heavy payloads were attached to the front of the MMU. The results will indicate if this mode offers better IRV performance and stability than the Primary control mode.

Simulation Runs

MILMU was implemented on a Hewlett-Packard 9825T minicomputer, and it took 7.5 seconds actual time for the pro-

V. Simulation Objectives, Results, and Analysis

Chapter Overview

This chapter answers Research Question 2 (i.e., IRV stability and performance) by explaining the simulation runs made with MILMU and presenting and analyzing the results.

Simulation Objectives

Research Question 2 was "What are the stability and performance of the proposed IRV?" Answering this question required obtaining the following information:

1. IRV response to translation commands along all three axes.

2. IRV response to rotation commands about all three axes.

3. Specific propellant consumption (propellant consumed/change achieved in translational or rotational velocity) for the maneuvers listed in 1. and 2. Note that this factor, divided into the 23.2 pounds of useable gaseous nitrogen propellant, yields the total change in translational or rotational velocity possible if all propellant were spent on that one maneuver. This parameter provides a useful comparison tool.

4. Phase plane plots for all three axes during the maneuvers listed in 1. and 2. Phase plane plots were de-

cessor to propagate the state of the IRV system through one integration step and then to update all of the pilot's displays and process his flight control inputs. Two types of simulation runs were made:

1. Five-second translation burns were commanded in the +X, +Y, and +Z directions, with AAH on. The simulation was continued until all induced rotational rates were nulled. Rotational rates were considered to be nulled when they were reduced below .1 deg/sec and had an algebraic sign opposite of the attitude error. Translational acceleration along the commanded axis was determined by dividing the resulting change in translational velocity by five seconds. Undesired coupled translational accelerations along the other two axes were determined by referring to the MILMU-produced acceleration response matrix. Specific propellant consumption was determined by dividing the propellant consumed by the resulting translational velocity. Stability was indicated by the phase plane plots.

2. One- or two-second positive rotational burns were commanded about the X axis, and five-second positive rotational burns about the Y and Z axes. The simulation was continued until all except the desired rotation rate were nulled. Rotations were considered nulled when they met the criteria in 1., above. Rotational acceleration was determined by dividing the resulting

angular rate by two or five seconds, as appropriate. Undesired coupled translational accelerations were determined by referring the the MILMU-produced acceleration response matrix. Specific propellant consumption was determined by dividing the propellant consumed by the resulting angular rate. Stability was indicated by the phase plane plots.

Simulation Runs 1. and 2. were made in four different mass properties/control mode configurations:

1. Solo MMU/Primary Control Mode. The program implementation was validated by comparing MILMU-predicted solo MMU translational and rotational acceleration rates to published MMU performance information.

2. IRV/Primary Control Mode.

3. IRV/Backup Control Mode. Only the Backup B Mode (used when the A propulsion subsystem is lost) was simulated. Similar results would be obtained in Backup mode A.

4. IRV/Satellite Stabilization Control Mode. Analysis of this control mode depended primarily on study of the thruster select tables (Appendix A) and the response matrix (explained below), instead of on simulation. However, rotations about all three axes were simulated to confirm the conclusions.

Simulation Results

Appendix D contains the phase plane plots for each simulation run, and constitutes the simulation results for stability. Accompanying each phase plane plot is the end-of-simulation state vector printout. Tables XV through XVIII present the simulation results for performance. Each table presents two sources of acceleration information. The first is a MILMU-produced response matrix which lists the IRV's ideal response to all possible combinations of pilot commands, as determined by application of the dynamics equations:

$$\text{translational acceleration} = \sum \text{forces/mass} \qquad (19)$$

and

$$\text{rotational acceleration} = \sum \text{moments/inertia} \qquad (20)$$

The response matrices take into account all forces (including plume impingement, if appropriate) but do not reflect degradation due to AAH modulation of thruster on-time as necessary to maintain the desired attitude. This reduction was documented in the second part of each table, where the final translational or rotational rate (obtained from the appropriate end-of-simulation state vector printout in Appendix D) was divided by the commanded on-time (one, two, or five seconds) to arrive at the actual acceleration.

Table XV

Simulation Results--Solo MMU/Primary Control Mode

PART 1--RESPONSE MATRIX

	CMD*	ACCELERATIONS						PROPELLANT	
		TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			WDOT (LB/SEC)	
C	(pyr)	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.275	0.000	0.000	-0.001	2.058	-0.061	0.0533	0.0533
2	-00	-0.275	0.000	0.000	0.001	-2.058	0.061	0.0533	0.0533
3	0+0	0.000	0.000	0.000	0.014	8.506	0.005	0.0533	0.0000
4	++0	0.138	0.000	0.000	0.014	9.535	-0.026	0.0266	0.0266
5	-+0	-0.138	0.000	0.000	0.015	7.477	0.035	0.0266	0.0266
6	0-0	0.000	0.000	0.000	-0.014	-8.506	-0.005	0.0000	0.0533
7	+-0	0.138	0.000	0.000	-0.015	-7.477	-0.035	0.0266	0.0266
8	--0	-0.138	0.000	0.000	-0.014	-9.535	0.026	0.0266	0.0266
9	00+	0.000	0.000	0.000	0.586	0.003	8.418	0.0533	0.0000
10	+0+	0.138	0.000	0.000	0.585	1.032	8.387	0.0266	0.0266
11	-0+	-0.138	0.000	0.000	0.586	-1.026	8.448	0.0266	0.0266
12	0++	0.000	0.000	0.000	0.600	8.509	8.422	0.0266	0.0266
13	+++	0.138	0.000	0.000	0.599	9.538	8.391	0.0799	0.0266
14	-++	-0.138	0.000	0.000	0.600	7.480	8.453	0.0266	0.0799
15	0-+	0.000	0.000	0.000	0.572	-8.503	8.413	0.0266	0.0266
16	+-+	0.138	0.000	0.000	0.571	-7.474	8.382	0.0266	0.0799
17	--+	-0.138	0.000	0.000	0.572	-9.532	8.444	0.0799	0.0266
18	00-	0.000	0.000	0.000	-0.586	-0.003	-8.418	0.0000	0.0533
19	+0-	0.138	0.000	0.000	-0.586	1.026	-8.448	0.0266	0.0266
20	-0-	-0.138	0.000	0.000	-0.585	-1.032	-8.387	0.0266	0.0266
21	0+-	0.000	0.000	0.000	-0.572	8.503	-8.413	0.0266	0.0266
22	++-	0.138	0.000	0.000	-0.572	9.532	-8.444	0.0266	0.0799
23	-+-	-0.138	0.000	0.000	-0.571	7.474	-8.382	0.0799	0.0266
24	0--	0.000	0.000	0.000	-0.600	-8.509	-8.422	0.0266	0.0266
25	+--	0.138	0.000	0.000	-0.600	-7.480	-8.453	0.0799	0.0266
26	---	-0.138	0.000	0.000	-0.599	-9.538	-8.391	0.0266	0.0799

	CMD	ACCELERATIONS						PROPELLANT	
		TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			WDOT (LB/SEC)	
C	(yrp)	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.275	0.000	-2.280	-0.004	-0.910	0.0533	0.0533
2	-00	0.000	-0.275	0.000	2.280	0.004	0.910	0.0533	0.0533
3	0+0	0.000	0.000	0.000	9.226	0.014	0.915	0.0533	0.0000
4	++0	0.000	0.138	0.000	8.086	0.012	0.460	0.0266	0.0266
5	-+0	0.000	-0.138	0.000	10.365	0.016	1.370	0.0266	0.0266
6	0-0	0.000	0.000	0.000	-9.226	-0.014	-0.915	0.0000	0.0533
7	+-0	0.000	0.138	0.000	-10.365	-0.016	-1.370	0.0266	0.0266
8	--0	0.000	-0.138	0.000	-8.086	-0.012	-0.460	0.0266	0.0266
9	00+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
10	+0+	0.000	0.138	0.000	-0.944	-0.001	2.361	0.0266	0.0266
11	-0+	0.000	-0.138	0.000	1.336	0.003	3.271	0.0266	0.0266
12	0++	0.000	0.000	0.000	9.422	0.015	3.731	0.0266	0.0266
13	+++	0.000	0.138	0.000	8.086	0.012	0.460	0.0266	0.0266
14	-++	0.000	-0.138	0.000	10.365	0.016	1.370	0.0266	0.0266
15	0-+	0.000	0.000	0.000	-9.030	-0.013	1.901	0.0266	0.0266
16	+-+	0.000	0.138	0.000	-10.365	-0.016	-1.370	0.0266	0.0266
17	--+	0.000	-0.138	0.000	-8.086	-0.012	-0.460	0.0266	0.0266
18	00-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
19	+0-	0.000	0.138	0.000	-1.336	-0.003	-3.271	0.0266	0.0266
20	-0-	0.000	-0.138	0.000	0.944	0.001	-2.361	0.0266	0.0266
21	0+-	0.000	0.000	0.000	9.030	0.013	-1.901	0.0266	0.0266
22	++-	0.000	0.138	0.000	8.086	0.012	0.460	0.0266	0.0266
23	-+-	0.000	-0.138	0.000	10.365	0.016	1.370	0.0266	0.0266
24	0--	0.000	0.000	0.000	-9.422	-0.015	-3.731	0.0266	0.0266
25	+--	0.000	0.138	0.000	-10.365	-0.016	-1.370	0.0266	0.0266
26	---	0.000	-0.138	0.000	-8.086	-0.012	-0.460	0.0266	0.0266

*X, Y, and Z refer to translations along the respective axes. p,y, and r stand for pitch, yaw, and roll, respectively.

Table XV (cont.)

Simulation Results--Solo MMU/Primary Control Mode

	CMD	ACCELERATIONS TRANSL (FT/SEC SEC)			ROTAT (DEG/SEC/SEC)			PROPELLANT WDOT (LB SEC)	
C	Zrp	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.000	0.275	0.045	0.446	0.005	0.0533	0.0533
2	-00	0.000	0.000	-0.275	-0.045	-0.446	-0.005	0.0533	0.0533
3	0+0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
4	++0	0.000	0.000	0.138	5.931	0.232	0.588	0.0266	0.0266
5	-+0	0.000	0.000	-0.138	5.886	-0.214	0.584	0.0266	0.0266
6	0-0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
7	+-0	0.000	0.000	0.138	-5.886	0.214	-0.584	0.0266	0.0266
8	--0	0.000	0.000	-0.138	-5.931	-0.232	-0.588	0.0266	0.0266
9	00+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
10	+0+	0.000	0.000	0.138	0.025	2.045	0.003	0.0266	0.0266
11	-0+	0.000	0.000	-0.138	-0.019	1.600	-0.001	0.0266	0.0266
12	0++	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
13	+++	0.000	0.000	0.138	0.025	2.045	0.003	0.0266	0.0266
14	-++	0.000	0.000	-0.138	-0.019	1.600	-0.001	0.0266	0.0266
15	0-+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
16	+-+	0.000	0.000	0.138	0.025	2.045	0.003	0.0266	0.0266
17	--+	0.000	0.000	-0.138	-0.019	1.600	-0.001	0.0266	0.0266
18	00-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
19	+0-	0.000	0.000	0.138	0.019	-1.600	0.001	0.0266	0.0266
20	-0-	0.000	0.000	-0.138	-0.025	-2.045	-0.003	0.0266	0.0266
21	0+-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
22	++-	0.000	0.000	0.138	0.019	-1.600	0.001	0.0266	0.0266
23	-+-	0.000	0.000	-0.138	-0.025	-2.045	-0.003	0.0266	0.0266
24	0--	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
25	+--	0.000	0.000	0.138	0.019	-1.600	0.001	0.0266	0.0266
26	---	0.000	0.000	-0.138	-0.025	-2.045	-0.003	0.0266	0.0266

	CMD	ACCELERATIONS TRANSL (FT/SEC SEC)			ROTAT (DEG/SEC/SEC)			PROPELLANT WDOT (LB SEC)	
C	rpy	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.000	0.000	9.226	0.014	0.915	0.0533	0.0000
2	-00	0.000	0.000	0.000	-9.226	-0.014	-0.915	0.0000	0.0533
3	0+0	0.000	0.000	0.000	0.014	8.506	0.005	0.0533	0.0000
4	++0	0.000	0.000	0.000	9.240	8.520	0.919	0.1065	0.0000
5	-+0	0.000	0.000	0.000	-9.212	8.492	-0.910	0.0533	0.0533
6	0-0	0.000	0.000	0.000	-0.014	-8.506	-0.005	0.0000	0.0533
7	+-0	0.000	0.000	0.000	9.212	-8.492	0.910	0.0533	0.0533
8	--0	0.000	0.000	0.000	-9.240	-8.520	-0.919	0.0000	0.1065
9	00+	0.000	0.000	0.000	0.586	0.003	8.418	0.0533	0.0000
10	+0+	0.000	0.000	0.000	10.008	0.018	12.149	0.0799	0.0266
11	-0+	0.000	0.000	0.000	-8.444	-0.010	10.319	0.0799	0.0266
12	0++	0.000	0.000	0.000	0.600	8.509	8.422	0.0266	0.0266
13	+++	0.000	0.000	0.000	10.022	8.524	12.153	0.0533	0.0533
14	-++	0.000	0.000	0.000	-8.430	8.496	10.324	0.0533	0.0533
15	0-+	0.000	0.000	0.000	0.572	-8.503	8.413	0.0266	0.0266
16	+-+	0.000	0.000	0.000	9.994	-8.488	12.144	0.0533	0.0533
17	--+	0.000	0.000	0.000	-8.458	-8.516	10.314	0.0533	0.0533
18	00-	0.000	0.000	0.000	-0.586	-0.003	-8.418	0.0000	0.0533
19	+0-	0.000	0.000	0.000	8.444	0.010	-10.319	0.0266	0.0799
20	-0-	0.000	0.000	0.000	-10.008	-0.018	-12.149	0.0266	0.0799
21	0+-	0.000	0.000	0.000	-0.572	8.503	-8.413	0.0266	0.0266
22	++-	0.000	0.000	0.000	8.458	8.516	-10.314	0.0533	0.0533
23	-+-	0.000	0.000	0.000	-9.994	8.488	-12.144	0.0533	0.0533
24	0--	0.000	0.000	0.000	-0.600	-8.509	-8.422	0.0266	0.0266
25	+--	0.000	0.000	0.000	8.430	-8.496	-10.324	0.0533	0.0533
26	---	0.000	0.000	0.000	-10.022	-8.524	-12.153	0.0533	0.0533

Table XV (cont.)

Simulation Results--Solo MMU/Primary Control Mode

PART 2--ACTUAL ACCELERATIONS		
Translational Acceleration		
Commanded Translation	Resulting Actual Accelerations (ft/sec^2)	Specific Propellant Consumption Rate (lbs/ft/sec)
+X	.246	.390
+Y	.240	.400
+Z	.270	.397
Rotational Acceleration		
Commanded Rotation	Resulting Actual Acceleration (deg/sec^2)	Specific Propellant Consumption Rate (lbs/deg/sec)
+X (roll)	9.079	.009
+Y (pitch)	8.506	.007
+Z (yaw)	8.270	.010
AAH maintained all uncommanded rotational rates within control law limits		

Table XVI

Simulation Results--IRV/Primary Control Mode

PART 1--RESPONSE MATRIX

C	CMD* Xpy	ACCELERATIONS TRANSL (FT SEC SEC) X	Y	Z	ROTAT (DEG SEC SEC) rol	pch	yaw	PROPELLANT WDOT (LB SEC) A	B
1	+00	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
2	-00	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
3	0+0	0.005	-0.003	0.004	-0.020	2.042	-0.126	0.0533	0.0000
4	++0	0.105	0.000	0.000	0.009	2.373	-0.003	0.0266	0.0266
5	-+0	-0.094	0.000	0.008	0.009	1.712	0.004	0.0266	0.0266
6	0-0	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
7	+-0	0.105	0.000	0.000	-0.010	-2.040	-0.005	0.0266	0.0266
8	--0	-0.096	0.000	-0.007	-0.010	-2.055	0.003	0.0266	0.0266
9	00+	0.005	-0.003	0.004	0.404	-0.164	1.473	0.0533	0.0000
10	+0+	0.105	0.000	0.000	0.433	0.167	1.596	0.0266	0.0266
11	-0+	-0.095	-0.005	0.000	0.378	-0.171	1.369	0.0266	0.0266
12	0++	0.005	-0.003	0.004	0.413	2.043	1.473	0.0266	0.0266
13	+++	0.110	-0.003	0.004	0.413	2.209	1.470	0.0799	0.0266
14	-++	-0.090	-0.002	0.004	0.416	1.871	1.496	0.0266	0.0799
15	0-+	0.004	-0.002	-0.004	0.398	-2.047	1.491	0.0266	0.0266
16	+-+	0.110	-0.002	-0.004	0.397	-1.881	1.487	0.0266	0.0799
17	--+	-0.091	-0.003	-0.003	0.394	-2.219	1.475	0.0799	0.0266
18	00-	0.005	0.003	0.004	-0.404	-0.165	-1.473	0.0000	0.0533
19	+0-	0.105	0.000	0.000	-0.433	0.166	-1.604	0.0266	0.0266
20	-0-	-0.095	0.005	0.000	-0.379	-0.172	-1.362	0.0266	0.0266
21	0+-	0.005	0.003	0.004	-0.395	2.042	-1.472	0.0266	0.0266
22	++-	0.110	0.003	0.004	-0.395	2.208	-1.476	0.0266	0.0799
23	-+-	-0.090	0.002	0.004	-0.399	1.870	-1.488	0.0799	0.0266
24	0--	0.004	0.002	-0.004	-0.418	-2.048	-1.493	0.0266	0.0266
25	+--	0.110	0.002	-0.004	-0.418	-1.882	-1.497	0.0799	0.0266
26	---	-0.091	0.003	-0.003	-0.415	-2.220	-1.470	0.0266	0.0799

C	CMD Yry	ACCELERATIONS TRANSL (FT SEC SEC) X	Y	Z	ROTAT (DEG SEC SEC) rol	pch	yaw	PROPELLANT WDOT (LB SEC) A	B
1	+00	0.000	0.210	0.000	-2.052	-0.002	-3.125	0.0533	0.0533
2	-00	0.000	-0.210	0.000	2.052	0.002	3.125	0.0533	0.0533
3	0+0	0.000	0.000	0.000	8.182	0.009	0.676	0.0533	0.0000
4	++0	0.000	0.105	0.000	7.156	0.008	-0.886	0.0266	0.0266
5	-+0	0.000	-0.105	0.000	9.208	0.011	2.239	0.0266	0.0266
6	0-0	0.000	0.000	0.000	-8.182	-0.009	-0.676	0.0000	0.0533
7	+-0	0.000	0.105	0.000	-9.208	-0.011	-2.239	0.0266	0.0266
8	--0	0.000	-0.105	0.000	-7.156	-0.008	0.886	0.0266	0.0266
9	00+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
10	+0+	0.000	0.105	0.000	-0.881	-0.001	-1.027	0.0266	0.0266
11	-0+	0.000	-0.105	0.000	1.171	0.001	2.098	0.0266	0.0266
12	0++	0.000	0.000	0.000	8.327	0.010	1.212	0.0266	0.0266
13	+++	0.000	0.105	0.000	7.156	0.008	-0.886	0.0266	0.0266
14	-++	0.000	-0.105	0.000	9.208	0.011	2.239	0.0266	0.0266
15	0-+	0.000	0.000	0.000	-8.037	-0.009	-0.141	0.0266	0.0266
16	+-+	0.000	0.105	0.000	-9.208	-0.011	-2.239	0.0266	0.0266
17	--+	0.000	-0.105	0.000	-7.156	-0.008	0.886	0.0266	0.0266
18	00-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
19	+0-	0.000	0.105	0.000	-1.171	-0.001	-2.098	0.0266	0.0266
20	-0-	0.000	-0.105	0.000	0.881	0.001	1.027	0.0266	0.0266
21	0+-	0.000	0.000	0.000	8.037	0.009	0.141	0.0266	0.0266
22	++-	0.000	0.105	0.000	7.156	0.008	-0.886	0.0266	0.0266
23	-+-	0.000	-0.105	0.000	9.208	0.011	2.239	0.0266	0.0266
24	0--	0.000	0.000	0.000	-8.327	-0.010	-1.212	0.0266	0.0266
25	+--	0.000	0.105	0.000	-9.208	-0.011	-2.239	0.0266	0.0266
26	---	0.000	-0.105	0.000	-7.156	-0.008	0.886	0.0266	0.0266

*X, Y, and Z refer to translations along the respective axes. p,y, and r stand for pitch, yaw, and roll, respectively.

Table XVI (cont.)

Simulation Results--IRV/Primary Control Mode

	CMD	********	ACCELERATIONS	********				PROPELLANT	
		TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			WDOT (LB/SEC)	
C	Crp	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.000	0.210	0.037	2.671	0.003	0.0533	0.0533
2	-00	0.000	0.000	-0.210	-0.037	-2.671	-0.003	0.0533	0.0533
3	0+0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
4	++0	0.000	0.000	0.105	5.259	1.342	0.435	0.0266	0.0266
5	-+0	0.000	0.000	-0.105	5.222	-1.329	0.432	0.0266	0.0266
6	0-0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
7	+-0	0.000	0.000	0.105	-5.222	1.329	-0.432	0.0266	0.0266
8	--0	0.000	0.000	-0.105	-5.259	-1.342	-0.435	0.0266	0.0266
9	00+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
10	+0+	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
11	-0+	0.000	0.000	-0.105	-0.017	-0.863	-0.001	0.0266	0.0266
12	0++	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
13	+++	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
14	-++	0.000	0.000	-0.105	-0.017	-0.863	-0.001	0.0266	0.0266
15	0-+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
16	+-+	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
17	--+	0.000	0.000	-0.105	-0.017	-0.863	-0.001	0.0266	0.0266
18	00-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
19	+0-	0.000	0.000	0.105	0.017	0.863	0.001	0.0266	0.0266
20	-0-	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
21	0+-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
22	++-	0.000	0.000	0.105	0.017	0.863	0.001	0.0266	0.0266
23	-+-	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
24	0--	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
25	+--	0.000	0.000	0.105	0.017	0.863	0.001	0.0266	0.0266
26	---	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266

	CMD	********	ACCELERATIONS	********				PROPELLANT	
		TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			WDOT (LB/SEC)	
C	rpy	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.000	0.000	8.182	0.009	0.676	0.0533	0.0000
2	-00	0.000	0.000	0.000	-8.182	-0.009	-0.676	0.0000	0.0533
3	0+0	0.005	-0.003	0.004	-0.020	2.042	-0.126	0.0533	0.0000
4	++0	0.005	-0.003	0.004	8.162	2.052	0.550	0.1065	0.0000
5	-+0	0.005	-0.003	0.004	-8.202	2.033	-0.803	0.0533	0.0533
6	0-0	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
7	+-0	0.004	-0.002	-0.004	8.147	-2.038	0.568	0.0533	0.0533
8	--0	0.004	-0.002	-0.004	-8.217	-2.057	-0.735	0.0000	0.1065
9	00+	0.005	-0.003	0.004	0.404	-0.164	1.473	0.0533	0.0000
10	+0+	0.005	-0.003	0.004	8.731	-0.154	2.684	0.0799	0.0266
11	-0+	0.005	-0.003	0.004	-7.633	-0.173	1.332	0.0799	0.0266
12	0++	0.005	-0.003	0.004	0.413	2.043	1.473	0.0266	0.0266
13	+++	0.005	-0.003	0.004	8.740	2.052	2.685	0.0533	0.0533
14	-++	0.005	-0.003	0.004	-7.624	2.033	1.332	0.0533	0.0533
15	0-+	0.004	-0.002	-0.004	0.398	-2.047	1.491	0.0266	0.0266
16	+-+	0.004	-0.002	-0.004	8.725	-2.038	2.703	0.0533	0.0533
17	--+	0.004	-0.002	-0.004	-7.639	-2.057	1.350	0.0533	0.0533
18	00-	0.005	0.003	0.004	-0.404	-0.165	-1.473	0.0000	0.0533
19	+0-	0.005	0.003	0.004	7.633	-0.155	-1.332	0.0266	0.0799
20	-0-	0.005	0.003	0.004	-8.731	-0.174	-2.685	0.0266	0.0799
21	0+-	0.005	0.003	0.004	-0.395	2.042	-1.472	0.0266	0.0266
22	++-	0.005	0.003	0.004	7.642	2.051	-1.331	0.0533	0.0533
23	-+-	0.005	0.003	0.004	-8.722	2.032	-2.684	0.0533	0.0533
24	0--	0.004	0.002	-0.004	-0.418	-2.048	-1.493	0.0266	0.0266
25	+--	0.004	0.002	-0.004	7.619	-2.039	-1.352	0.0533	0.0533
26	---	0.004	0.002	-0.004	-8.745	-2.058	-2.705	0.0533	0.0533

Table XVI (cont.)

Simulation Results--IRV/Primary Control Mode

PART 2--ACTUAL ACCELERATIONS		
Translational Acceleration		
Commanded Translation	Resulting Accelerations (ft/sec^2)	Specific Propellant Consumption Rate (lbs/ft/sec)
+X	.198	.511
-X	-.176	.568
+Y	.114	.937
+Z	.136	.807
Rotational Acceleration		
Commanded Rotation	Resulting Actual Acceleration (deg/sec^2)	Specific Propellant Consumption Rate (lbs/deg/sec)
+X (roll)	7.801	.057
+Y (pitch)	2.024	.030
+Z (yaw)	1.413	.049
AAH maintained all uncommanded rotational rates within control law limits.		

Table XVII

Simulation Results--IRV/Backup Control Mode

PART 1--RESPONSE MATRIX

C	CMD* Xpy	ACCELERATIONS TRANSL (FT/SEC/SEC) X	Y	Z	ROTAT (DEG/SEC/SEC) rol	pch	yaw	PROPELLANT WDOT (LB/SEC) A	B
1	+00	0.105	0.000	0.000	-0.000	0.166	-0.004	0.0000	0.0533
2	-00	-0.095	0.000	0.000	0.003	-0.172	0.023	0.0000	0.0533
3	0+0	0.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
4	++0	0.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
5	-+0	0.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
6	0-0	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
7	+-0	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
8	--0	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
9	00+	0.004	-0.002	-0.004	0.407	0.159	1.492	0.0000	0.0533
10	+0+	0.004	-0.002	-0.004	0.407	0.159	1.492	0.0000	0.0533
11	-0+	0.004	-0.002	-0.004	0.407	0.159	1.492	0.0000	0.0533
12	0++	6.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
13	+++	0.053	0.000	0.000	0.221	1.187	0.798	0.0000	0.0266
14	-++	-0.043	0.000	0.000	0.224	1.015	0.821	0.0000	0.0799
15	0-+	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
16	+-+	0.057	-0.002	-0.004	0.186	-0.861	0.690	0.0000	0.0799
17	--+	-0.048	-0.002	-0.004	0.186	-1.027	0.694	0.0000	0.0266
18	00-	0.005	0.003	0.004	-0.404	-0.165	-1.473	0.0000	0.0533
19	+0-	0.005	0.003	0.004	-0.404	-0.165	-1.473	0.0000	0.0533
20	-0-	0.005	0.003	0.004	-0.404	-0.165	-1.473	0.0000	0.0533
21	0+-	0.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
22	++-	0.058	0.003	0.004	-0.183	1.022	-0.675	0.0000	0.0799
23	-+-	-0.047	0.003	0.004	-0.183	0.856	-0.671	0.0000	0.0266
24	0--	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
25	+--	0.053	0.000	0.000	-0.221	-1.020	-0.802	0.0000	0.0266
26	---	-0.043	0.000	0.000	-0.218	-1.192	-0.779	0.0000	0.0799

C	CMD YZr	ACCELERATIONS TRANSL (FT/SEC/SEC) X	Y	Z	ROTAT (DEG/SEC/SEC) rol	pch	yaw	PROPELLANT WDOT (LB/SEC) A	B
1	+00	0.000	0.105	0.000	-1.026	-0.001	-1.563	0.0000	0.0533
2	-00	0.000	-0.105	0.000	1.026	0.001	1.563	0.0000	0.0533
3	0+0	0.000	0.000	0.105	0.019	1.336	0.001	0.0000	0.0533
4	++0	0.000	0.105	0.105	-1.007	1.334	-1.561	0.0000	0.1065
5	-+0	0.000	-0.105	0.105	1.044	1.337	1.564	0.0000	0.1065
6	0-0	0.000	0.000	-0.105	-0.019	-1.336	-0.001	0.0000	0.0533
7	+-0	0.000	0.105	-0.105	-1.044	-1.337	-1.564	0.0000	0.1065
8	--0	0.000	-0.105	-0.105	1.007	-1.334	1.561	0.0000	0.1065
9	00+	0.000	0.000	0.000	8.182	0.009	0.676	0.0000	0.0533
10	+0+	0.000	0.105	0.000	4.215	0.005	-1.130	0.0000	0.1065
11	-0+	0.000	-0.105	0.006	6.266	0.007	1.996	0.0000	0.1065
12	0++	0.000	0.000	0.105	8.201	1.345	0.678	0.0000	0.1065
13	+++	0.000	0.000	0.105	8.201	1.345	0.678	0.0000	0.1065
14	-++	0.000	0.000	0.105	8.201	1.345	0.678	0.0000	0.1065
15	0-+	0.000	0.000	-0.105	8.163	-1.326	0.675	0.0000	0.1065
16	+-+	0.000	0.000	-0.105	8.163	-1.326	0.675	0.0000	0.1065
17	--+	0.000	0.000	-0.105	8.163	-1.326	0.675	0.0000	0.1065
18	00-	0.000	0.000	0.000	-8.182	-0.009	-0.676	0.0000	0.0533
19	+0-	0.000	0.105	0.000	-6.266	-0.007	-1.996	0.0000	0.1065
20	-0-	0.000	-0.105	0.000	-4.215	-0.005	1.130	0.0000	0.1065
21	0+-	0.000	0.000	0.105	-8.163	1.326	-0.675	0.0000	0.1065
22	++-	0.000	0.000	0.105	-8.163	1.326	-0.675	0.0000	0.1065
23	-+-	0.000	0.000	0.105	-8.163	1.326	-0.675	0.0000	0.1065
24	0--	0.000	0.000	-0.105	-8.201	-1.345	-0.678	0.0000	0.1065
25	+--	0.000	0.000	-0.105	-8.201	-1.345	-0.678	0.0000	0.1065
26	---	0.000	0.000	-0.105	-8.201	-1.345	-0.678	0.0000	0.1065

*X, Y, and Z refer to translations along the respective axes. p,y, and r stand for pitch, yaw, and roll, respectively.

Table XVII (cont.)

Simulation Results--IRV/Backup Control Mode

	CMD	ACCELERATIONS TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			PROPELLANT WDOT (LB/SEC)	
C	rpy	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.000	0.000	8.182	0.009	0.676	0.0000	0.0533
2	-00	0.000	0.000	0.000	-8.182	-0.009	-0.676	0.0000	0.0533
3	0+0	0.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
4	++0	0.005	0.003	0.004	8.220	2.052	0.804	0.0000	0.1065
5	-+0	0.005	0.003	0.004	-8.144	2.033	-0.549	0.0000	0.1065
6	0-0	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
7	+-0	0.004	-0.002	-0.004	8.147	-2.038	0.568	0.0000	0.1065
8	--0	0.004	-0.002	-0.004	-8.217	-2.057	-0.785	0.0000	0.1065
9	00+	0.004	-0.002	-0.004	0.407	0.159	1.492	0.0000	0.0533
10	+0+	0.004	-0.002	-0.004	8.589	0.169	2.168	0.0000	0.1065
11	-0+	0.004	-0.002	-0.004	-7.775	0.150	0.816	0.0000	0.1065
12	0++	0.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
13	+++	0.005	0.003	0.004	8.220	2.052	0.804	0.0000	0.1065
14	-++	0.005	0.003	0.004	-8.144	2.033	-0.549	0.0000	0.1065
15	0-+	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
16	+-+	0.004	-0.002	-0.004	8.147	-2.038	0.568	0.0000	0.1065
17	--+	0.004	-0.002	-0.004	-8.217	-2.057	-0.785	0.0000	0.1065
18	00-	0.005	0.003	0.004	-0.404	-0.165	-1.473	0.0000	0.0533
19	+0-	0.005	0.003	0.004	7.778	-0.155	-0.797	0.0000	0.1065
20	-0-	0.005	0.003	0.004	-8.586	-0.174	-2.149	0.0000	0.1065
21	0+-	0.005	0.003	0.004	0.038	2.042	0.127	0.0000	0.0533
22	++-	0.005	0.003	0.004	8.220	2.052	0.804	0.0000	0.1065
23	-+-	0.005	0.003	0.004	-8.144	2.033	-0.549	0.0000	0.1065
24	0--	0.004	-0.002	-0.004	-0.035	-2.048	-0.108	0.0000	0.0533
25	+--	0.004	-0.002	-0.004	8.147	-2.038	0.568	0.0000	0.1065
26	---	0.004	-0.002	-0.004	-8.217	-2.057	-0.785	0.0000	0.1065

PART 2--ACTUAL ACCELERATIONS

Translational Acceleration

Commanded Translation	Resulting Actual Accelerations (ft/sec^2)	Specific Propellant Consumption Rate (lbs/ft/sec)
+X	.100	.544
-X	-.090	.620
+Y	.102	1.167
+Z	.102	.892

Rotational Acceleration

Commanded Rotation	Resulting Actual Acceleration (deg/sec^2)	Specific Propellant Consumption Rate (lbs/deg/sec)
+X (roll)	7.717	.025
+Y (pitch)	2.030	.030
+Z (yaw)	1.400	.050

Table XVIII

Simulation Results--IRV/Satellite Stabilization Control Mode

PART 1--RESPONSE MATRIX

	CMD	ACCELERATIONS						PROPELLANT	
		TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			WDOT (LB/SEC)	
C	Xpy	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
2	-00	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
3	0+0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
4	++0	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
5	-+0	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
6	0-0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
7	+-0	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
8	--0	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
9	00+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
10	+0+	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
11	-0+	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
12	0++	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
13	+++	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
14	-++	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
15	0-+	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
16	+-+	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
17	--+	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
18	00-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
19	+0-	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
20	-0-	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
21	0+-	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
22	++-	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
23	-+-	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533
24	0--	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
25	+--	0.210	0.000	0.000	-0.001	0.333	-0.008	0.0533	0.0533
26	---	-0.191	0.000	0.000	-0.001	-0.343	0.007	0.0533	0.0533

	CMD	ACCELERATIONS						PROPELLANT	
		TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			WDOT (LB/SEC)	
C	Yry	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.210	0.000	-2.052	-0.002	-3.125	0.0533	0.0533
2	-00	0.000	-0.210	0.000	2.052	0.002	3.125	0.0533	0.0533
3	0+0	0.000	0.000	0.000	16.364	0.019	1.353	0.0533	0.0533
4	++0	0.000	0.105	0.000	7.156	0.008	-0.886	0.0266	0.0266
5	-+0	0.000	-0.105	0.000	9.208	0.011	2.239	0.0266	0.0266
6	0-0	0.000	0.000	0.000	-16.364	-0.019	-1.353	0.0533	0.0533
7	+-0	0.000	0.105	0.000	-9.208	-0.011	-2.239	0.0266	0.0266
8	--0	0.000	-0.105	0.000	-7.156	-0.008	0.886	0.0266	0.0266
9	00+	0.000	-0.105	0.000	1.171	0.001	2.098	0.0266	0.0266
10	+0+	0.000	0.000	0.000	0.290	0.000	1.070	0.0533	0.0533
11	-0+	0.000	-0.105	0.000	1.171	0.001	2.098	0.0266	0.0266
12	0++	0.000	-0.105	0.000	9.353	0.011	2.774	0.0266	0.0799
13	+++	0.000	0.000	0.000	8.327	0.010	1.212	0.0266	0.0266
14	-++	0.000	-0.105	0.000	9.353	0.011	2.774	0.0266	0.0799
15	0-+	0.000	-0.105	0.000	-7.011	-0.008	1.422	0.0799	0.0266
16	+-+	0.000	0.000	0.000	-8.037	-0.009	-0.141	0.0266	0.0266
17	--+	0.000	-0.105	0.000	-7.011	-0.008	1.422	0.0799	0.0266
18	00-	0.000	0.105	0.000	-1.171	-0.001	-2.098	0.0266	0.0266
19	+0-	0.000	0.105	0.000	-1.171	-0.001	-2.098	0.0266	0.0266
20	-0-	0.000	0.000	0.000	-0.290	-0.000	-1.070	0.0533	0.0533
21	0+-	0.000	0.105	0.000	7.011	0.008	-1.422	0.0266	0.0799
22	++-	0.000	0.105	0.000	7.011	0.008	-1.422	0.0266	0.0799
23	-+-	0.000	0.000	0.000	8.037	0.009	0.141	0.0266	0.0266
24	0--	0.000	0.105	0.000	-9.353	-0.011	-2.774	0.0799	0.0266
25	+--	0.000	0.105	0.000	-9.353	-0.011	-2.774	0.0799	0.0266
26	---	0.000	0.000	0.000	-8.327	-0.010	-1.212	0.0266	0.0266

X, Y, and Z refer to translations along the respective axes. p,y, and r stand for pitch, yaw, and roll, respectively.

Table XVIII (cont.)

Simulation Results--IRV/Satellite Stabilization Control Mode

	CMD	ACCELERATIONS TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			PROPELLANT WDOT (LB/SEC)	
C	Zrp	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.000	0.210	0.037	2.671	0.003	0.0533	0.0533
2	-00	0.000	0.000	-0.210	-0.037	-2.671	-0.003	0.0533	0.0533
3	0+0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
4	++0	0.000	0.000	0.210	0.037	2.671	0.003	0.0533	0.0533
5	-+0	0.000	0.000	-0.210	-0.037	-2.671	-0.003	0.0533	0.0533
6	0-0	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.0000
7	+-0	0.000	0.000	0.210	0.037	2.671	0.003	0.0533	0.0533
8	--0	0.000	0.000	-0.210	-0.037	-2.671	-0.003	0.0533	0.0533
9	00+	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
10	+0+	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
11	-0+	0.000	0.000	0.000	0.004	0.946	0.000	0.0533	0.0533
12	0++	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
13	+++	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
14	-++	0.000	0.000	0.000	0.004	0.946	0.000	0.0533	0.0533
15	0-+	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
16	+-+	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
17	--+	0.000	0.000	0.000	0.004	0.946	0.000	0.0533	0.0533
18	00-	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
19	+0-	0.000	0.000	0.000	-0.004	-0.946	-0.000	0.0533	0.0533
20	-0-	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
21	0+-	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
22	++-	0.000	0.000	0.000	-0.004	-0.946	-0.000	0.0533	0.0533
23	-+-	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
24	0--	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
25	+--	0.000	0.000	0.000	-0.004	-0.946	-0.000	0.0533	0.0533
26	---	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266

	CMD	ACCELERATIONS TRANSL (FT/SEC/SEC)			ROTAT (DEG/SEC/SEC)			PROPELLANT WDOT (LB/SEC)	
C	rpy	X	Y	Z	rol	pch	yaw	A	B
1	+00	0.000	0.000	0.000	16.364	0.019	1.353	0.0533	0.0533
2	-00	0.000	0.000	0.000	-16.364	-0.019	-1.353	0.0533	0.0533
3	0+0	0.000	0.000	0.105	0.021	1.808	0.002	0.0266	0.0266
4	++0	0.000	0.000	0.105	16.384	1.827	1.354	0.0799	0.0799
5	-+0	0.000	0.000	0.105	-16.343	1.789	-1.351	0.0799	0.0799
6	0-0	0.000	0.000	-0.105	-0.021	-1.808	-0.002	0.0266	0.0266
7	+-0	0.000	0.000	-0.105	16.343	-1.789	1.351	0.0799	0.0799
8	--0	0.000	0.000	-0.105	-16.384	-1.827	-1.354	0.0799	0.0799
9	00+	0.000	-0.105	0.000	1.171	0.001	2.098	0.0266	0.0266
10	+0+	0.000	-0.105	0.000	9.353	0.011	2.774	0.0266	0.0799
11	-0+	0.000	-0.105	0.000	-7.011	-0.008	1.422	0.0799	0.0266
12	0++	0.000	-0.105	0.105	1.191	1.810	2.100	0.0533	0.0533
13	+++	0.000	-0.105	0.105	9.373	1.819	2.776	0.0533	0.1065
14	-++	0.000	-0.105	0.105	-6.991	1.800	1.423	0.1065	0.0533
15	0-+	0.000	-0.105	-0.105	1.150	-1.807	2.096	0.0533	0.0533
16	+-+	0.000	-0.105	-0.105	9.332	-1.798	2.773	0.0533	0.1065
17	--+	0.000	-0.105	-0.105	-7.032	-1.817	1.420	0.1065	0.0533
18	00-	0.000	0.105	0.000	-1.171	-0.001	-2.098	0.0266	0.0266
19	+0-	0.000	0.105	0.000	7.011	0.008	-1.422	0.0266	0.0799
20	-0-	0.000	0.105	0.000	-9.353	-0.011	-2.774	0.0799	0.0266
21	0+-	0.000	0.105	0.105	-1.150	1.807	-2.096	0.0533	0.0533
22	++-	0.000	0.105	0.105	7.032	1.817	-1.420	0.0533	0.1065
23	-+-	0.000	0.105	0.105	-9.332	1.798	-2.773	0.1065	0.0533
24	0--	0.000	0.105	-0.105	-1.191	-1.810	-2.100	0.0533	0.0533
25	+--	0.000	0.105	-0.105	6.991	-1.800	-1.423	0.0533	0.1065
26	---	0.000	0.105	-0.105	-9.373	-1.819	-2.776	0.1065	0.0533

Table XVIII (cont.)

Simulation Results--IRV/Satellite Stabilization Control Mode

PART 2--ACTUAL ACCELERATIONS			
Rotational Acceleration			
Commanded Rotation	Acceleration		Specific Propellant Consumption Rate (lbs/deg/sec)
	Rotation (deg/sec^2)	Translation (ft/sec^2)	
+X (roll)	14.701	X = -.010 Y = -.040 Z = .040	.029
+Y (pitch)	1.808	X = .104 Y = -.002 Z = .014	.030
+Z (yaw)	1.982	X = .014 Y = -.102 Z = -.046	.041
AAH maintained all uncommanded rotational rates within control law limits.			

<u>Analysis of Results</u>

<u>Validation</u>. MILMU predicted solo MMU translational acceleration in the +X direction of .246 ft/sec^2, .240 ft/sec^2 in the +Y direction, and .270 in the +Z direction. Predicted rotational accelerations were 9.079 deg/sec^2 in roll, 8.506 deg/sec^2 in pitch, and 8.270 deg/sec^2 in yaw. Predicted propellant consumption rate was .0266 lbs/sec per thruster. These values generally agree with published MMU performance data of .280 ft/sec^2 translational acceleration along all three axes; rotational accelerations of 9.17 deg/sec^2 roll, 8.75 deg/sec^2 pitch, and 8.72 deg/sec^2 yaw; and a

propellant consumption rate of .027 lb/sec per thruster (12:9). The agreement between MILMU-predicted performance parameters and published information validated the program and increased confidence in subsequent results.

IRV Stability. Study of the phase plane plots in Appendix D revealed that AAH was able to limit uncommanded rotations to within the control law deadbands, for all translations and rotations and in all control modes except one. While operating in the Backup control mode, during translations along the Y axis, yaw due to the offset mass center was driven beyond the .2 deg/sec rate error deadband and continued to increase as long as a +/- Y translation was commanded. The yaw acceleration was opposite in sign to the translation direction. Upon termination of the Y translation command, however, AAH was able to null all rates and reestablish the IRV within the original attitude deadband. This inability of AAH to maintain a fixed yaw attitude implies that the IRV pilot forced to operate in the Backup mode should limit Y-axis translations to short durations followed by a quiet period to allow AAH to null the resulting yaw attitude error.

IRV Performance. Comparison of Primary Mode (Table XVI, Part 2) runs with the Solo MMU runs (Table XV, Part 2) confirmed the anticipated reduction in translational and rotational acceleration, and increase in specific fuel consumption. Table XIX documents the decrease in IRV performance. IRV translational accelerations along all three axes

Table XIX

Solo MMU/IRV Performance Comparison

Translational Acceleration						
Command	Resulting Accelerations (ft/sec^2)			Specific Propellant Consumption Rate (lbs/ft/sec)		
	Solo MMU	IRV	% Change	Solo MMU	IRV	% Change
+X	.246	.198	-20	.390	.511	+31
-X	-.246	-.176	-28	.390	.568	+46
+Y	.240	.114	-53	.400	.937	+134
+Z	.270	.136	-50	.397	.807	+103
Rotational Acceleration						
Command	Resulting Acceleration (deg/sec^2)			Specific Propellant Consumption Rate (lbs/deg/sec)		
	Solo MMU	IRV	% Change	Solo MMU	IRV	% Change
+X (roll)	9.08	7.80	-14	.009	.057	+533
+Y (pitch)	8.51	2.02	-76	.007	.030	+329
+Z (yaw)	8.27	1.41	-83	.010	.049	+390

suffered from the IRV's increased mass; however, Y-and Z-axis translational accelerations were also degraded by the IRV's 12-inch X-axis offset between the center of mass and center of thrust. This offset forced the automatic attitude hold (AAH) control system to modulate the appropriate thrusters' on-times to cancel the significant rotational moments induced by full-on Y- and Z-axis translational commands.

IRV rotational accelerations were degraded by the increases in moments of inertia. IRV roll acceleration was reduced only 14 percent, while pitch and yaw accelerations were reduced an average of 80 percent. These results reflect the relatively small increase in IRV Ixx (15 percent) compared to the solo MMU, and the large increases in Iyy and Izz (285 and 435 percent, respectively).

Increases in IRV specific fuel consumption (compared to the solo MMU) resulted from the increases in mass and moments of inertia. However, roll axis specific propellant consumption increased much more than could be accounted for by the increased Ixx. Comparison of the applicable phase plane plots in Appendix D revealed that plume impingement during IRV roll commands caused significantly greater coupled yaw, which was nulled by AAH at the expense of more propellant.

The effect of plume impingement was revealed in Table XVI, Part 2, wherein it was noted that the -X thrusters (which impinge upon the attached PRE) produced 11 percent less acceleration and suffered 11 percent greater specific fuel consumption than the +X thrusters (which do not impinge).

As already mentioned, of the two Backup control modes only the Backup B mode was simulated. The results, however, are also generally applicable to the Backup A mode. As displayed in Table XX, the Backup B control mode provided IRV rotational accelerations equivalent to those in the Primary mode. This was as expected because, as shown in the

Table XX

IRV: Primary Control Mode/Backup B Control Mode Performance Comparison

Translational Acceleration						
Command	Resulting Accelerations (ft/sec^2)			Specific Propellant Consumption Rate (lbs/ft/sec)		
	Prim	BUB	% Change	Prim	BUB	% Change
+X	.198	.100	-49	.511	.544	+6
-X	-.176	-.090	-49	.568	.620	+9
+Y	.114	.102	-11	.937	1.167	+25
+Z	.136	.102	-25	.807	.892	+11
Rotational Acceleration						
Command	Resulting Acceleration (deg/sec^2)			Specific Propellant Consumption Rate (lbs/deg/sec)		
	Prim	BUB	% Change	Prim	BUB	% Change
+X (roll)	7.80	7.72	+1	.057	.025	-128
+Y (pitch)	2.02	2.03	0	.030	.030	0
+Z (yaw)	1.41	1.40	0	.049	.050	+2

thruster select tables in Appendix A, both modes use two thrusters to produce the necessary moments. Backup mode translational accelerations, however, were significantly degraded because only two thrusters, instead of the normal four, were available for use. Specific propellant consumption remained the same, except for the positive roll command, where a 50 percent decrease occurred from that experienced in the Primary mode. Reference to the applicable phase plane plots (Appendix D) showed that the fuel savings resulted from a decrease in coupled yaw. The reason for this decreased coupled yaw was not clear from the results of the limited number of simulation runs conducted in the Backup mode.

Analysis of the Satellite Stabilization (Sat Stab) mode thruster select logic tables (Appendix A) and the response matrix in Table XVIII (Part 1), revealed that this control mode was not preferred. Sat Stab mode reduces plume impingement on forward mounted payloads by producing rotations without utilizing the forward-firing thrusters. This would be marginally advantageous for the IRV, except that Sat Stab produces yaw and pitch by taking advantage of rotations coupled from translational commands. For example, to obtain a positive yaw, Sat Stab fires two +Y thrusters (L1B and L3A--see Appendix A for thruster positions) which produce a moment about the forward displaced mass center. For the IRV, however, this firing scheme also produced an undesireable -Y translational acceleration of .104 ft/sec^2. Similar rotation-to-translation coupling was obtained from pitch commands. This was determined to be undesireable because the IRV must be capable of delicate maneuvering to successfully rendezvous with a tumbling stranded orbiter.

Chapter Summary

MILMU simulation was conducted to determine IRV stability and performance. The program was first validated by simulating the solo MMU and comparing the predicted performance to published figures. IRV simulation runs included translational and rotational commands in the Primary, Backup, and Satellite Stabilization modes. Results showed that AAH was capable of limiting uncommanded IRV rotations to within the control law deadbands during all simulated maneuvers and in all control modes, except during Y translations in the Backup control mode. The IRV's increased mass and increased center-of-mass/center-of-thrust offset caused significant reductions in acceleration and increases in specific fuel consumption. Plume impingement, however, was found to be of minor importance. Translational accelerations in the Backup control mode were found to be one-half those in the Primary mode, but rotational accelerations were unaffected. The Satellite Stabilization mode was found to have significant rotational-to-translational coupling which made it undesireable for IRV use.

VI. IRV Operation

Chapter Overview

This chapter answers Research Question 3 by presenting procedures which crewmembers of both stranded and rescue orbiters could implement to effect a successful rescue using the IRV. Only an all-American, orbiter-to-orbiter rescue scenario was studied, but portions of the procedures presented herein would also apply to a U.S.-U.S.S.R. rescue mission.

Preparations

Rescue Orbiter. Within three days of notification, a rescue shuttle would be outfitted with two MMUs, two modified stingers, and the required number of PREs and portable oxygen systems. The rescue orbiter would be launched to rendezvous with the disabled spacecraft, and would take up a stationkeeping position approximately 100 feet away from the stranded orbiter (12:27).

Two rescue astronauts would enter the rescue orbiter's airlock and don their spacesuits. The MMU pilot's spacesuit would be equipped with a Mini-Work Station carrying the modified Probe in a tool caddy, and two adjustable wrist tethers attached to the torso tether rings as explained in Chapter III.

Following depressurization, the IRV pilot would translate via handrails to the Flight Service Station and prepare and don the MMU as described in Chapter II. The other rescue astronaut would disconnect a modified ACD from its carrying bracket and help the IRV pilot attach it to the MMU hand controller arms (11:28). The IRV pilot would then release the IRV from the Flight Support Station and set his course for the stranded orbiter.

Stranded Orbiter. Upon discovery of the emergency situation, the stranded crewmembers would conserve consumables by powering down all unnecessary systems and limiting their activities.

After rendezvous by the rescue orbiter, one stranded astronaut would don his spacesuit, undergo depressurization, and exit into the payload bay so as to be able to aid the approaching IRV pilot. Two non-spacesuited astronauts would don PREs as described in Chapter II. The one astronaut now in the stranded orbiter's cabin who was allocated a spacesuit would act as a PRE "shepherd", and would position the two PREs inside the airlock, attach an air umbilical to each PRE, close the inner hatch, and depressurize the airlock. The PREs would remain in the airlock, connected to air umbilicals, until removed by the spacesuited stranded astronaut for attachment to the IRV.

Rescue Operations

As explained in Chapter I, this scenario assumes that the stranded orbiter is slowly tumbling. MILMU, as implemented on the Hewlett-Packard 9825, was found unsuitable for simulating the complicated maneuvering required to successfully dock with a tumbling target. This was because the graphics screen was updated only once every 7.5 seconds, which was not frequent enough to give the simulation pilot enough information for accurate flying. Consequently, the following approach and docking procedure is presented without the benefit of simulation testing. It is offered as a baseline procedure, subject to modification or abandonment, as justified by follow-on simulation.

The IRV pilot would time his approach so that the stranded orbiter's payload bay rotated into the line of flight just as he arrived. Once established in the payload bay, the IRV pilot could dock with the stranded orbiter in one of two ways. The first method would be to lock his boots into a portable foot restraint (see Appendix B) affixed to the sidewall or the centerline of the payload bay. The second method would be for the IRV pilot to "land" on the forward payload bay bulkhead, as shown in Figure 6.1. He would then attach the free end of the left adjustable wrist tether (the other end being connected to the left torso tether ring) to the vertical handrail above the airlock hatch and shorten it until it held the the IRV firmly against the bulkhead. The thermal protection blanket which covers the bulkhead would serve as a docking fender to prevent damage to the MMU or the orbiter.

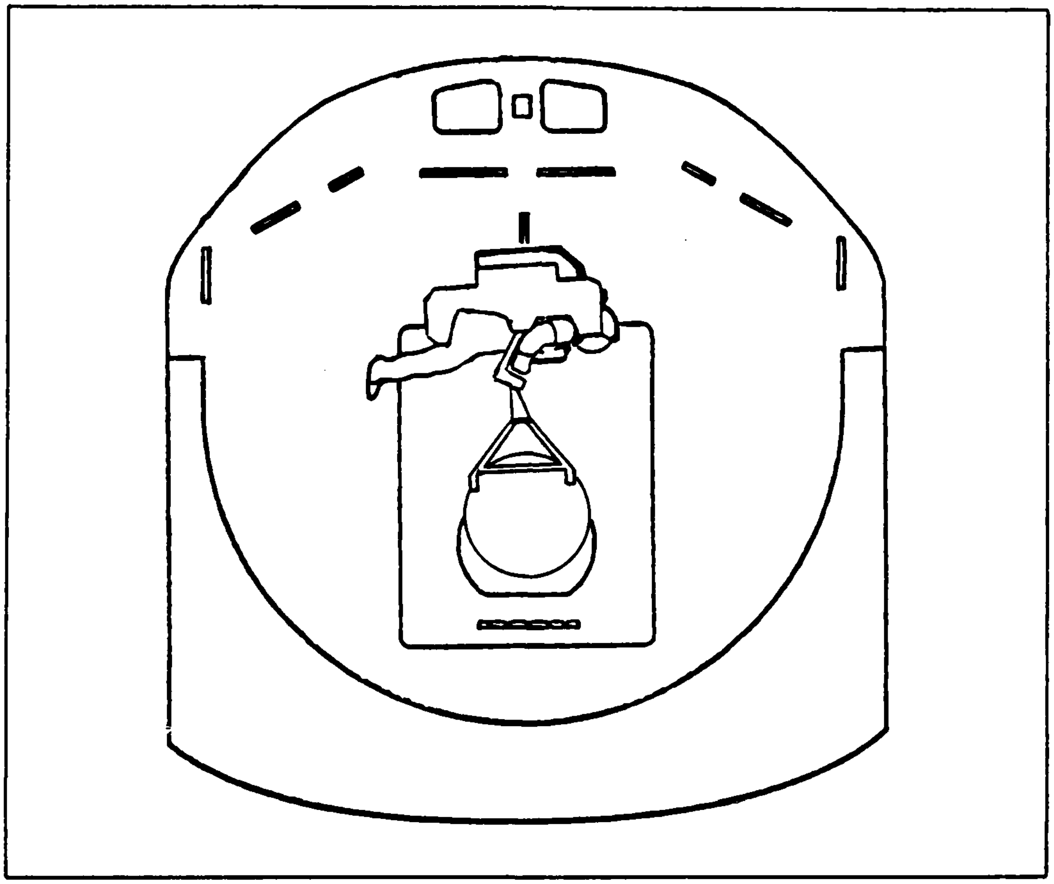


Figure 6.1. IRV Attached to Forward Bulkhead of Stranded Orbiter

After docking, the EVA stranded astronaut would open the outer airlock hatch, disconnect one PRE from its air umbilical and remove it from the airlock, and position it for attachment to the modified ACD.

To attach the PRE, the EVA stranded astronaut would extend the 4-foot tether from the MMU pilot's Mini-Work Station so that the tether projected forward out of the modified ACD's "basket", and would attach the tether to the

PRE's carrying strap. The self-reeling tether's .6 lb of takeup force would slowly retract the PRE into the modified ACD's "basket" and pull the carrying strap within reach of the MMU pilot (18:3.3-3). The MMU pilot would connect the adjustable wrist tether from the right torso tether ring to the carrying strap, and tighten it as necessary to secure the PRE against the modified ACD structure (34). The IRV would then return to the rescue orbiter.

Upon reaching the rescue orbiter's payload bay, the IRV pilot and EVA rescue astronaut would disconnect the PRE and place it in the airlock. The EVA rescue astronaut would attach an air umbilical to the PRE. The IRV pilot would then begin another flight to the stranded orbiter to pick up the next PRE.

After the IRV's departure from the stranded orbiter with the second PRE, the stranded EVA astronaut would close the outer airlock door and the airlock would be pressurized to accept two more PREs. After the second PRE was inserted into the rescue orbiter's airlock it, too, would be pressurized and the PREs removed into the main cabin, where their occupants would egress. The rescue orbiter's airlock would then be depressurized again in preparation for receiving two more PREs. This cycle would be repeated until all PREs were transferred.

IRV Recharging

Definitive IRV endurance figures which take into account the intense maneuvering necessary for docking with the tumbling orbiter can only be obtained in a real-time, high fidelity simulation, and therefore were beyond the capabilities of MILMU. However, it is certain that the rescue procedure described above would have to be interrupted several times to allow recharging of the MMU's propellant tanks.

When recharging was necessary, the IRV pilot would hand off the PRE to the EVA rescue astronaut, then land on the Flight Support Station's foot restraint platform and lock the MMU into the Flight Support Station's latches as described in Chapter II. To save time, he and the modified ACD would stay attached to the MMU. After depositing the PRE in the airlock, the EVA rescue astronaut would translate to the Flight Support Station, connect the recharging hose, and refuel the MMU's propellant tanks. A full recharge would take approximately five minutes (9:4-23--4-24).

Spacesuited Stranded Astronaut Transfer

The two spacesuited stranded astronauts would be transferred to the rescue orbiter after all PREs had been transported. Procedures for this transfer have been developed and tested by Johnson Space Center's Crew System's Division and the Martin Marietta Aerospace Corporation.

Following the transfer of the last PRE, the modified ACD would be removed from the MMU and returned to its cradle. The Mini-Work Station would also be doffed. The

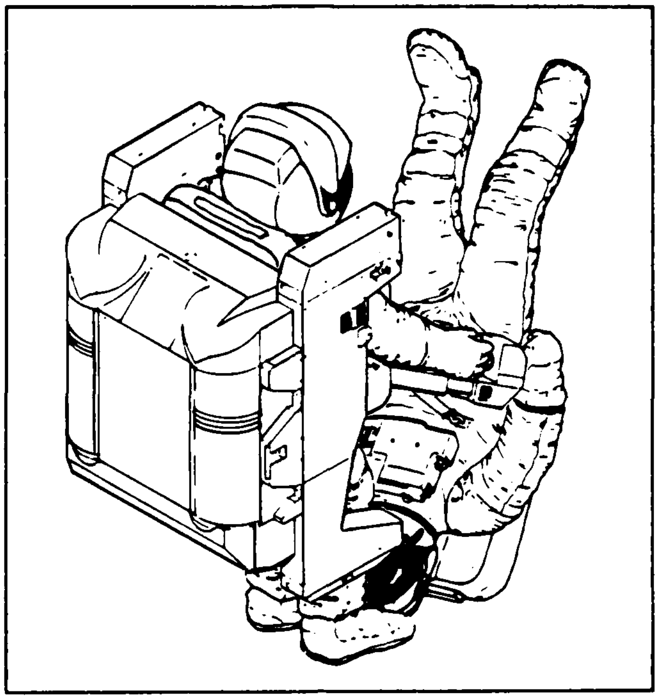


Figure 6.2. Spacesuited Crewmember Rescue (26:6)

MMU pilot would then return to the stranded orbiter and position himself in front of, but upside down with respect to, a stranded EVA astronaut who would be secured in a portable foot restraint.

The MMU pilot would attach the two adjustable wrist tethers from his torso rings to the victim's torso rings and shorten them to pull the victim securely against the MMU controller arms and the pilot's lower legs. Figure 6.2 shows the resulting configuration. The stranded EVA astronaut would then step out of the foot restraint, and the MMU pilot would fly back to the rescue orbiter. The procedure would be repeated for the second spacesuited stranded astronaut (26:6).

Rogers reports that this method of connecting a spacesuited astronaut to the MMU has been tested in Johnson Space Center's Weightless Environment Training Facility, and found acceptable (26:4). In addition, Martin Marietta's MMU simulator was programmed with the mass properties of this configuration and several simulated rescue scenarios flown. The results of the simulations showed control response to be sluggish but stable (26:7).

Comments

Faster rescue operations could be achieved by simultaneously using two IRVs. Essentially the same procedures as described above could be used.

The proposed rescue procedures assume that the required number of PREs and portable oxygen systems are carried aboard the stranded orbiter. If this were not the case, portable oxygen systems and deflated PREs could be carried to the stranded orbiter by the IRV on its first fly-over. All equipment would be placed inside one PRE, which would be inflated and attached to the modified ACD as already explained. Upon arrival at the stranded orbiter, the PRE would be inserted into the airlock, repressurized, and its contents distributed to the non-spacesuited stranded astronauts. Subsequent procedures would remain unchanged from those already described.

The proposed procedures also assume an operational airlock on the stranded orbiter. Should this not be the case, two stranded astronauts could don their spacesuits and all others would enter their PREs. The stranded orbiter's entire cabin would then be depressurized and rescue operations conducted through either the airlock hatch or the side hatch. This alternative procedure would require close monitoring of each PRE's remaining oxygen, and possibly cycling the PREs across the two air umbilicals to preclude portable oxygen system exhaustion prior to rescue.

Chapter Summary

This chapter has answered Research Question 3 by proposing procedures for using the IRV to rescue the crew of a stranded space shuttle orbiter. Although approach and docking simulation proved impossible because of MILMU's slow update cycle time, baseline procedures were presented for rescue preparations, rescue operations, and IRV recharging. Alternative procedures were outlined for the simultaneous use of two IRVs, carrying the PREs to a non-equipped stranded orbiter, and rescue operations with a stranded orbiter suffering airlock failure.

VII. Conclusions and Recommendations

Chapter Overview

This chapter presents the three research questions and summarizes the answers as determined by this project. Also presented is a list of recommended follow-on research.

Conclusions

Research Question 1: "What is a mechanically and operationally sound method of attaching the PRE to the MMU, using only minimally modified and available flight-qualified hardware, to arrive at an Interim Rescue Vehicle (IRV)?

Answer: A list of requirements was developed describing a suitable MMU/PRE connecting device. This list included: off-the-shelf components, adequate pilot visibility, ease of use, ease of stowage, lack of critical fits, quick response, crew safety, and adequate IRV performance and stability. The Apogee Kick Motor Capture Device (ACD) was modified and fit tests conducted with the MMU, PRE, and ACD payload bay attachment bracket. These tests revealed that the modified ACD adequately fulfilled all requirements except ease of use, and was inconclusive concerning visibility, stability, and performance.

The ease of use requirement was violated because the PRE carrying strap fell eight inches outside the reach of the MMU pilot. Therefore, it was recommended that the PRE carrying straps be lengthened from their current six to twenty inches. Furthermore, it was recommended that the IRV pilot be equipped with a hook tool for grappling the PRE handle and pulling it within his grasp. It was shown that this tool could be obtained by modifying the standard EVA Probe tool.

A visibility experiment was conducted on 22 USAF pilots which indicated that the visibility afforded by the IRV configuration was sufficient for successful flight operations.

Research Question 2: "What is the stability and performance of the IRV?

Answer: This question was answered by simulating IRV flying qualities with an already existing NASA MMU flight simulation computer program, Man-In-The-Loop Maneuvering Unit (MILMU). First, the required inputs were gathered concerning MMU, modified ACD, PRE, victim, and portable oxygen system mass properties to arrive at the mass properties of the complete IRV. Also, plume impingement information was obtained. The program was validated by simulating the solo MMU and comparing the predicted performance to published figures. Simulation was then conducted to determine IRV stability and performance. IRV simulation runs included translational and rotational commands in the Primary, Backup, and Satellite Stabilization modes. Results showed that the automatic attitude hold control system was capable of limiting uncommanded IRV rotations to within the control law deadbands during all simulated maneuvers and in all control modes, except during Y translations in the

Backup control mode. The IRV's increased mass and increased center-of-mass/center-of-thrust offset significantly degraded acceleration and specific fuel consumption rate when operating in the Primary control mode, especially for Y- and Z-axis maneuvers. Plume impingement, however, was found to be of minor importance. Translational accelerations in the Backup control mode were found to be one-half those in the Primary mode, but rotational accelerations were unaffected. The Satellite Stabilization mode was found to have significant rotational-to-translational coupling which made it undesireable for IRV use.

Research Question 3: What procedures will the stranded and rescue crews follow to conduct a successful save using the IRV?"

Answer: Current EVA procedures were studied and predicted IRV capabilities considered to propose baseline procedures for IRV use in rescuing the crew of a stranded space shuttle orbiter. Procedures were presented for rescue preparations, rescue operations, and IRV recharging. Alternative procedures were outlined for the simultaneous use of two IRVs, carrying the PREs to a non-equipped stranded orbiter, and rescue operations with a stranded orbiter suffering airlock failure.

Recommendations

This report has been furnished to NASA, and the enclosed data on IRV stability and performance should be evaluated by

NASA EVA experts to determine if this vehicle offers acceptable control response for space rescue operations.

Assuming an affirmative determination is made, additional simulation is required to document IRV propellant consumption during tthe approach and docking to the tumbling stranded orbiter, and to validate or amend the rescue procedures presented in Chapter VI. MILMU as implemented on the Hewlett-Packard 9825 had an excessive integration cycle time which made it unsuitable for simulating the approach and docking phase. Therefore, it is recommended that such simulations be conducted using the MILMU program on a faster computer or with the Martin Marietta Corporation's MMU simulator.

IRV performance and stability suffer because the modified ACD is larger and weighs more than would a specifically designed connecting device. Therefore, it is recommended that procurement of a next-generation MMU/PRE attachment device be pursued. If properly planned, this device could also serve as a "generic" MMU attachment device suitable for carrying a wide range of payloads. Design of such a device should be preceded by a study which explores the tradeoff between the favorable mass properties obtained by a closely mounted payload versus the stability and performance degradation caused by the accompanying increased plume impingement. In this way, an optimum compromise location could be identified.

The increasing space shuttle flight rate is exposing a growing number of astronauts to the hazards inherent in a space operations program which does not include a formal rescue plan. This report has proposed an interim space rescue ferry vehicle which appears to provide a rudimentary but immediately available capability for rescuing the crew of a stranded, slowly tumbling spacecraft. If the recommended additional studies are pursued and the results favorable, the proposed design can fulfill, for the short term, a segment of the nation's space rescue requirements.

Appendix A

Thruster Label Diagram and Thruster Select Tables

The following tables present the thruster select logic incorporated in the MMU's Control Electronics Assembly. The first page is a diagram explaining the thruster labeling scheme. All information is reprinted from Volume I of the MMU Operational Data Book (Reference 9).

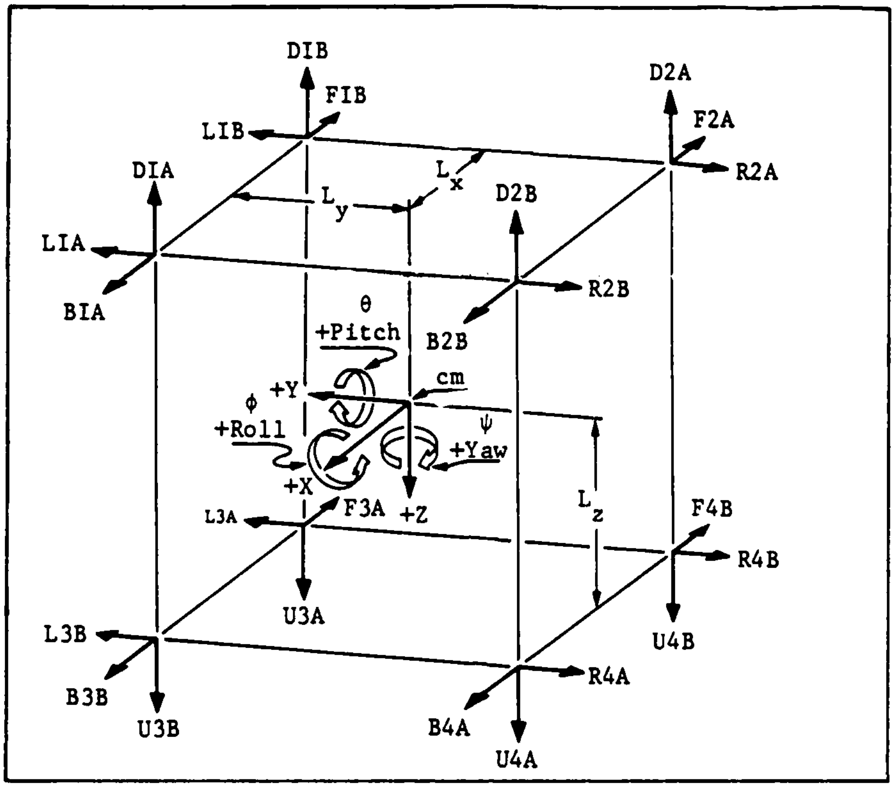


Figure A.1. Thruster Label Diagram

Note:

1. Intended direction of motion when thruster is activated: F, Forward; B, Backward; R, Right; L, Left; U, Up; D, Down.
2. A and B are separate redundant systems.
3. X, Y, and Z axes' origins are at center of mass (cm).
4. +X direction, forward (astronaut faces toward +X). +Y direction, right (along astronaut's extended right arm). +Z direction, down (along astronaut's extended legs).
5. L-lever arm for thrusters.
6. The arrows at the thruster designators indicate the nitrogen expulsion direction. Force on the MMU is in the opposite direction.

Reference Coordinate System, Thruster Triad Arrangement, and Nomenclature

X, Theta (Pitch), and Psi (Yaw) Logic Prime Mode

	CMDS			PRIME MODE							
	X	Θ	Ψ	F1B	F2A	F3A	F4B	B1A	B2B	B3B	B4A
1	+			1	1	1	1				
2	-							1	1	1	1
3		+				1		1			
4		-		1						1	
5			+		1			1			
6			-	1					1		
7	+	+				1	1				
8	+	-		1	1						
9	-	+						1	1		
10	-	-								1	1
11	+		+		1		1				
12	+		-	1		1					
13	-		+					1		1	
14	-		-						1		1
15		+	+				1	1			
16		+	-			1			1		
17		-	+		1					1	
18		-	-	1							1
19	+	+	+		1	1	1	1			
20	+	+	-	1		1	1		1		
21	+	-	+	1	1		1			1	
22	+	-	-	1	1	1					1
23	-	+	+				1	1	1	1	
24	-	+	-			1		1	1		1
25	-	-	+		1			1		1	1
26	-	-	-	1					1	1	1

Table XXI

Thruster Select Logic Tables

Y, Phi (Roll), and Psi (Yaw) Logic Prime Mode

	CMDS			PRIME MODE							
	Y	Φ	Ψ	R2A	R2B	R4A	R4B	L1A	L1B	L3A	L3B
64	+			1	1	1	1				
65	-							1	1	1	1
66		+		1						1	
67		-					1		1		
68			+				All Zero				
69			-								
70	+	+		1	1						
71	+	-				1	1				
72	-	+								1	1
73	-	-						1	1		
74	+		+		1	1					
75	+		-	1			1				
76	-		+						1	1	
77	-		-					1			1
78		+	+		1					1	
79		+	-	1							1
80		-	+			1			1		
81		-	-				1	1			
82	+	+	+	1	1						
83	+	+	-	1	1						
84	+	-	+			1	1				
85	+	-	-			1	1				
86	-	+	+							1	1
87	-	+	-							1	1
88	-	-	+					1	1		
89	-	-	-					1	1		

Z, Phi (Roll), and Theta (Pitch) Logic Prime Mode

	CMDS			PRIME MODE							
	Z	ϕ	Θ	D1A	D1B	D2A	D2B	U3A	U3B	U4A	U4B
127	+			1	1	1	1				
128	-							1	1	1	1
129		+		All Zero							
130		-									
131			+	All Zero							
132			-								
133	+	+		1	1						
134	+	-				1	1				
135	-	+								1	1
136	-	-						1	1		
137	+		+		1	1					
138	+		-	1			1				
139	-		+						1	1	
140	-		-					1			1
141		+	+	All Zero							
142		+	-								
143		-	+	All Zero							
144		-	-								
145	+	+	+		1	1					
146	+	+	-	1			1				
147	+	-	+		1	1					
148	+	-	-	1			1				
149	-	+	+						1	1	
150	-	+	-					1			1
151	-	-	+						1	1	
152	-	-	-					1			1

X, Theta (Pitch), and Psi (Yaw) Logic Backup Mode

	CMDS			BACK UP MODE A				BACK UP MODE B			
	X	Θ	Ψ	F2A	F3A	B1A	B4A	F1B	F4B	B2B	B3B
1											
2	+			1	1			1	1		
3	-					1	1			1	1
4		+			1	1			1	1	
5		-		1			1	1			1
6			+	1		1			1		1
7			-		1		1	1		1	
8	+	+			1	1			1	1	
9	+	-		1			1	1			1
10	-	+			1	1			1	1	
11	-	-		1			1	1			1
12	+		+	1		1			1		1
13	+		-		1		1	1		1	
14	-		+	1		1			1		1
15	-		-		1		1	1		1	
16		+	+		1	1			1	1	
17		+	-		1	1			1	1	
18		-	+	1			1	1			1
19		-	-	1			1	1			1
20	+	+	+	1	1	1			1		
21	+	+	-		1			1	1	1	
22	+	-	+	1				1	1		1
23	+	-	-	1	1		1	1			
24	-	+	+			1			1	1	1
25	-	+	-		1	1	1			1	
26	-	-	+	1		1	1				1
27	-	-	-				1	1		1	1

Y, Z, and Phi (Roll) Logic Backup Mode

	CMDS			BACKUP MODE A								BACKUP MODE B							
	Y	Z	ϕ	R2A	R4A	L1A	L3A	D1A	D2A	U3A	U4A	R2B	R4B	L1B	L3B	D1B	D2B	U3B	U4B
65																			
66	+			1	1							1	1						
67	-					1	1							1	1				
68		+						1	1							1	1		
69		-								1	1							1	1
70			+	1			1					1			1				
71			-		1	1							1	1					
72	+	+		1	1			1	1			1	1			1	1		
73	+	-		1	1					1	1	1	1					1	1
74	-	+				1	1	1	1					1	1	1	1		
75	-	-				1	1			1	1			1	1			1	1
76	+		+	1	1			1			1	1	1			1			1
77	+		-	1	1				1	1		1	1				1	1	
78	-		+			1	1	1			1			1	1	1			1
79	-		-			1	1		1	1				1	1		1	1	
80		+	+	1			1	1	1			1			1	1	1		
81		+	-		1	1		1	1				1	1		1	1		
82		-	+	1			1			1	1	1			1			1	1
83		-	-		1	1				1	1		1	1				1	1
84	+	+	+	1			1	1	1			1			1	1	1		
85	+	+	-		1	1		1	1				1	1		1	1		
86	+	-	+	1			1			1	1	1			1			1	1
87	+	-	-		1	1				1	1		1	1				1	1
88	-	+	+	1			1	1	1			1			1	1	1		
89	-	+	-		1	1		1	1				1	1		1	1		
90	-	-	+	1			1			1	1	1			1			1	1
91	-	-	-		1	1				1	1		1	1				1	1

X, Theta (Pitch), Psi (Yaw) Logic

	X	θ	ψ	F1B	F2A	F3A	F4B	B1A	B2B	B3B	B4A
				SATELLITE STABILIZATION							
1	+			1	1	1	1				
2	-							1	1	1	1
3		+									
4		-									
5			+								
6			-								
7	+	+		1	1	1	1				
8	+	-		1	1	1	1				
9	-	+						1	1	1	1
10	-	-						1	1	1	1
11	+		+	1	1	1	1				
12	+		-	1	1	1	1				
13	-		+					1	1	1	1
14	-		-					1	1	1	1
15		+	+								
16		+	-								
17		-	+								
18		-	-								
19	+	+	+	1	1	1	1				
20	+	+	-	1	1	1	1				
21	+	-	+	1	1	1	1				
22	+	-	-	1	1	1	1				
23	-	+	+					1	1	1	1
24	-	+	-					1	1	1	1
25	-	-	+					1	1	1	1
26	-	-	-					1	1	1	1

Y, Phi (Roll), and Psi (Yaw) Logic

	CMDS			SATELLITE STABILIZATION							
	Y	Ø	Ψ	R2A	R2B	R4A	R4B	L1A	L1B	L3A	L3B
64	+			1	1	1	1				
65	-							1	1	1	1
66		+		1	1					1	1
67		-				1	1	1	1		
68			+						1	1	
69			-	1			1				
70	+	+		1	1						
71	+	-				1	1				
72	-	+								1	1
73	-	-						1	1		
74	+		+		1	1			1	1	
75	+		-	1			1				
76	-		+						1	1	
77	-		-	1			1	1			1
78		+	+		1				1	1	1
79		+	-	1	1		1				1
80		-	+			1		1	1	1	
81		-	-	1		1	1	1			
82	+	+	+		1					1	
83	+	+	-	1	1		1				1
84	+	-	+			1			1		
85	+	-	-	1		1	1	1			
86	-	+	+		1				1	1	1
87	-	+	-	1							1
88	-	-	+			1		1	1	1	
89	-	-	-				1	1			

Z, Phi (Roll), and Theta (Pitch) Logic

	CMDS			SATELLITE STABILIZATION							
	Z	Ø	Θ	D1A	D1B	D2A	D2B	U3A	U3B	U4A	U4B
127	+			1	1	1	1				
128	-							1	1	1	1
129		+									
130		-									
131			+		1	1					
132			-					1			1
133	+	+		1	1	1	1				
134	+	-		1	1	1	1				
135	-	+						1	1	1	1
136	-	-						1	1	1	1
137	+		+		1	1					
138	+		-	1			1	1			1
139	-		+		1	1			1	1	
140	-		-					1			1
141		+	+		1	1					
142		+	-					1			1
143		-	+		1	1					
144		-	-					1			1
145	+	+	+		1	1					
146	+	+	-	1			1	1			1
147	+	-	+		1	1					
148	+	-	-	1			1	1			1
149	-	+	+		1	1			1	1	
150	-	+	-					1			1
151	-	-	+		1	1			1	1	
152	-	-	-					1			1

Appendix B

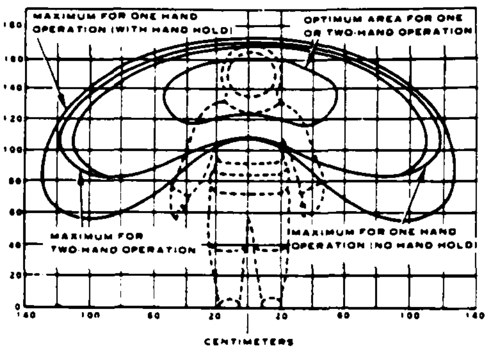
Standard EVA Equipment

This appendix contains further descriptions of standard NASA extra-vehicular activity (EVA) equipment items referred to in the main text. The following descriptions are reprinted from NASA's Satellite Services Catalog (Reference 20).

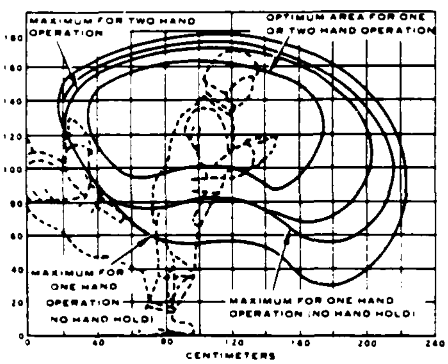
EXTRAVEHICULAR MOBILITY UNIT

Overview

The Extravehicular Mobility Unit (EMU) is a self-contained system which provides crew members with environmental protection, life support, communication, visibility, and mobility to perform numerous types of extravehicular activities (EVA's).



EVA CREW MEMBER SIDE REACH ENVELOPE



EVA CREW MEMBER FORE-AFT REACH ENVELOPE

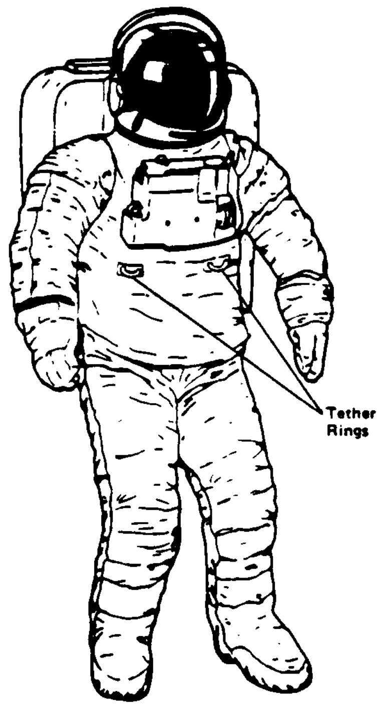


Figure B.1

Catalog no. A1-101
September 1983

Performance Description

The EMU can provide the crew member with multiple EVA periods during a single flight. The EMU has an on-orbit recharge capability.

Standard Orbiter provisioning for each mission includes required expendables to provide two crew members the capability each to perform two 6-hour, planned EVA's and one 6-hour Orbiter contingency EVA. A 30-minute secondary oxygen supply is provided as a backup to the primary oxygen system. Instrumentation and a microprocessor subsystem provide for monitoring the status of the EMU performance and expendables, for alerting the crew member to any abnormal system function, and for advising that any subsequent corrective action be taken.

Standard interface attachments include the Manned Maneuvering Unit, the Mini Work Station, the Tool Caddies, the EMU Television System, the EMU Lights, and the Wrist and Waist Tethers. Two EMU's are flown on all Shuttle missions to provide contingency EVA capability.

References

Space Transportation System: EVA Description and Design Criteria, Rev. A. JSC-10615.

Information Contact

Harley L. Stutesman, Jr./EC6 (713) 483-4931

MINI WORK STATION

Overview

The Mini Work Station (MWS) is used to tether an extravehicular (EVA) crew member at a worksite and to serve as a tool carrier during the EVA performance.

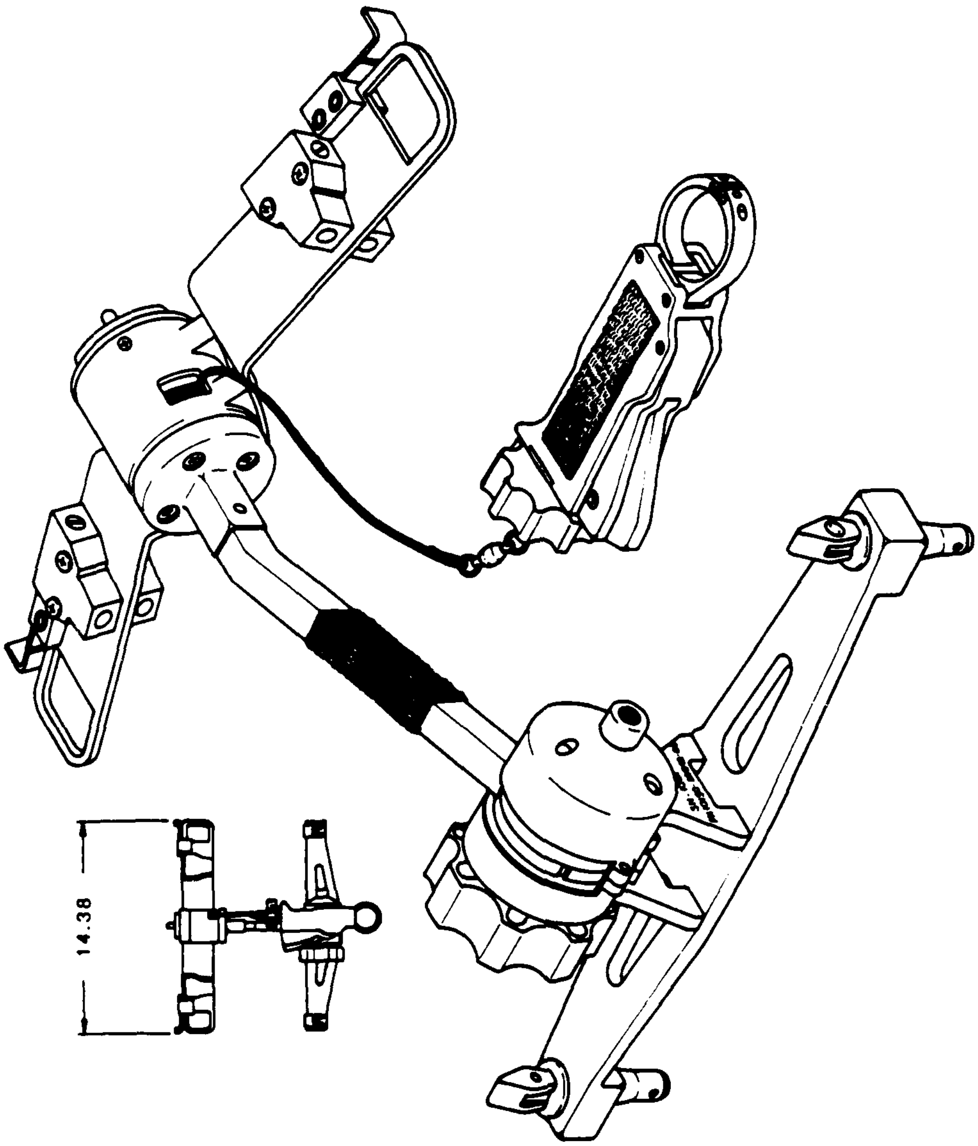


Figure B.2. MINI-WORKSTATION 10150-10050-05

Performance Description

The MWS consists of an attaching bracket and pins, a position-adjusting mechanism, a T-bar, and a work tether. The MWS attaching bracket has two integral pip pins which insert into a mounting bracket on the hard upper torso of the Extravehicular Mobility Unit (EMU). The position-adjusting mechanism attaches the T-bar to the MWS attaching bracket and allows the T-bar to pivot. The T-bar may be rotated away from the EMU up to 170° and secured in the desired position. It is controlled by a lock-release hand knob on the right-hand side. The MWS T-bar incorporates four pin-and-slot mounting brackets for attaching tool carriers or tools. Caddies are locked in place by slide locks. Two brackets are on the inside of the bar and two are on the outside. The T-bar also incorporates the work tether and tether D-rings. The MWS work tether holds the crew member in the work area. The tether, mounted at the upper T-intersection, is a 4-ft self-retracting cord with a multipurpose end effector; it is either released or locked by means of a lever on top of the reel case. The end effector will hook around circular sections (handrails, door drive linkages, latch actuating rods) up to 1.6 in. in diameter. The end effector can also be clamped onto a flat plate by using a torque knob which is tightened down to prevent slippage. Silicone tips on the end of the jaws also aid in keeping the end effector from slipping when installed on a flat plate. A clutch on the tether lock will slip when a 75-lb force is applied.

The crew member attaches the end effector, positions himself as desired, and locks the tether in place. One MWS is stowed in a crew compartment middeck locker. The second MWS is stowed in the Cargo Bay Stowage Assembly.

References

Beiriger, J.: EVA PLBD Contingency Tools Description Document. Flight Operations Directorate, NASA/JSC, Houston, Texas. Jan. 1981.

Information Contact

Ralph J. Marak/EC6 (713) 483-4336

WRIST AND WAIST TETHERS

Overview

Wrist and Waist Tethers are used to attach a crew member to a worksite or to tether tools which are not capable of being stowed during the work period.

Performance Description

The Wrist and Waist Tethers consist of a fabric strip with a hook on each end. Buttons on both sides of the hook must be squeezed simultaneously to open the hook. The Waist Tethers are 24 in. in length (excluding hooks) and are limited to 60 lb of force. The Wrist Tethers are 14 in. in length, and one of them is adjustable. The Wrist Tether is attached to a loop on the Extravehicular Mobility Unit (EMU) glove, and the Waist Tether is attached to a ring on the EMU waist.

Normally flown on each flight are one nonadjustable Wrist Tether per suit (total of two); one adjustable Wrist Tether per suit (total of two); and two Waist Tethers per suit (total of four).

References

Beiriger, J.: EVA PLBD Contingency Tools Description Document. Flight Operations Directorate, NASA/JSC, Houston, Texas. Jan. 1981.

Information Contact

Ralph J. Marak/EC6 (713) 483-4336

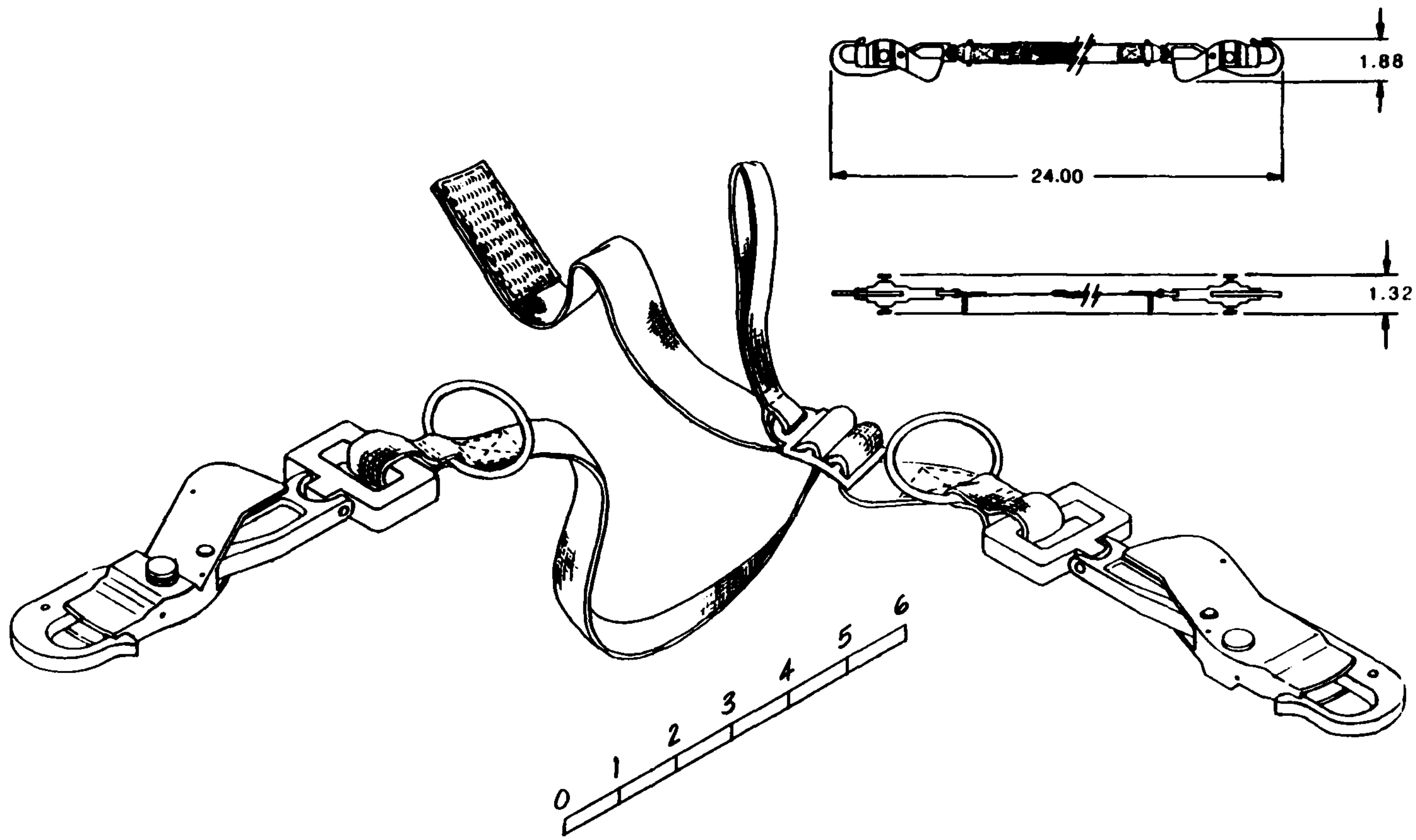


Figure B.3. **WRIST TETHER ASSY 10151-20041-02**

TOOL CADDY

Overview

The Tool Caddy serves three purposes - the stowage of extravehicular activity tools in the Cargo Bay Stowage Assembly, the transfer of tools to the worksite, and the tethering of the tools at the worksite.

Performance Description

The Tool Caddy consists of an 8- by 13-in. stiffened fabric which folds over the tools, closes, and seals with velcro; a tether tab with a 1-in. ring; a pin lock which attaches to a slot fitting on the Mini Work Station; and two split-ring-and-swivel attachments on 3-ft, self-retracting tethers. The split rings and swivels attach a maximum of two tools to each caddy, and four caddies can be attached to one Mini Work Station simultaneously. The tools are held in place by mating velcro on the tools with velcro on the caddy surface. Four caddies containing eight jam removal tools are stowed in middeck locker MF43G with the Mini Work Station. Other caddies are stowed in the Cargo Bay Stowage Assembly.

PROBE

Overview

The Probe is used as a disconnect and jam removal tool.

Performance Description

The Probe is a rod, 0.188-in. in diameter, with a flattened tip similar to that of a screwdriver. It is 8-5/8-in. long excluding the handle.

References

Beiriger, J.: EVA PLBD Contingency Tools Description Document. Flight Operations Directorate, NASA/JSC, Houston, Texas. Jan. 1981.

Information Contact

Fred A. McAllister/EC3 (713) 483-4729

GETAWAY SPECIAL BEAM

Overview

The Getaway Special (GAS) Beam is a structural frame to which small payloads can be attached.

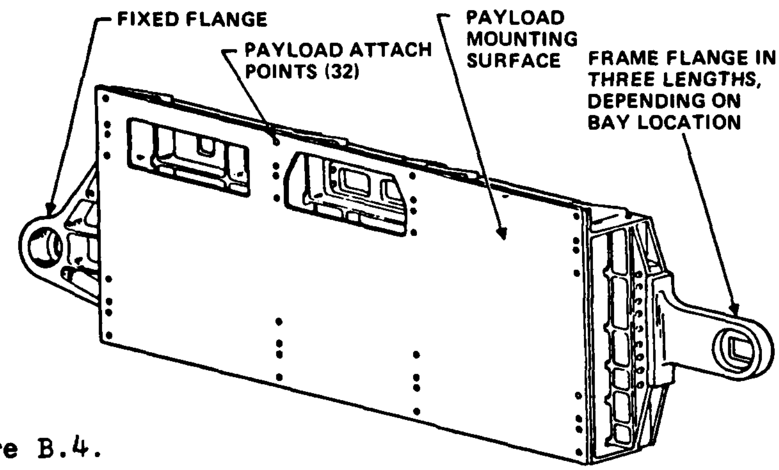


Figure B.4.

Performance Description

The GAS Beam, which connects to the longerons on either side of the Cargo Bay, can be attached at any of 30 sites, and a total of 30 GAS Beams may be carried on a Shuttle mission. The GAS Beam does not contain any interface provisions for electrical power, control, or monitoring.

Specifications

Beam length: 52.3 in.
Beam width: 6.0 in.
Beam height: 22.4 in.

Maximum weight of payload at a 6.0-in. moment arm: 300 lb

References

Fitting Assembly - Adapter Beam Bridge Getaway Special. Drawing no. V724-340001, Rockwell.

Space Shuttle Interface Control Document. ICD-A-14021, November 1979.

STS and Get Away Special (GAS) Payload Integration Plan, Rev. B. JSC-14021, March 1983.

Catalog no. B3-107
September 1983

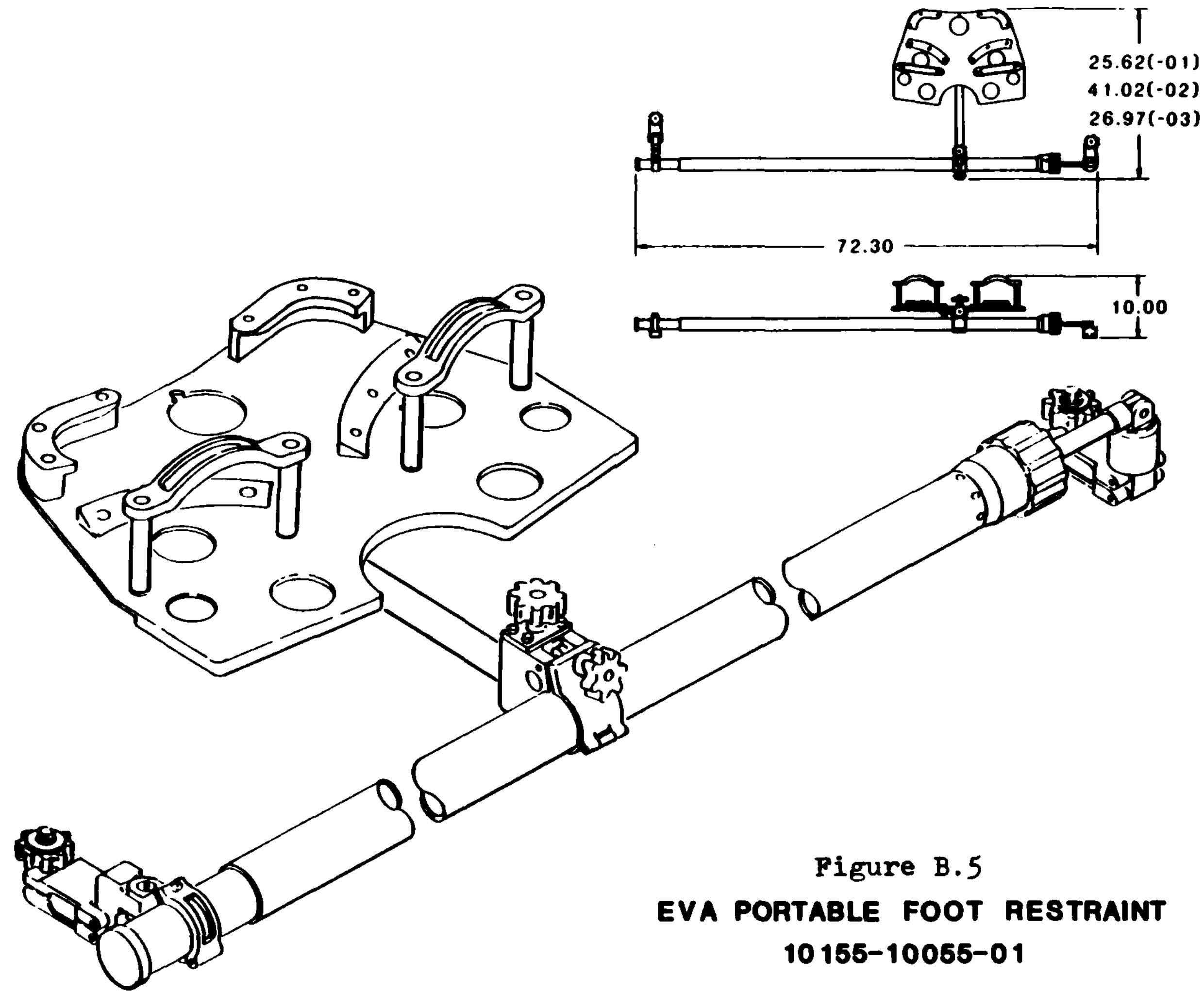


Figure B.5

EVA PORTABLE FOOT RESTRAINT

10155-10055-01

Appendix C

IRV Visibility Experiment

This appendix contains the results for the MMU visibility experiment referenced in Chapter III. The first page is a tabulation of the results. The second page presents the statistical calculations performed on the results.

Table XXII

Experimental Results

Test Subject Eye Level (inches)	Disc Height (inches)	"Over-the-top" Visibility (inches)	(degrees)
68.75	67.75	1.00	1.081
67.75	66.75	1.00	1.081
67.375	68.00	- .625	- .676
71.125	71.75	- .625	- .676
63.75	63.75	0.0	0.0
64.3125	64.50	- .1875	- .203
62.375	62.5	- .125	- .135
68.00	66.50	1.50	1.621
69.875	67.50	2.375	2.566
68.00	68.3125	- .3125	- .338
64.25	64.25	0.00	0.00
68.625	67.125	1.50	1.621
68.25	68.4375	- .1875	- .203
66.5	67.00	- .50	- .541
62.25	62.6875	- .4375	- .473
67.00	66.875	.125	.135
70.50	69.50	1.00	1.081
64.125	64.75	- .625	- .676
64.50	64.00	.50	.541
67.00	66.875	.125	.135
68.25	67.50	.75	.811
69.0625	66.50	2.5625	2.768

Over-the-top visibility (inches) = Eye Level - Disc Height
Over-the-top visibility (degrees): [illegible]

Statistical Calculations

$$\text{Mean} = X = (\ X\ )/N \quad \text{(Miller:150)} \qquad (21)$$

and

$$\text{Standard Deviation} = \frac{(X - X)}{N - 1} \quad \text{(Miller:151)} \qquad (22)$$

where X is the ith experimental result and N is the sample size. Applying Eqns (21) and (22) to the experimental results on the previous page resulted in:

$$\text{Mean (degrees)} = X = .433 \qquad (23)$$

$$\text{Standard Deviation (degrees)} = s = 1.023 \qquad (24)$$

Establishing a null hypothesis H : 3.341 = X, and an alternative hypothesis H : 3.341 > X, and assuming that the sample comes from a normal population, the Student-t distribution is the appropriate distribution for testing the hypotheses (Miller:172). The normalized test statistic is defined as:

$$t = \frac{3.341 - X}{s/\ N} \qquad (25)$$

Applying Eqn (25) to the experimental results:

$$t = \frac{3.341 - .433}{1.023/22} = 13.33 \qquad (26)$$

Entering the Student-t distribution chart (Miller:488) with a value of 13.33, for N-1 = 21 degrees of freedom, reveals that it can be said with greater than 99.5 percent confidence that the null hypothesis (3.341 = X) is false.

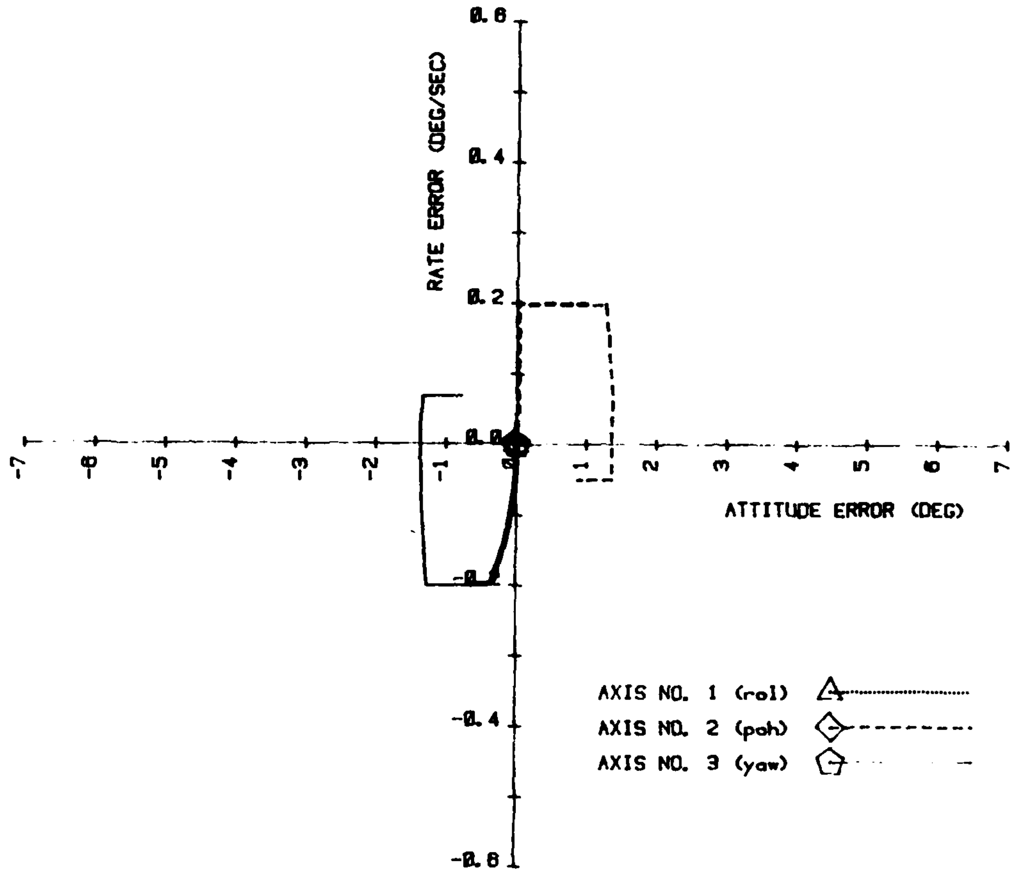
Appendix D

MILMU IRV Simulation Phase Plane Plots and End-of-Simulation State Vector Printouts

This appendix contains the phase plane plots and end-of-simulation state vector printouts for all MILMU simulation runs. The particular run can be identified by the label at the top of the phase plane plot. The accompanying end-of-simulation printout follows each phase plane plot. All runs began with the same initial conditions, which were:

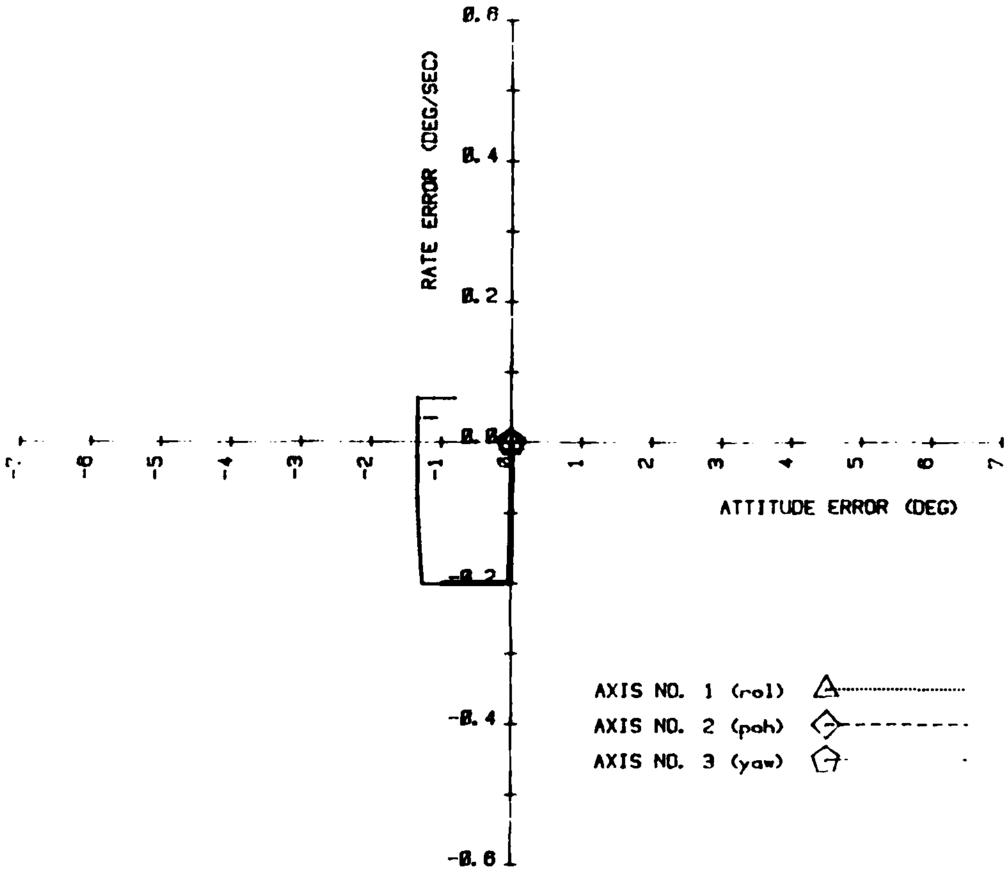
```
PET =      0.000 HHMM.SS          MET =      0.000 HHMM.SS

MU:RM50          0            0 -628537270 XYZ    4732.40       0.00       0.00 DXYZ
PL:RM50        300            0 -628537270 XYZ    4732.40       0.00       0.00 DXYZ

MU DATA ******** H     -90.00 DEC   -72.28 LON      1041 WT      111 ESUN    64.6 BETA
PL DATA ******** H     -90.00 DEC   -72.28 LON        21 WT      111 ESUN    64.6 BETA

MU:OM50 ******** SMA 0.00000 ECC    90.00 INC     0.00 RAN   -90.00 ARG      0.00 TRA
MU:IMLD ******** HA ******** HP     90.00 INC     0.00 RAN   -90.00 ARG      0.00 TRA

MU: M50      0.00 PCH     0.00 YAW     0.00 ROL    0.000 RXB    0.000 RYB    0.000 RZB
MU: MLV      0.00 PCH     0.00 YAW     0.00 ROL    0.000 RXB    0.000 RYB    0.000 RZB

PL:OM50 ******** SMA 0.00000 ECC    90.00 INC     0.00 RAN    90.00 ARG -180.00 TRA
PL:IMLD ******** HA ******** HP     90.00 INC     0.00 RAN    90.00 ARG -180.00 TRA

PL: M50     -0.00 PCH     0.00 YAW     0.00 ROL    6.000 RXB   -0.008 RYB    1.207 RZB
PL: PLV      0.00 PCH     0.00 YAW     0.00 ROL    6.000 RXB   -0.008 RYB    1.207 RZB

MU:CPLV     -0.049        0.000        0.000 XYZ       0.00       0.00      -0.00 DXYZ
PL:RMLV        300            0            0 XYZ      -0.00       0.00       0.00 DXYZ
PL:RMBY        300            0            0 XYZ      -0.00       0.00       0.00 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')


ISOLATION VALVE                   OPEN  A JETS        OPEN  B JETS
TEMPERATURE      (deg F)          0.00 A TANK         0.00 B TANK
PRESSURE         (LB/IN^2)     3000.00 A TANK      3000.00 B TANK
PROPELLANT WT    (LB)          15.1154 A TANK      15.1154 B TANK       30.2308 TOTAL

AMOUNT USED      (LB)           0.0000 A TANK       0.0000 B TANK        0.0000 TOTAL
```

#POST/MILMU VERSION Ø4GF (1134/18jun84)   SESSION BEGUN @ Ø53Ø / Ø8 NOV 1985
5 SEC +X TRANSLATION, SOLO MMU, PRIMARY CONTROL MODE
RUN Ø



```
PET =      0.200 HHMM.SS         MET =      0.200 HHMM.SS

MU:RM50       94666          -0 -628537263 XYZ    4733.63      -0.01        0.70 DXYZ
PL:RM50       94948           0 -628537263 XYZ    4732.40       0.00        0.71 DXYZ

MU DATA ######## H     -89.99 DEC   -72.36 LON       794 WT      111 ESUN    64.6 BETA
PL DATA ######## H     -89.99 DEC   -72.36 LON        21 WT      111 ESUN    64.6 BETA

MU:OM50 ######## SMA 0.00052 ECC    90.00 INC    -0.00 RAN  -90.24 ARG     0.25 TRA
MU:IMLD ######## HA ######## HP     90.00 INC    -0.00 RAN  -90.24 ARG     0.25 TRA

MU: M50      0.87 PCH    -0.80 YAW    -0.07 ROL   0.003 RXB  -0.049 RYB   0.069 RZB
MU: MLV      0.88 PCH    -0.80 YAW    -0.07 ROL   0.003 RXB  -0.049 RYB   0.069 RZB

PL:OM50 ######## SMA 0.00000 ECC    90.00 INC     0.00 RAN   90.00 ARG -180.00 TRA
PL:IMLD ######## HA ######## HP     90.00 INC     0.00 RAN   90.00 ARG -180.00 TRA

PL: M50      3.20 PCH    46.86 YAW   111.52 ROL   4.700 RXB   3.891 RYB  -0.487 RZB
PL: PLV      3.21 PCH    46.86 YAW   111.52 ROL   4.700 RXB   3.891 RYB  -0.487 RZB

MU:CPLV     -0.046      -0.000      -0.000 XYZ       1.23       -0.01       -0.01 DXYZ
PL:RMLV        282           0           0 XYZ      -1.23        0.01        0.01 DXYZ
PL:RMBY        282           4           4 XYZ      -1.22       -0.35       -0.25 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)         -2.93 A TANK        -2.93 B TANK
PRESSURE        (LB/IN^2)     2933.56 A TANK      2933.60 B TANK
PROPELLANT WT   (LB)          14.8755 A TANK      14.8757 B TANK      29.7512 TOTAL

AMOUNT USED     (LB)           0.2399 A TANK       0.2397 B TANK       0.4796 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0530 / 08 NOV 1985

5 SEC +X TRANSLATION,SOLO MMU,PRIMARY CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION Ø4GF (1134/18 Jun84)   SESSION BEGUN @ 0540 / 08 NOV 1985
5 SEC +Y TRANSLATION, SOLO MMU, PRIMARY CONTROL MODE
RUN Ø

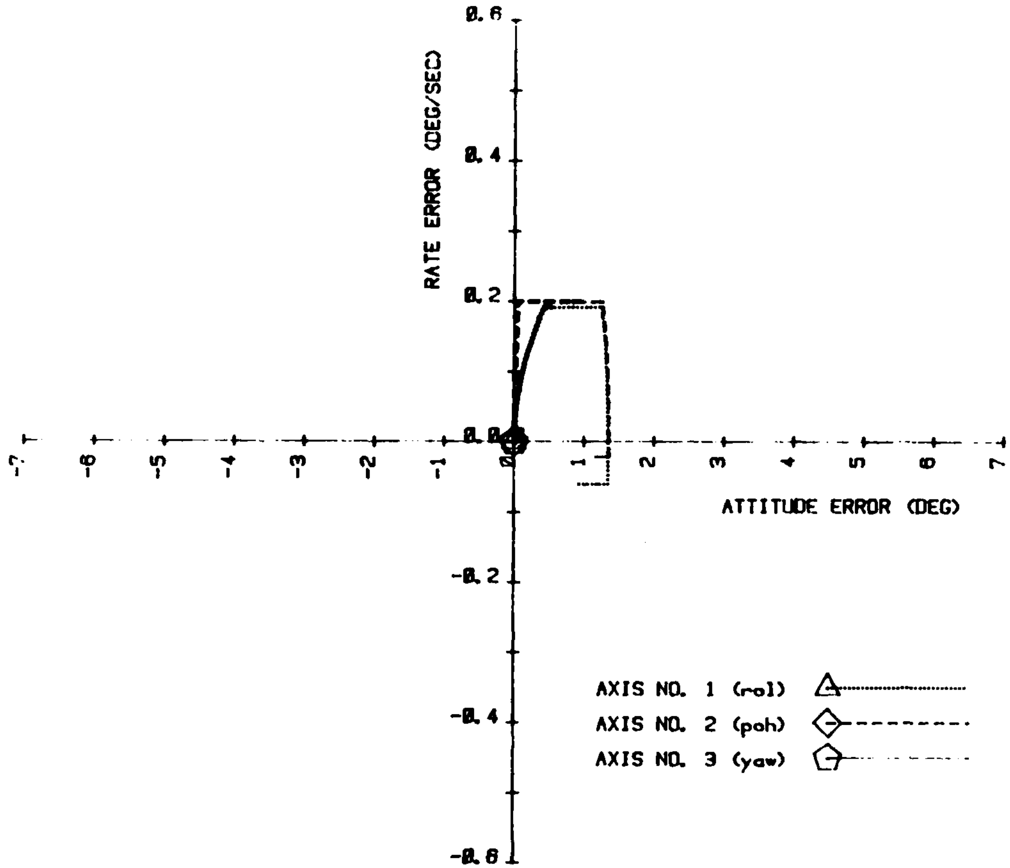


```
PET =      0.180 HHMM.SS          MET =      0.180 HHMM.SS

MU:RM50       85183          16 -628537265 XYZ    4732.41       1.20       0.63 DXYZ
PL:RM50       85483           0 -628537265 XYZ    4732.40       0.00       0.64 DXYZ

MU DATA ******** H      -89.99 DEC   -72.34 LON     794 WT      111 ESUN    64.7 BETA
PL DATA ******** H      -89.99 DEC   -72.35 LON      21 WT      111 ESUN    64.6 BETA

MU:OM50 ******** SMA 0.00000 ECC     90.00 INC     0.01 RAN -117.00 ARG    27.01 TRA
MU:IMLD ******** HA 99999.95 HP      90.00 INC     0.01 RAN -117.00 ARG    27.01 TRA

MU: M50     -0.02 PCH    -0.79 YAW    -1.05 ROL   0.035 RXB  -0.001 RYB   0.064 RZB
MU: MLV     -0.01 PCH    -0.81 YAW    -1.05 ROL   0.035 RXB  -0.001 RYB   0.064 RZB

PL:OM50 ******** SMA 0.00000 ECC     90.00 INC     0.00 RAN   90.00 ARG -180.00 TRA
PL:IMLD ******** HA ******** HP      90.00 INC     0.00 RAN   90.00 ARG -180.00 TRA

PL: M50      5.20 PCH    39.42 YAW   100.52 ROL   4.929 RXB   3.625 RYB  -0.188 RZB
PL: PLV      5.21 PCH    39.42 YAW   100.52 ROL   4.929 RXB   3.625 RYB  -0.189 RZB

MU:CPLV     -0.049        0.003       -0.000 XYZ       0.01       1.20      -0.01 DXYZ
PL:RMLV        300          -16            0 XYZ      -0.01      -1.20       0.01 DXYZ
PL:RMBY        300          -11           -0 XYZ      -0.01      -1.54      -0.01 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                 OPEN  A JETS        OPEN  B JETS
TEMPERATURE    (deg F)         -3.02 A TANK        -2.84 B TANK
PRESSURE       (LB/IN^2)     2931.45 A TANK      2935.50 B TANK
PROPELLANT WT  (LB)          14.8679 A TANK      14.8825 B TANK      29.7504 TOTAL

AMOUNT USED    (LB)           0.2475 A TANK       0.2329 B TANK       0.4804 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0540 / 08 NOV 1985

5 SEC +Y TRANSLATION,SOLO MMU,PRIMARY CONTROL MODE

END RUN NO.  0
```

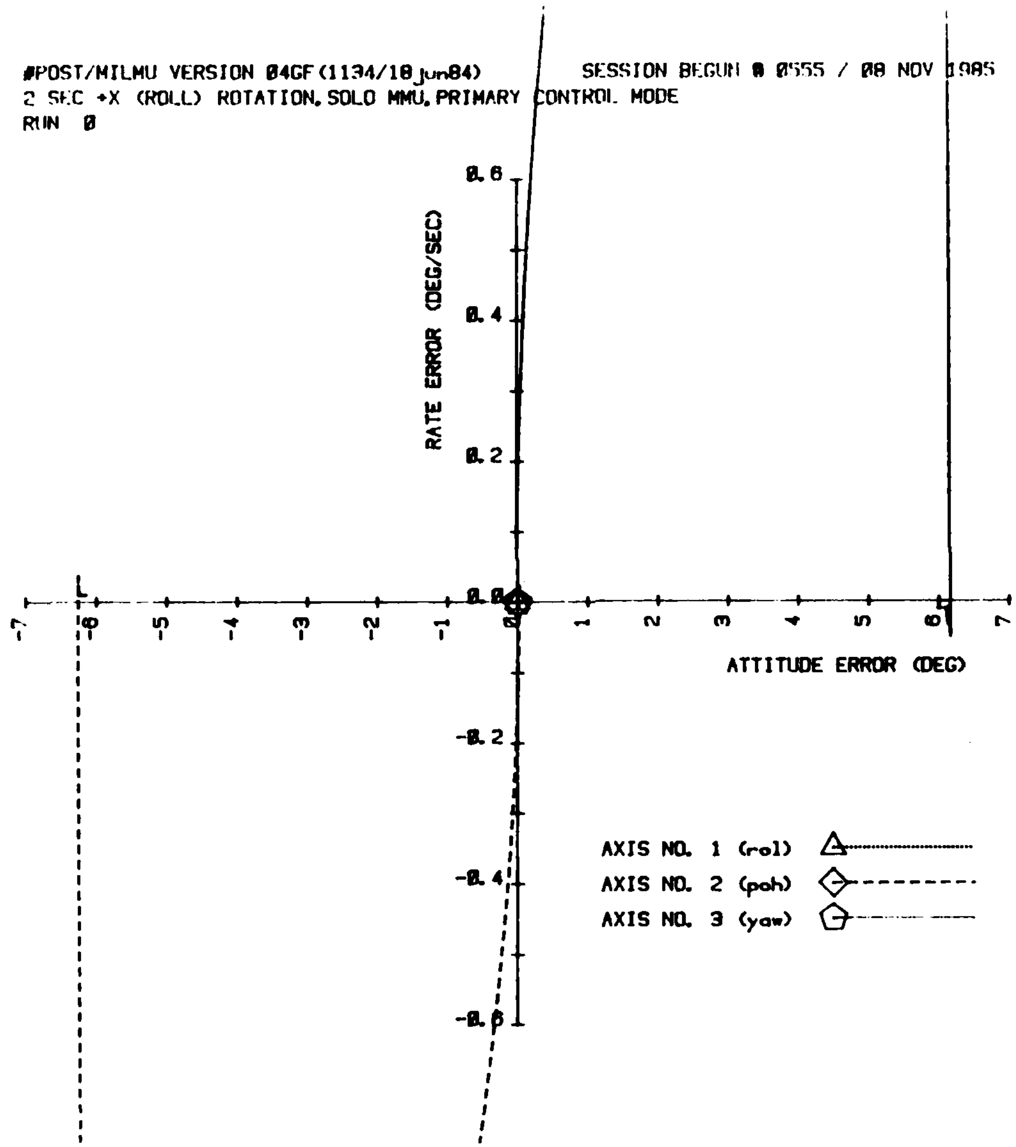
#POST/MILMU VERSION 04GF (1134/18 jun84)

5 SEC +Z TRANSLATION, SOLO MMU, PRIMARY CONTROL

RUN 0

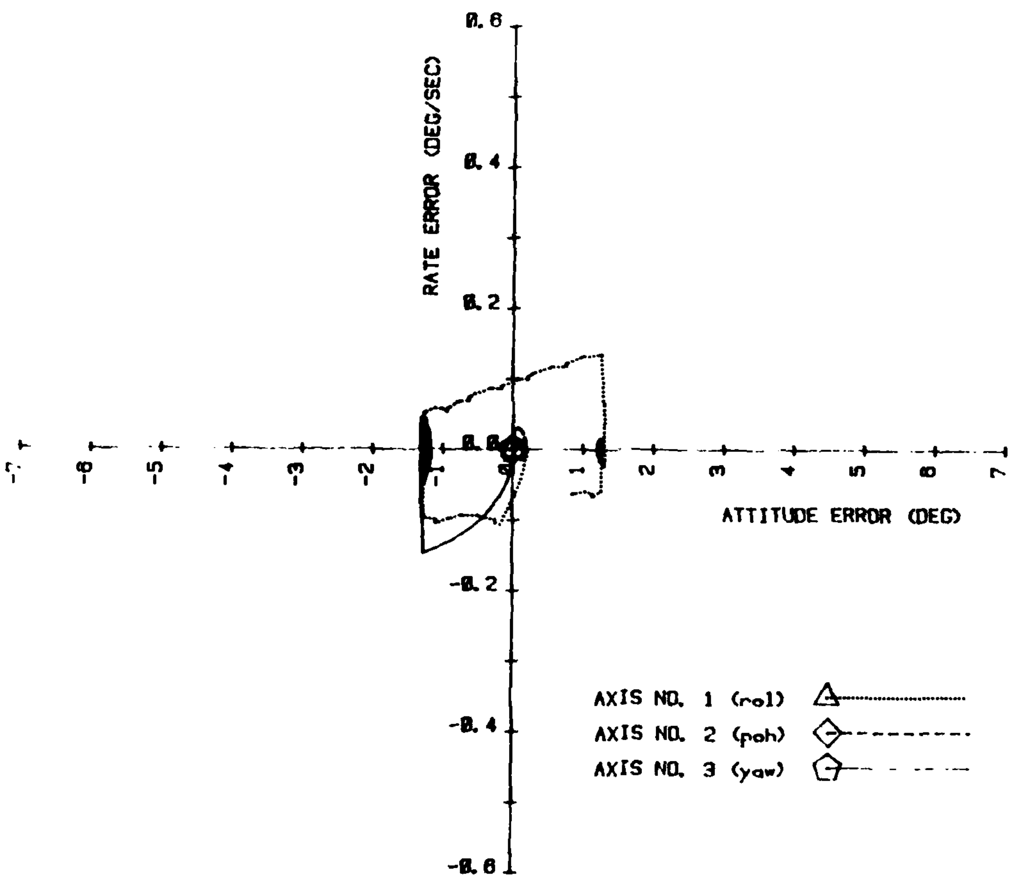


```
PET =      0.190 HHMM.SS          MET =      0.190 HHMM.SS

MU:RM50       89916          -0 -628537244 XYZ    4732.41      -0.00       2.03 DXYZ
PL:RM50       90216           0 -628537264 XYZ    4732.40       0.00       0.68 DXYZ

MU DATA $$$$$$$$ H     -89.99 DEC   -72.36 LON      794 WT      111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H     -89.99 DEC   -72.36 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00029 ECC    90.00 INC    -0.00 RAN    -0.91 ARG   -89.08 TRA
MU:IMLD $$$$$$$$ HA 99970.95 HP     90.00 INC    -0.00 RAN    -0.91 ARG   -89.08 TRA

MU: M50      1.16 PCH     0.09 YAW     0.90 ROL  -0.060 RXB  -0.021 RYB  -0.006 RZB
MU: MLV      1.17 PCH     0.09 YAW     0.90 ROL  -0.060 RXB  -0.021 RYB  -0.006 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC     0.00 RAN    90.00 ARG -180.00 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC     0.00 RAN    90.00 ARG -180.00 TRA

PL: M50      4.35 PCH    43.13 YAW   105.94 ROL   4.817 RXB   3.761 RYB  -0.334 RZB
PL: PLV      4.36 PCH    43.13 YAW   105.94 ROL   4.818 RXB   3.761 RYB  -0.334 RZB

MU:CPLV     -0.049     -0.000        0.003 XYZ       0.01      -0.00       1.35 DXYZ
PL:RMLV        300          0          -20 XYZ      -0.01       0.00      -1.35 DXYZ
PL:RMBY        300         -1          -14 XYZ       0.01       0.03      -1.46 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                   OPEN  A JETS       OPEN  B JETS
TEMPERATURE     (deg F)          -3.19 A TANK       -3.35 B TANK
PRESSURE        (LB/IN^2)      2927.61 A TANK     2923.97 B TANK
PROPELLANT WT   (LB)           14.8539 A TANK     14.8408 B TANK     29.6947 TOTAL

AMOUNT USED     (LB)            0.2614 A TANK      0.2746 B TANK      0.5361 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0545 / 08 NOV 1985

5 SEC +Z TRANSLATION,SOLO MMU,PRIMARY CONTROL MODE

END RUN NO.  0
```

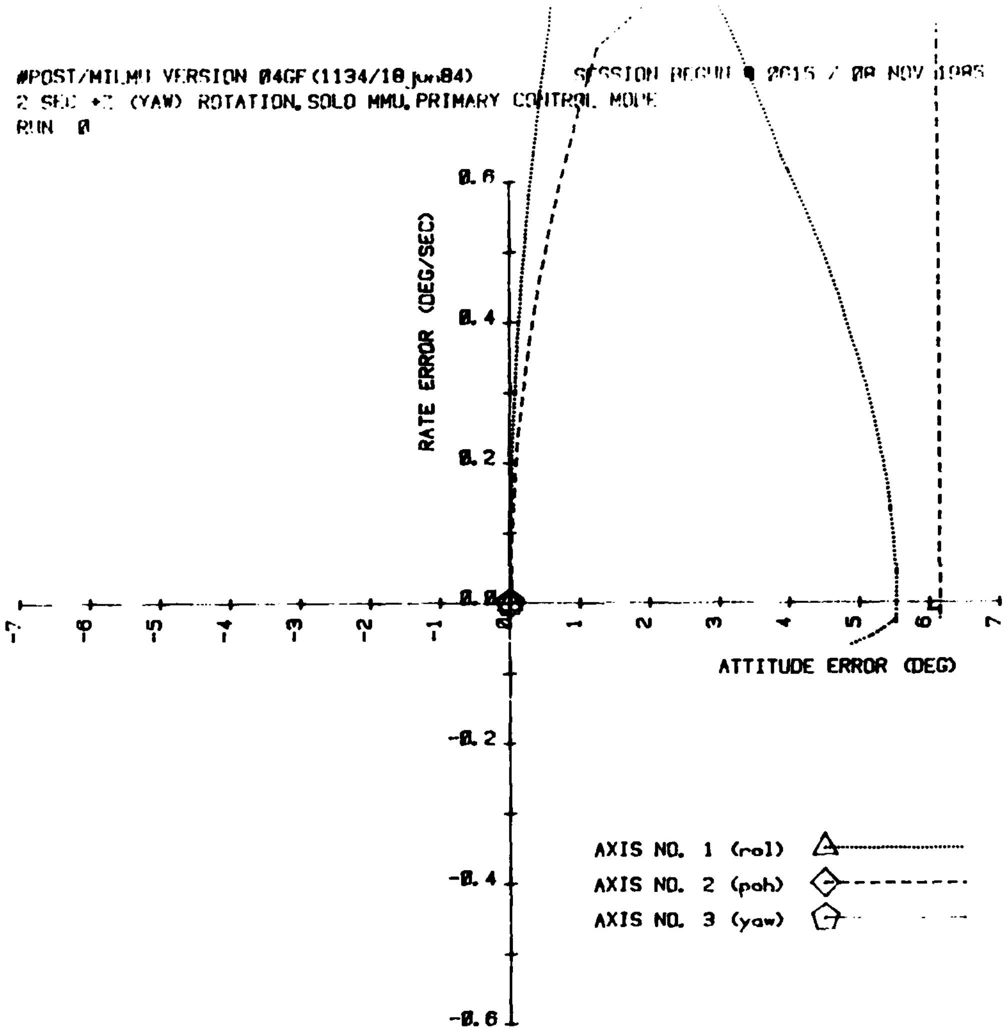

#POST/MILMU VERSION Ø4GF(1134/18jun84)
SESSION BEGUN @ Ø555 / Ø8 NOV 1985
2 SEC +X (ROLL) ROTATION, SOLO MMU, PRIMARY CONTROL MODE
RUN Ø
RATE ERROR (DEG/SEC)
Ø.6
Ø.4
Ø.2
Ø.Ø
-Ø.2
-Ø.4
-Ø.6
-7
-6
-5
-4
-3
-2
-1
Ø
1
2
3
4
5
6
7
ATTITUDE ERROR (DEG)
AXIS NO. 1 (rol)
AXIS NO. 2 (pch)
AXIS NO. 3 (yaw)

```
PET =      0.220 HHMM.SS          MET =      0.220 HHMM.SS

MU:RM50     104113           0 -628537262 XYZ    4732.40      0.00       0.78 DXYZ
PL:RM50     104413           0 -628537262 XYZ    4732.40      0.00       0.79 DXYZ

MU DATA $$$$$$$$ H     -89.99 DEC  -72.37 LON     794 WT     111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H     -89.99 DEC  -72.37 LON      21 WT     111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC    0.00 RAN  -89.99 ARG    0.00 TRA
MU:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC    0.00 RAN  -89.99 ARG    0.00 TRA

MU: M50     -4.50 PCH   -0.73 YAW   -0.90 ROL  18.159 RXB   0.010 RYB  -0.010 RZB
MU: MLV     -4.49 PCH   -0.73 YAW   -0.90 ROL  18.159 RXB   0.010 RYB  -0.010 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC    0.00 RAN   90.00 ARG -179.99 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC    0.00 RAN   90.00 ARG -179.99 TRA

PL: M50     -0.41 PCH   54.41 YAW  123.57 ROL   4.449 RXB   4.128 RYB  -0.814 RZB
PL: PLV     -0.40 PCH   54.41 YAW  123.57 ROL   4.449 RXB   4.128 RYB  -0.814 RZB

MU:CPLV      -0.049       0.000       0.000 XYZ      0.00      0.00      -0.00 DXYZ
PL:RMLV         300           0          -0 XYZ     -0.00      0.00       0.00 DXYZ
PL:RMBY         299           7         -23 XYZ      0.00     -7.11      -2.29 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)         -1.85 A TANK        -0.17 B TANK
PRESSURE        (LB/IN^2)     2957.97 A TANK      2996.13 B TANK
PROPELLANT WT   (LB)          14.9638 A TANK      15.1015 B TANK      30.0653 TOTAL

AMOUNT USED     (LB)           0.1516 A TANK       0.0139 B TANK       0.1655 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0555 / 08 NOV 1985

2 SEC +X (ROLL) ROTATION,SOLO MMU,PRIMARY CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 04GF (1134/18 jun84)   SESSION BEGUN @ 0000 / 08 NOV 1985
2 SEC +Y (PITCH) ROTATION, SOLO MMU, PRIMARY CONTROL MODE
RUN 0

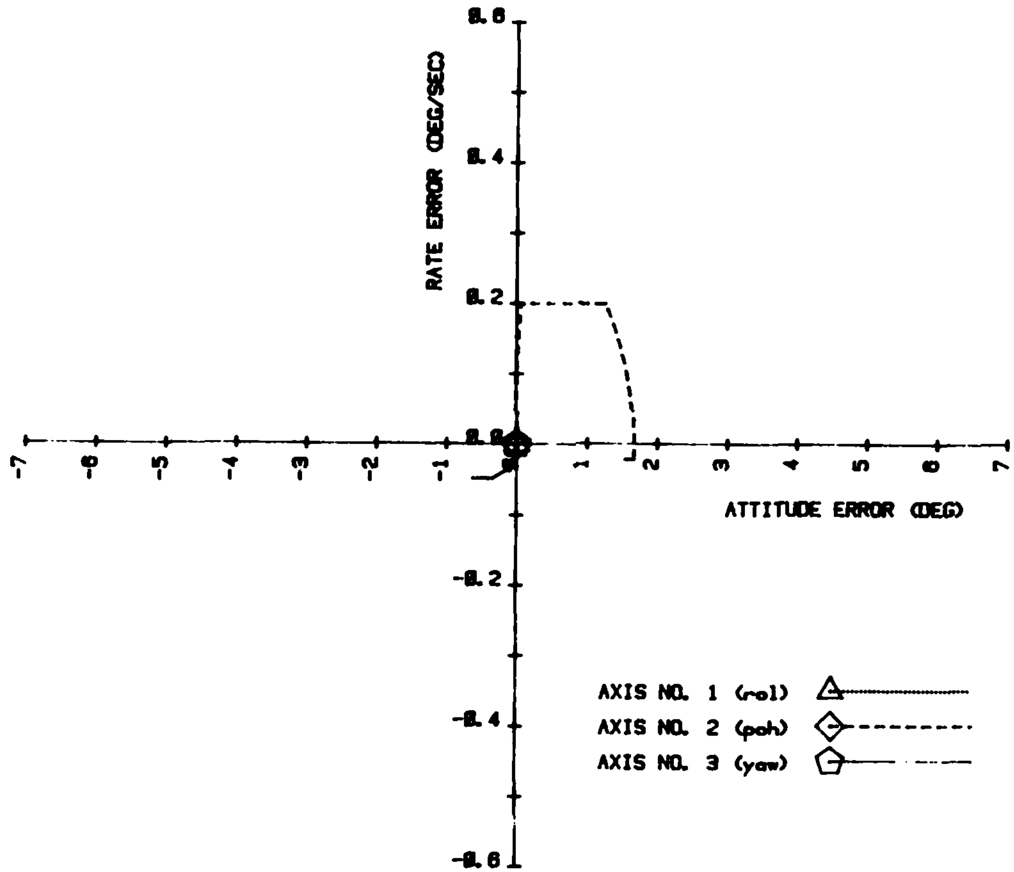


```
PET =      1.320 HHMM.SS          MET =      1.320 HHMM.SS

MU:RM50      435381          0 -628537120 XYZ     4732.40       0.00         3.28 DXYZ
PL:RM50      435681          0 -628537119 XYZ     4732.40       0.00         3.28 DXYZ

MU DATA ******** H     -89.96 DEC   -72.66 LON      794 WT      111 ESUN    64.6 BETA
PL DATA ******** H     -89.96 DEC   -72.66 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 ******** SMA 0.00000 ECC     90.00 INC     0.00 RAN   -89.96 ARG     0.00 TRA
MU:IMLD ******** HA ******** HP      90.00 INC     0.00 RAN   -89.96 ARG     0.00 TRA

MU: M50     37.80 PCH   -0.34 YAW    -1.16 ROL   -0.064 RXB  17.011 RYB   -0.024 RZB
MU: MLV     37.84 PCH   -0.34 YAW    -1.16 ROL   -0.064 RXB  17.011 RYB   -0.024 RZB

PL:OM50 ******** SMA 0.00000 ECC     90.00 INC     0.00 RAN    90.02 ARG -179.98 TRA
PL:IMLD ******** HA ******** HP      90.00 INC     0.00 RAN    90.02 ARG -179.98 TRA

PL: M50   -109.02 PCH   64.66 YAW    59.72 ROL    2.948 RXB  -4.597 RYB   -2.771 RZB
PL: PLV   -108.98 PCH   64.66 YAW    59.72 ROL    2.948 RXB  -4.597 RYB   -2.771 RZB

MU:CPLV      -0.049       0.000       0.000 XYZ       0.00       0.00        -0.00 DXYZ
PL:RMLV         300           0           0 XYZ      -0.00       0.00         0.00 DXYZ
PL:RMBY         237          -2         184 XYZ     -54.63      -0.11        70.34 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                    OPEN  A JETS        OPEN  B JETS
TEMPERATURE    (deg F)            -1.38 A TANK        -0.02 B TANK
PRESSURE       (LB/IN^2)        2968.48 A TANK      2999.63 B TANK
PROPELLANT WT  (LB)             15.0018 A TANK      15.1141 B TANK       30.1158 TOTAL

AMOUNT USED    (LB)              0.1136 A TANK       0.0013 B TANK        0.1149 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0600 / 08 NOV 1985

2 SEC +Y (PITCH) ROTATION,SOLO MMU,PRIMARY CONTROL MODE

END RUN NO.  0
```


#POST/MILMU VERSION 04GF (1134/18 jun84)
SESSION BEGUN 2015 / 08 NOV 1985
2 SEC +Z (YAW) ROTATION, SOLO MMU, PRIMARY CONTROL MODE
RUN 0
RATE ERROR (DEG/SEC)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
ATTITUDE ERROR (DEG)
AXIS NO. 1 (rol)
AXIS NO. 2 (pch)
AXIS NO. 3 (yaw)

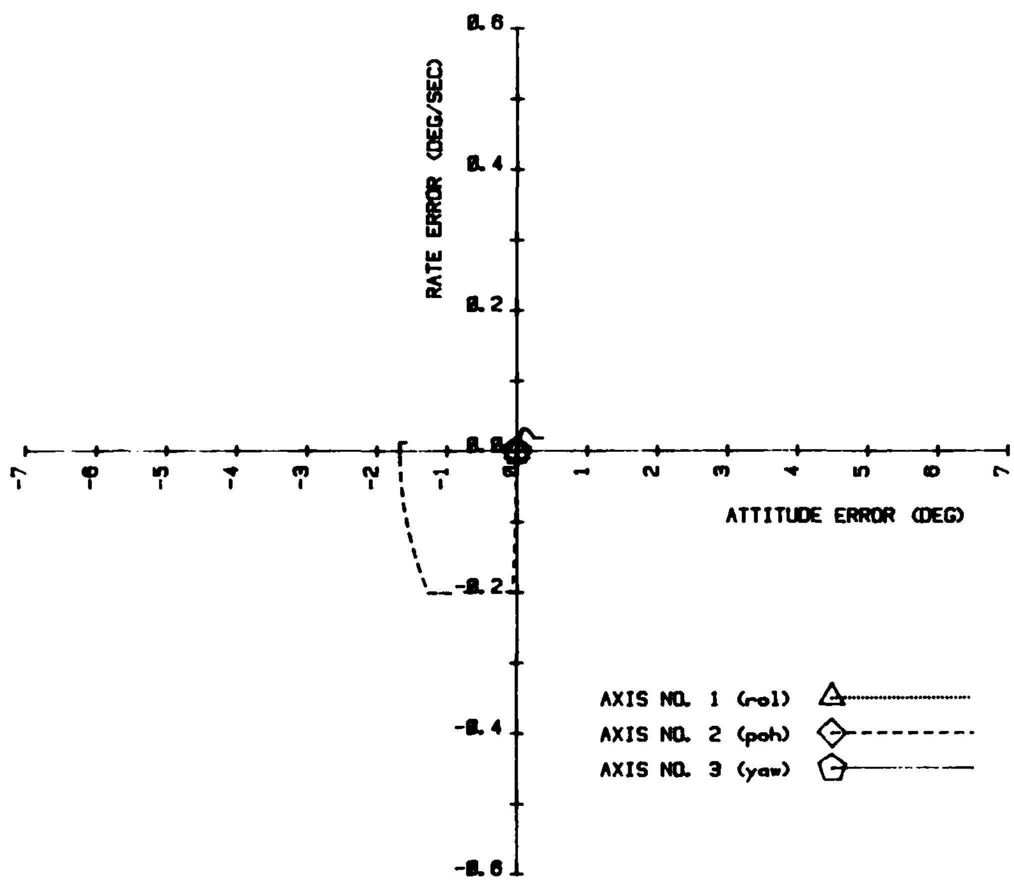
```
PET =      0.300 HHMM.SS          MET =       0.300 HHMM.SS

MU:RM50      141972           0 -628537254 XYZ     4732.40        0.00        1.07 DXYZ
PL:RM50      142272           0 -628537254 XYZ     4732.40        0.00        1.07 DXYZ

MU DATA $$$$$$$$ H     -89.99 DEC   -72.41 LON      794 WT      111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H     -89.99 DEC   -72.41 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC     0.00 RAN  -89.99 ARG     0.00 TRA
MU:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC     0.00 RAN  -89.99 ARG     0.00 TRA

MU: M50     7.03 PCH    62.55 YAW    -4.98 ROL  -0.061 RXB  -0.010 RYB  16.539 RZB
MU: MLV     7.04 PCH    62.55 YAW    -4.98 ROL  -0.061 RXB  -0.010 RYB  16.539 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC     0.00 RAN   90.01 ARG -179.99 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC     0.00 RAN   90.01 ARG -179.99 TRA

PL: M50   -83.07 PCH    70.95 YAW -127.97 ROL    3.373 RXB   4.602 RYB  -2.216 RZB
PL: PLV   -83.05 PCH    70.95 YAW -127.97 ROL    3.373 RXB   4.602 RYB  -2.216 RZB

MU:CPLV      -0.049       0.000       0.000 XYZ        0.00        0.00       -0.00 DXYZ
PL:RMLV         300           0          -0 XYZ       -0.00        0.00        0.00 DXYZ
PL:RMBY         137        -266          14 XYZ      -76.90      -39.63       -0.31 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)         -1.30 A TANK        -0.69 B TANK
PRESSURE        (LB/IN^2)     2970.43 A TANK      2984.31 B TANK
PROPELLANT WT   (LB)          15.0088 A TANK      15.0589 B TANK      30.0677 TOTAL

AMOUNT USED     (LB)           0.1066 A TANK       0.0565 B TANK       0.1631 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0615 / 08 NOV 1985

2 SEC +Z (YAW) ROTATION,SOLO MMU,PRIMARY CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 04GF(1134/18jun84) SESSION BEGUN @ 2045 / 07 NOV 1985
5 SEC +X TRANSLATION, IRV, W/IMPINGEMENT, PRIMARY CONTROL MODE
RUN 0



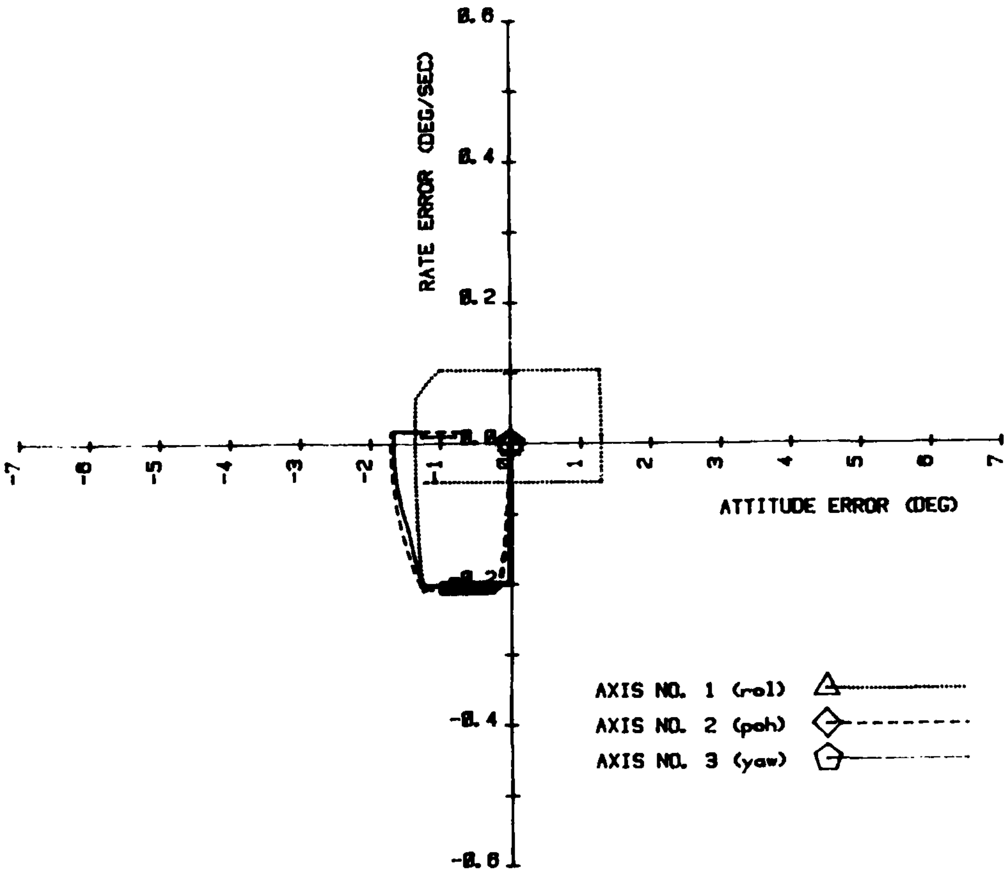
```
PET =       0.210 HHMM.SS          MET =       0.210 HHMM.SS

MU:RM50       99395          -0 -628537263 XYZ     4733.39      -0.00        0.74 DXYZ
PL:RM50       99680           0 -628537263 XYZ     4732.40       0.00        0.75 DXYZ

MU DATA ######## H      -89.99 DEC   -72.37 LON     1040 WT      111 ESUN    64.6 BETA
PL DATA ######## H      -39.99 DEC   -72.37 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 ######## SMA 0.00042 ECC    90.00 INC    -0.00 RAN   -90.23 ARG    0.24 TRA
MU:IMLD ######## HA ######## HP     90.00 INC    -0.00 RAN   -90.23 ARG    0.24 TRA

MU: M50       1.54 PCH    -0.62 YAW    -0.16 ROL  -0.013 RXB  -0.021 RYB  -0.048 RZB
MU: MLV       1.55 PCH    -0.62 YAW    -0.16 ROL  -0.013 RXB  -0.021 RYB  -0.048 RZB

PL:OM50 ######## SMA 0.00000 ECC    90.00 INC     0.00 RAN    90.00 ARG -179.99 TRA
PL:IMLD ######## HA ######## HP     90.00 INC     0.00 RAN    90.00 ARG -179.99 TRA

PL: M50       1.43 PCH    50.73 YAW   117.48 ROL   4.580 RXB   4.009 RYB  -0.643 RZB
PL: PLV       1.44 PCH    50.73 YAW   117.48 ROL   4.580 RXB   4.009 RYB  -0.643 RZB

MU:CPLV     -0.047      -0.000       -0.000 XYZ        0.99      -0.00       -0.01 DXYZ
PL:RMLV        286           0            0 XYZ       -0.99       0.00        0.01 DXYZ
PL:RMBY        286           3            8 XYZ       -0.99       0.23       -0.12 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS         OPEN  B JETS
TEMPERATURE     (deg F)         -3.05 A TANK         -3.12 B TANK
PRESSURE        (LB/IN^2)     2930.72 A TANK       2929.12 B TANK
PROPELLANT WT   (LB)          14.8652 A TANK       14.8594 B TANK        29.7247 TOTAL

AMOUNT USED     (LB)           0.2502 A TANK        0.2559 B TANK         0.5061 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)         SESSION BEGUN @ 2045 / 07 NOV 1985

5 SEC +X TRANSLATION,IRV,W/IMPINGEMENT,PRIMARY CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 04GF (1134/10 jun84)   SESSION BEGUN @ 2100 / 07 NOV 1985
5 SEC -X TRANSLATION, IRV, W/IMPINGEMENT, PRIMARY CONTROL MODE
RUN 0



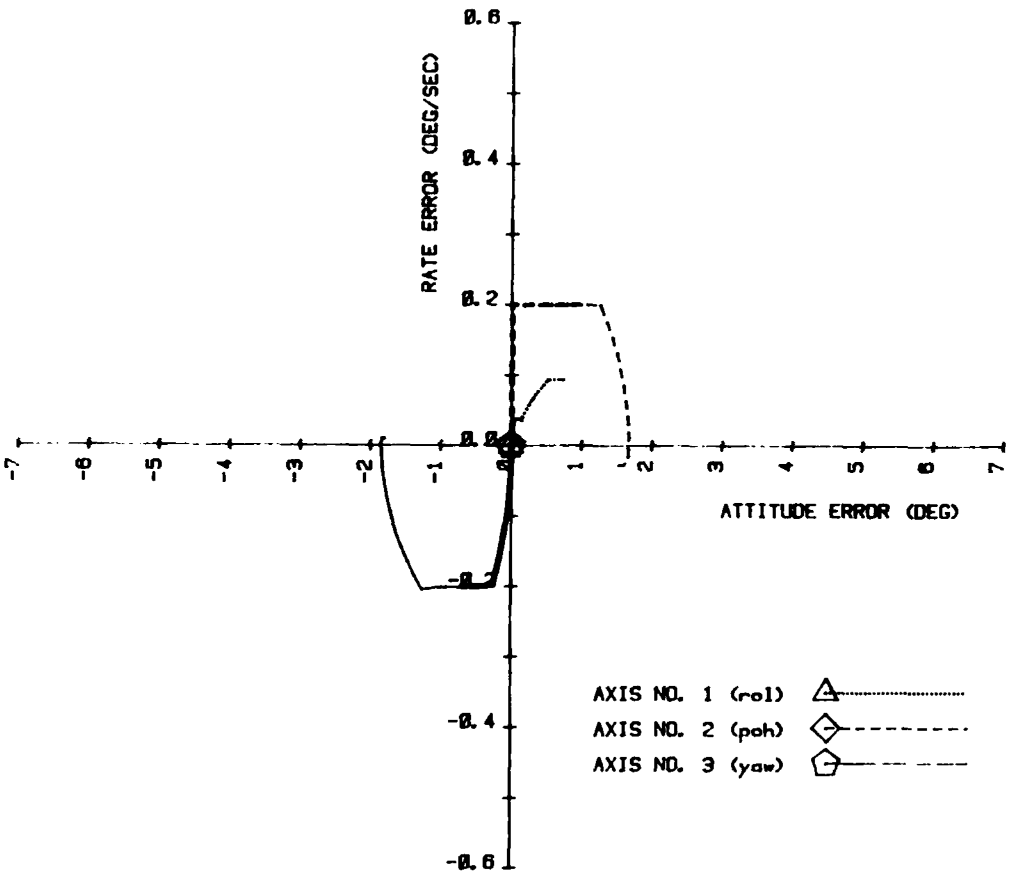
```
PET =      0.200 HHMM.SS          MET =      0.200 HHMM.SS


MU:RM50       94635          -0 -628537263 XYZ    4731.52      -0.00        0.71 DXYZ
PL:RM50       94948           0 -628537263 XYZ    4732.40       0.00        0.71 DXYZ

MU DATA $$$$$$$$ H    -89.99 DEC  -72.36 LON     1040 WT      111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H    -89.99 DEC  -72.36 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00037 ECC    90.00 INC   -0.00 RAN    89.97 ARG -179.96 TRA
MU:IMLD $$$$$$$$ HA 99922.95 HP     90.00 INC   -0.00 RAN    89.97 ARG -179.96 TRA

MU: M50     -1.58 PCH    0.37 YAW    0.02 ROL   0.001 RXB    0.013 RYB    0.019 RZB
MU: MLV     -1.57 PCH    0.37 YAW    0.02 ROL   0.001 RXB    0.014 RYB    0.019 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC    0.00 RAN    90.00 ARG -180.00 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC    0.00 RAN    90.00 ARG -180.00 TRA

PL: M50      3.14 PCH   46.89 YAW  111.55 ROL   4.701 RXB    3.890 RYB   -0.486 RZB
PL: PLV      3.15 PCH   46.89 YAW  111.55 ROL   4.701 RXB    3.890 RYB   -0.486 RZB

MU:CPLV     -0.052     -0.000      -0.000 XYZ      -0.88      -0.00        0.00 DXYZ
PL:RMLV        313          0           0 XYZ       0.88       0.00       -0.00 DXYZ
PL:RMBY        313         -2          -8 XYZ       0.88      -0.11        0.05 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS        OPEN  B JETS
TEMPERATURE    (deg F)          -3.08  A TANK       -3.01  B TANK
PRESSURE       (LB/IN^2)      2930.08  A TANK     2931.62  B TANK
PROPELLANT WT  (LB)           14.8629  A TANK     14.8685  B TANK      29.7314 TOTAL

AMOUNT USED    (LB)            0.2525  A TANK      0.2469  B TANK       0.4994 TOTAL
```

#POST/MILMU VERSION Ø4GF (1134/18 jun84)   SESSION BEGUN @ 2115 / Ø7 NOV 1985
5 SEC +Y TRANSLATION, IRV, W/IMPINGEMENT, PRIMARY CONTROL MODE
RUN Ø

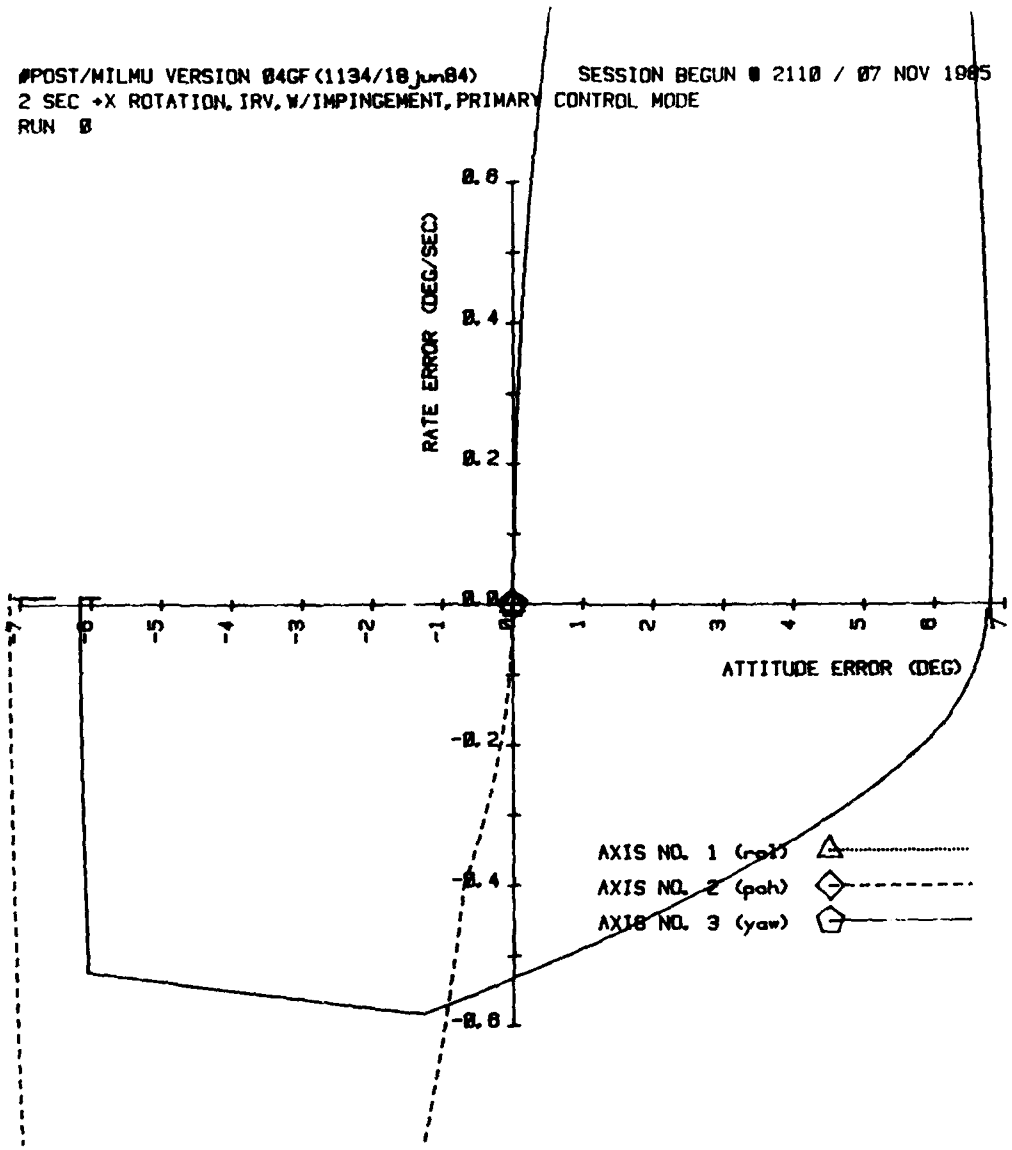


```
PET =      1.240 HHMM.SS          MET =      1.240 HHMM.SS

MU:RM50      397524          44 -628537144 XYZ     4732.43       0.57        3.01 DXYZ
PL:RM50      397821           0 -628537145 XYZ     4732.40       0.00        3.00 DXYZ

MU DATA ######## H      -89.96 DEC   -72.62 LON      1040 WT      111 ESUN    64.6 BETA
PL DATA ######## H      -89.96 DEC   -72.63 LON        21 WT      111 ESUN    64.6 BETA

MU:OM50 ######## SMA 0.00001 ECC    90.00 INC     0.01 RAN   -78.09 ARG   -11.87 TRA
MU:IMLD ######## HA 99999.97 HP     90.00 INC     0.01 RAN   -78.09 ARG   -11.87 TRA

MU: M50     -0.60 PCH    -0.76 YAW    -1.25 ROL   -0.055 RXB    0.016 RYB    0.011 RZB
MU: MLV     -0.56 PCH    -0.77 YAW    -1.25 ROL   -0.055 RXB    0.016 RYB    0.011 RZB

PL:OM50 ######## SMA 0.00000 ECC    90.00 INC     0.00 RAN    90.02 ARG -179.98 TRA
PL:IMLD ######## HA ######## HP     90.00 INC     0.00 RAN    90.02 ARG -179.98 TRA

PL: M50  -115.80 PCH   -30.04 YAW   170.99 ROL   -9.435 RXB   -9.446 RYB -18.903 RZB
PL: PLV  -115.76 PCH   -30.04 YAW   170.99 ROL   -9.435 RXB   -9.446 RYB -18.903 RZB

MU:CPLV      -0.049        0.007        0.000 XYZ        0.03        0.57        0.01 DXYZ
PL:RMLV         298          -44           -1 XYZ       -0.03       -0.57       -0.01 DXYZ
PL:RMBY         298          -40           -5 XYZ       -0.03       -0.62        0.02 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                 OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)        -4.67 A TANK        -1.86 B TANK
PRESSURE        (LB/IN^2)    2894.57 A TANK      2957.61 B TANK
PROPELLANT WT   (LB)         14.7340 A TANK      14.9625 B TANK       29.6966 TOTAL

AMOUNT USED     (LB)          0.3814 A TANK       0.1529 B TANK        0.5342 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 2115 / 07 NOV 1985

5 SEC +Y TRANSLATION,IRV,W/IMPINGEMENT,PRIMARY CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION Ø4GF (1134/18 jun84) SESSION BEGUN @ 2130 / 7 NOV 1985
5 SEC +Z TRANSLATION, IRV, W/IMPINGEMENT, PRIMARY CONTROL MODE
RUN Ø



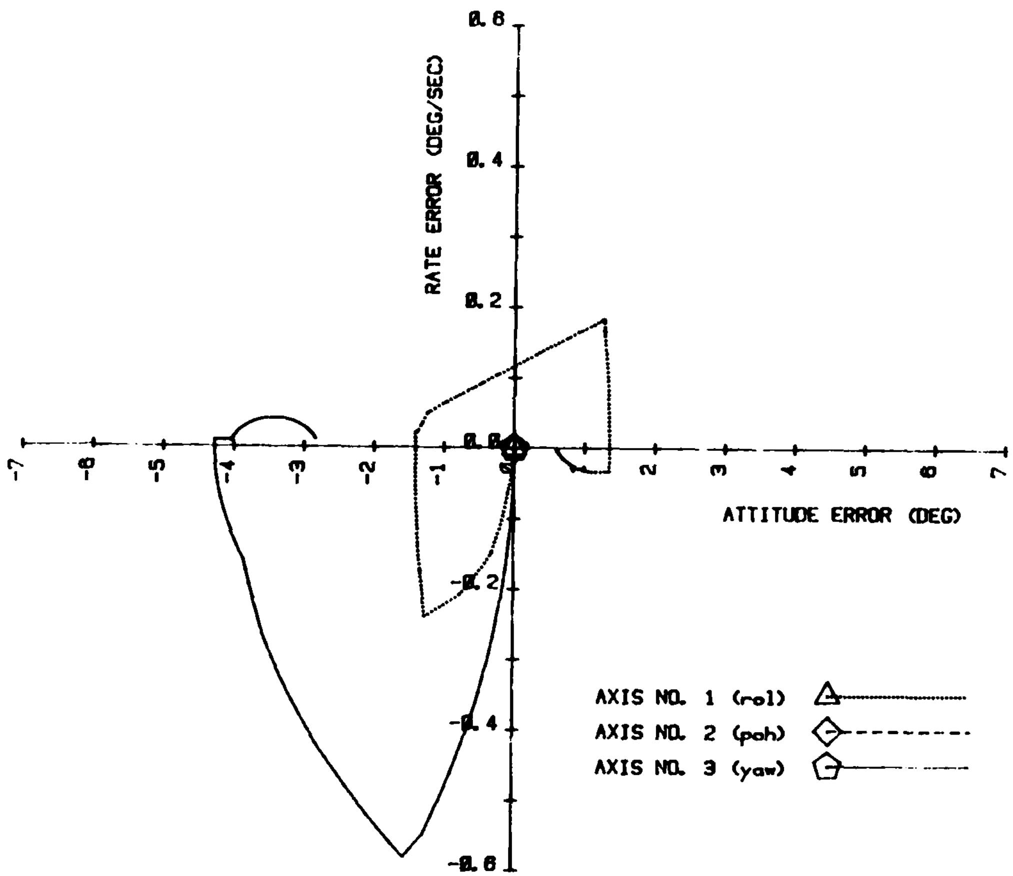
```
PET =      0.210 HHMM.SS         MET =      0.210 HHMM.SS

MU:RM50      99381          -0 -628537253 XYZ    4732.42      -0.01      1.43 DXYZ
PL:RM50      99680           0 -628537262 XYZ    4732.40       0.00      0.75 DXYZ

MU DATA ######## H     -89.99 DEC   -72.37 LON    1040 WT      111 ESUN   64.6 BETA
PL DATA ######## H     -89.99 DEC   -72.37 LON      21 WT      111 ESUN   64.6 BETA

MU:OM50 ######## SMA 0.00014 ECC    90.00 INC    -0.00 RAN    -3.76 ARG   -86.23 TRA
MU:IMLD ######## HA 99986.06 HP     90.00 INC    -0.00 RAN    -3.76 ARG   -86.23 TRA

MU: M50      1.53 PCH    -1.81 YAW     0.82 ROL   0.094 RXB  -0.027 RYB   0.011 RZB
MU: MLV      1.54 PCH    -1.81 YAW     0.82 ROL   0.094 RXB  -0.027 RYB   0.011 RZB

PL:OM50 ######## SMA 0.00000 ECC    90.00 INC     0.00 RAN    90.00 ARG -179.99 TRA
PL:IMLD ######## HA ######## HP     90.00 INC     0.00 RAN    90.00 ARG -179.99 TRA

PL: M50      1.61 PCH    50.66 YAW  117.38 ROL    4.578 RXB   4.012 RYB  -0.646 RZB
PL: PLV      1.62 PCH    50.66 YAW  117.38 ROL    4.578 RXB   4.012 RYB  -0.647 RZB

MU:CPLV    -0.049      -0.000       0.002 XYZ        0.02      -0.01       0.68 DXYZ
PL:RMLV       300           0          -9 XYZ       -0.02       0.01      -0.68 DXYZ
PL:RMBY       300          10          -1 XYZ       -0.00      -0.06      -0.84 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)       -2.28  A TANK       -4.42  B TANK
PRESSURE        (LB/IN^2)   2948.07  A TANK     2900.06  B TANK
PROPELLANT WT   (LB)        14.9280  A TANK     14.7540  B TANK      29.6820 TOTAL

AMOUNT USED     (LB)         0.1874  A TANK      0.3614  B TANK       0.5488 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 2130 /  7 NOV 1985

5 SEC +Z TRANSLATION,IRV,W/IMPINGEMENT,PRIMARY CONTROL MODE

END RUN NO.  0
```



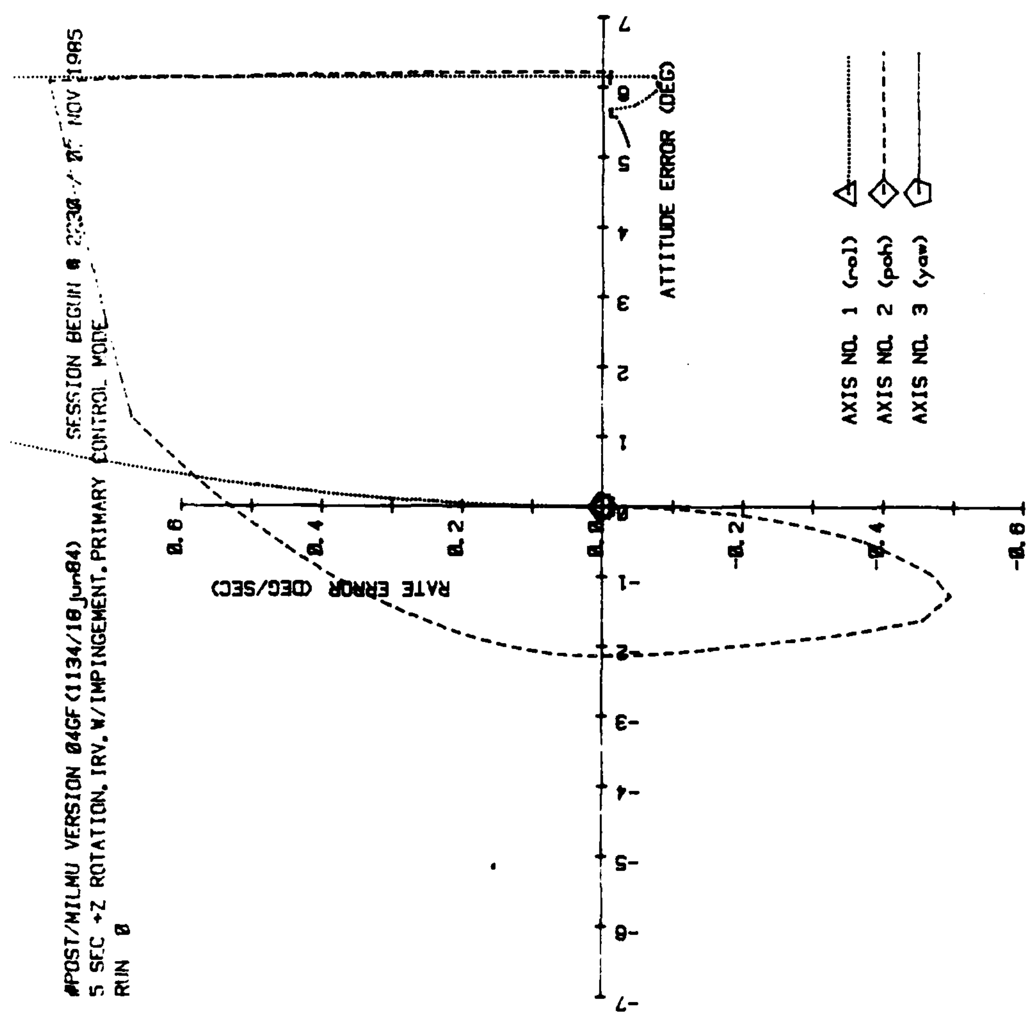
ØPOST/MILMU VERSION Ø4GF(1134/18jun84) SESSION BEGUN @ 2110 / 07 NOV 1985
2 SEC +X ROTATION, IRV, W/IMPINGEMENT, PRIMARY CONTROL MODE
RUN Ø
RATE ERROR (DEG/SEC)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
ATTITUDE ERROR (DEG)
AXIS NO. 1 (rol)
AXIS NO. 2 (pch)
AXIS NO. 3 (yaw)

```
PET =       1.180 HHMM.SS          MET =      1.180 HHMM.SS

MU:RM50      369130          -0 -628537163 XYZ     4732.48      -0.00       2.79 DXYZ
PL:RM50      369427           0 -628537162 XYZ     4732.40       0.00       2.78 DXYZ

MU DATA $$$$$$$$ H      -89.97 DEC   -72.61 LON     1040 WT      111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H      -89.97 DEC   -72.61 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00003 ECC     90.00 INC    -0.00 RAN  -87.17 ARG    -2.80 TRA
MU:IMLD $$$$$$$$ HA $$$$$$$$ HP      90.00 INC    -0.00 RAN  -87.17 ARG    -2.80 TRA

MU: M50     -3.65 PCH    -0.55 YAW    66.57 ROL  15.601 RXB   0.010 RYB   0.010 RZB
MU: MLV     -3.62 PCH    -0.55 YAW    66.57 ROL  15.601 RXB   0.010 RYB   0.009 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC     90.00 INC     0.00 RAN   90.01 ARG -179.98 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP      90.00 INC     0.00 RAN   90.01 ARG -179.98 TRA

PL: M50     67.46 PCH    34.68 YAW -144.11 ROL   1.209 RXB  -3.280 RYB  -5.036 RZB
PL: PLV     67.49 PCH    34.68 YAW -144.11 ROL   1.209 RXB  -3.280 RYB  -5.036 RZB

MU:CPLV      -0.049      -0.000      -0.000 XYZ       0.08      -0.00       0.01 DXYZ
PL:RMLV         297           0           1 XYZ      -0.08       0.00      -0.01 DXYZ
PL:RMBY         296         -15         -10 XYZ      -0.08      -2.72       4.12 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                   OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)          -9.69 A TANK        -1.25 B TANK
PRESSURE        (LB/IN^2)      2784.06 A TANK      2971.51 B TANK
PROPELLANT WT   (LB)           14.3300 A TANK      15.0127 B TANK     29.3427 TOTAL

AMOUNT USED     (LB)            0.7854 A TANK       0.1027 B TANK      0.8881 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)         SESSION BEGUN @ 2110 / 07 NOV 1985

2 SEC +X ROTATION,IRV,W/IMPINGEMENT,PRIMARY CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION Ø4GF (1134/18 jun 84)   SESSION BEGUN @ Ø44Ø / Ø9 NOV 1985
5 SEC +Y (PITCH) ROTATION, IRV, W/IMPINGEMENT, PRIMARY CONTROL MODE
RUN Ø

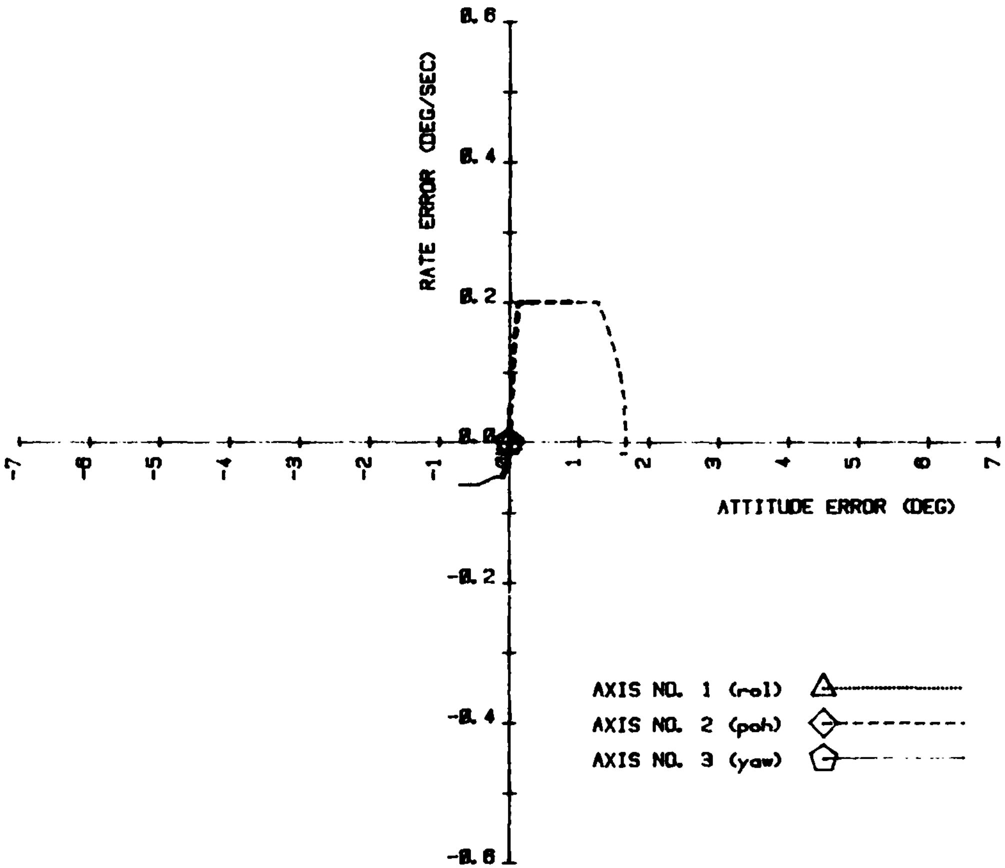


```
PET =      1.270 HHMM.SS          MET =      1.270 HHMM.SS

MU:RM50     411721          -1 -628537135 XYZ    4732.43     -0.01      3.11 DXYZ
PL:RM50     412019           0 -628537135 XYZ    4732.40      0.00      3.10 DXYZ

MU DATA $$$$$$$$ H     -89.96 DEC   -72.64 LON     1041 WT     111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H     -89.96 DEC   -72.64 LON       21 WT     111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00001 ECC    90.00 INC   -0.00 RAN  -76.88 ARG  -13.09 TRA
MU:IMLD $$$$$$$$ HA 99999.96 HP     90.00 INC   -0.00 RAN  -76.88 ARG  -13.09 TRA

MU: M50    86.73 PCH   -2.82 YAW    0.80 ROL  -0.002 RXB  10.122 RYB   0.011 RZB
MU: MLV    86.77 PCH   -2.82 YAW    0.80 ROL  -0.002 RXB  10.122 RYB   0.011 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC    0.00 RAN   90.02 ARG -179.98 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC    0.00 RAN   90.02 ARG -179.98 TRA

PL: M50    55.35 PCH   87.51 YAW -117.59 ROL   2.265 RXB  -4.358 RYB  -3.661 RZB
PL: PLV    55.39 PCH   87.51 YAW -117.59 ROL   2.265 RXB  -4.358 RYB  -3.661 RZB

MU:CPLV    -0.049      -0.000       0.000 XYZ      0.03      -0.01      0.01 DXYZ
PL:RMLV       298           1           0 XYZ     -0.03       0.01     -0.01 DXYZ
PL:RMBY        17           6         297 XYZ    -52.47      -0.00      2.92 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS       OPEN  B JETS
TEMPERATURE      (deg F)        -3.65  A TANK      -0.03  B TANK
PRESSURE         (LB/IN^2)    2917.37  A TANK    2999.27  B TANK
PROPELLANT WT    (LB)         14.8168  A TANK    15.1128  B TANK     29.9296 TOTAL

AMOUNT USED      (LB)          0.2986  A TANK     0.0026  B TANK      0.3012 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0440 / 08 NOV 1985

5 SEC +Y (PITCH) ROTATION,IRV,W/IMPINGEMENT,PRIMARY CONTROL MODE

END RUN NO.  0
```


#POST/MILMU VERSION 04GF(1134/18Jun84)
5 SEC +Z ROTATION, IRV, W/IMPINGEMENT, PRIMARY CONTROL MODE
RUN 0
SESSION BEGUN
NOV 1985
ATTITUDE ERROR (DEG)
RATE ERROR (DEG/SEC)
AXIS NO. 1 (rol)
AXIS NO. 2 (pch)
AXIS NO. 3 (yaw)

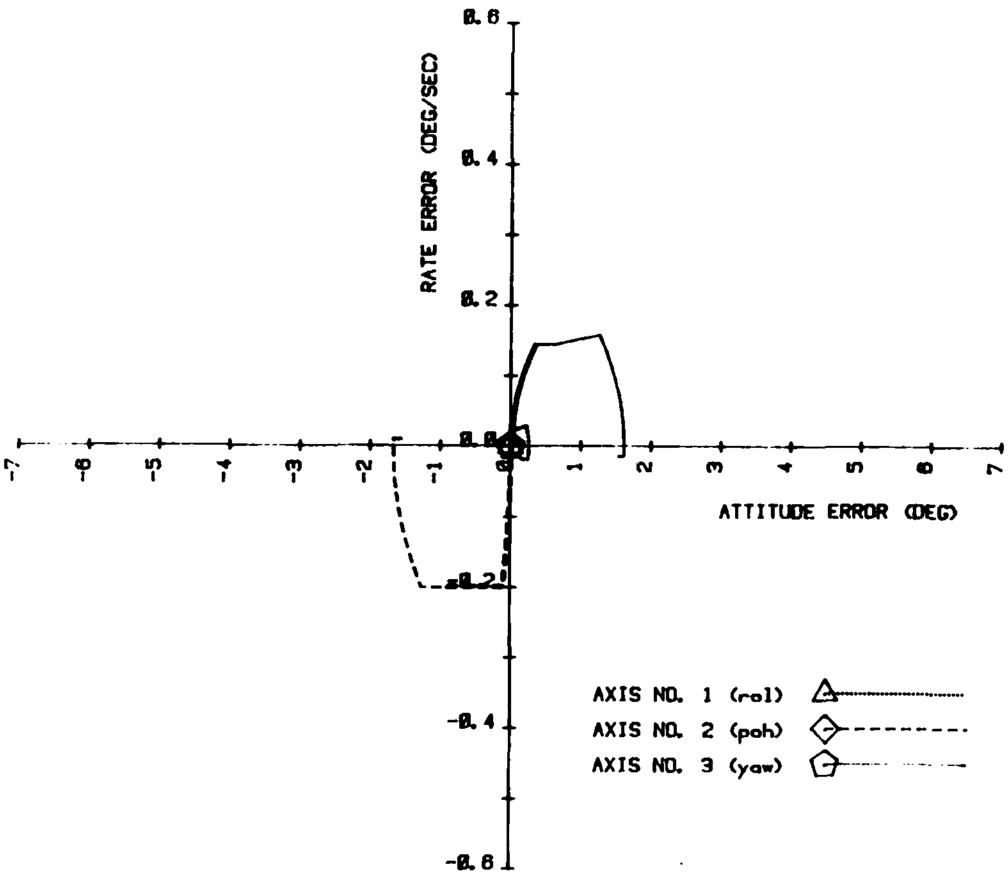
```
PET =       0.500 HHMM.SS          MET =       0.500 HHMM.SS

MU:RM50      236621          -0 -628537226 XYZ     4732.42      -0.01        1.80 DXYZ
PL:RM50      236920           0 -628537226 XYZ     4732.40       0.00        1.78 DXYZ

MU DATA $$$$$$$$ H     -89.98 DEC   -72.49 LON      1041 WT      111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H     -89.98 DEC   -72.49 LON        21 WT      111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00001 ECC    90.00 INC    -0.00 RAN  -73.07 ARG  -16.91 TRA
MU:IMLD $$$$$$$$ HA 99999.95 HP     90.00 INC    -0.00 RAN  -73.07 ARG  -16.91 TRA

MU: M50     -4.76 PCH  -77.55 YAW    -0.60 ROL  -0.037 RXB  -0.010 RYB   7.066 RZB
MU: MLV     -4.74 PCH  -77.55 YAW    -0.60 ROL  -0.038 RXB  -0.010 RYB   7.066 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC     0.00 RAN   90.01 ARG -179.99 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC     0.00 RAN   90.01 ARG -179.99 TRA

PL: M50  -148.44 PCH  -33.45 YAW   -47.99 ROL   0.923 RXB   2.713 RYB  -5.410 RZB
PL: PLV  -148.42 PCH  -33.45 YAW   -47.99 ROL   0.922 RXB   2.713 RYB  -5.410 RZB

MU:CPLV      -0.049      -0.000       0.000 XYZ        0.02       -0.01        0.01 DXYZ
PL:RMLV         299           0          -0 XYZ       -0.02        0.01       -0.01 DXYZ
PL:RMBY          64         291         -22 XYZ       35.90       -7.88        0.17 DXYZ

MU PROPELLANT STATUS ('PRIM' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                    OPEN  A JETS        OPEN  B JETS
TEMPERATURE      (deg F)          -3.32 A TANK        -0.87 B TANK
PRESSURE         (LB/IN^2)      2924.82 A TANK      2980.08 B TANK
PROPELLANT WT    (LB)           14.8438 A TANK      15.0436 B TANK      29.8875 TOTAL

AMOUNT USED      (LB)            0.2716 A TANK       0.0717 B TANK       0.3433 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 2230 / 07 NOV 1985

5 SEC +Z ROTATION,IRV,W/IMPINGEMENT,PRIMARY CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 04GF (1134/18 jun84)   SESSION BEGUN @ 0300 / 08 NOV 1985
5 SEC +X TRANSLATION, IRV, W/IMPINGEMENT, BACKUP B CONTROL MODE
RUN 0



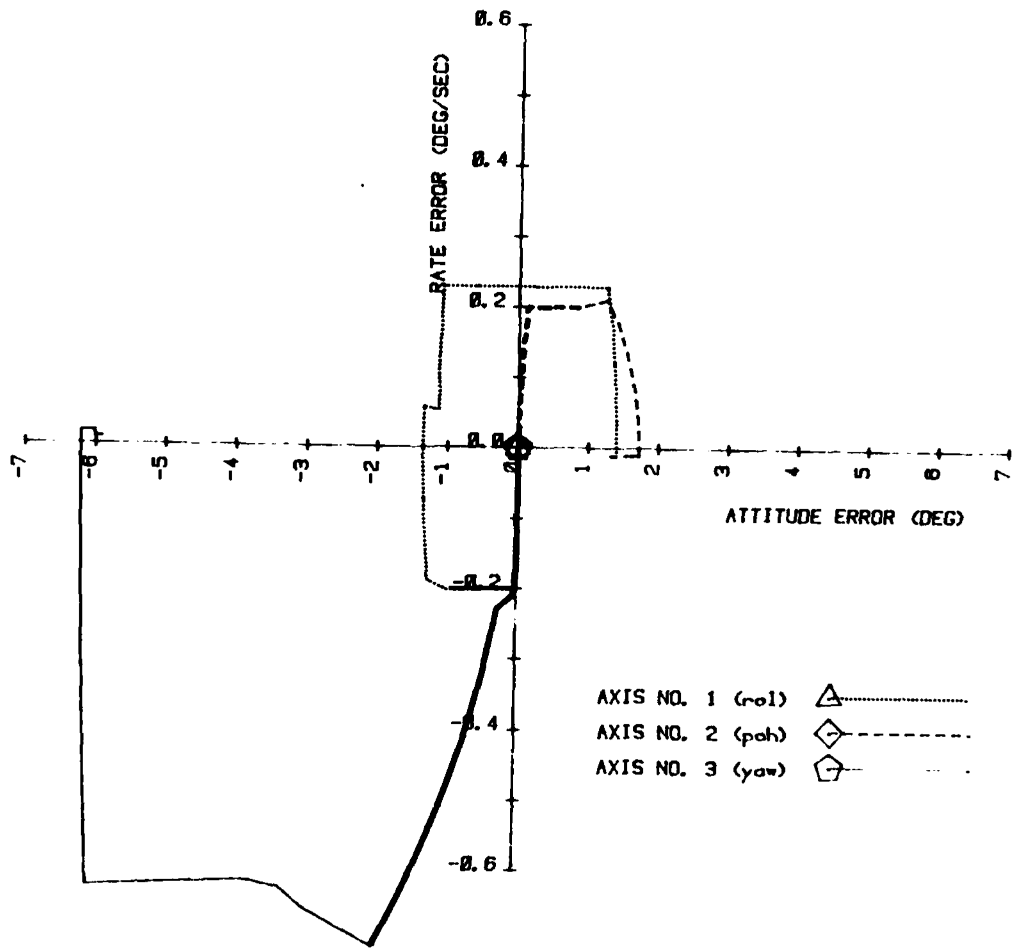
```
PET =      0.250 HHMM.SS          MET =      0.250 HHMM.SS

MU:RM50      118317        -0 -628537260 XYZ     4732.90     -0.00      0.89 DXYZ
PL:RM50      118610         0 -628537259 XYZ     4732.40      0.00      0.89 DXYZ

MU DATA ######## H     -89.99 DEC  -72.38 LON     1041 WT     111 ESUN   64.6 BETA
PL DATA ######## H     -89.99 DEC  -72.38 LON       21 WT     111 ESUN   64.6 BETA

MU:OM50 ######## SMA 0.00021 ECC    90.00 INC   -0.00 RAN  -90.27 ARG    0.28 TRA
MU:IMLD ######## HA ######## HP     90.00 INC   -0.00 RAN  -90.27 ARG    0.28 TRA

MU: M50      1.60 PCH   -0.70 YAW   -0.17 ROL  -0.016 RXB  -0.015 RYB  -0.060 RZB
MU: MLV      1.61 PCH   -0.70 YAW   -0.17 ROL  -0.016 RXB  -0.015 RYB  -0.060 RZB

PL:OM50 ######## SMA 0.00000 ECC    90.00 INC    0.00 RAN   90.00 ARG -179.99 TRA
PL:IMLD ######## HA ######## HP     90.00 INC    0.00 RAN   90.00 ARG -179.99 TRA

PL: M50    -15.22 PCH   65.74 YAW  149.18 ROL   4.065 RXB   4.383 RYB  -1.314 RZB
PL: PLV    -15.21 PCH   65.74 YAW  149.18 ROL   4.065 RXB   4.383 RYB  -1.314 RZB

MU:CPLV    -0.048      -0.000      -0.000 XYZ      0.50     -0.00     -0.00 DXYZ
PL:RMLV       293           0           0 XYZ     -0.50      0.00      0.00 DXYZ
PL:RMBY       293           4           9 XYZ     -0.50      0.30     -0.08 DXYZ

MU PROPELLANT STATUS ( BUPB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                   OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)           0.00 A TANK        -3.32 B TANK
PRESSURE        (LB/IN^2)      3000.00 A TANK      2924.63 B TANK
PROPELLANT WT   (LB)           15.1154 A TANK      14.8432 B TANK     29.9585 TOTAL

AMOUNT USED     (LB)            0.0000 A TANK       0.2722 B TANK      0.2722 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0300 / 08 NOV 1985

5 SEC +X TRANSLATION,IRV,W/IMPINGEMENT,BACKUP B CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 04GF(1134/18jun84)   SESSION BEGUN @ 0310 / 08 NOV 1985
5 SEC -X TRANSLATION, IRV, W/IMPINGEMENT, BACKUP B CONTROL MODE
RUN 0



```
PET =       0.250 HHMM.SS          MET =       0.250 HHMM.SS

MU:RM50     118301            0 -628537260 XYZ    4731.95      0.00       0.89 DXYZ
PL:RM50     118610            0 -628537259 XYZ    4732.40      0.00       0.89 DXYZ

MU DATA ******** H     -89.99 DEC  -72.38 LON     1041 WT     111 ESUN   64.6 BETA
PL DATA ******** H     -89.99 DEC  -72.38 LON       21 WT     111 ESUN   64.6 BETA

MU:OM50 ******** SMA 0.00019 ECC   90.00 INC    0.00 RAN   90.00 ARG -179.99 TPA
MU:IMLD ******** HA 99961.07 HP    90.00 INC    0.00 RAN   90.00 ARG -179.99 TPA

MU: M50     -1.57 PCH    1.54 YAW    0.15 ROL  -0.018 RXB   0.010 RYB  -0.014 RZB
MU: MLV     -1.55 PCH    1.54 YAW    0.15 ROL  -0.018 RXB   0.010 RYB  -0.014 RZB

PL:OM50 ******** SMA 0.00000 ECC   90.00 INC    0.00 RAN   90.00 ARG -179.99 TPA
PL:IMLD ******** HA ******** HP    90.00 INC    0.00 RAN   90.00 ARG -179.99 TRA

PL: M50    -15.09 PCH   65.73 YAW  149.08 ROL   4.064 RXB   4.384 RYB  -1.316 RZB
PL: PLV    -15.08 PCH   65.73 YAW  149.08 ROL   4.064 RXB   4.384 RYB  -1.316 RZB

MU:CPLV      -0.051        0.000      -0.000 XYZ      -0.45      0.00       0.00 DXYZ
PL:RMLV         309           -0           0 XYZ       0.45     -0.00      -0.00 DXYZ
PL:RMBY         308           -8          -8 XYZ       0.45      0.06       0.04 DXYZ

MU PROPELLANT STATUS ('BUPB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS        OPEN  B JETS
TEMPERATURE    (deg F)           0.00 A TANK        -3.41 B TANK
PRESSURE       (LB/IN^2)      3000.00 A TANK      2922.80 B TANK
PROPELLANT WT  (LB)           15.1154 A TANK      14.8365 B TANK      29.9519 TOTAL

AMOUNT USED    (LB)            0.0000 A TANK       0.2789 B TANK       0.2789 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)       SESSION BEGUN @ 0310 / 08 NOV 1985

5 SEC -X TRANSLATION,IRV,W/IMPINGEMENT,BACKUP B CONTROL MODE

END RUN NO.  0
```

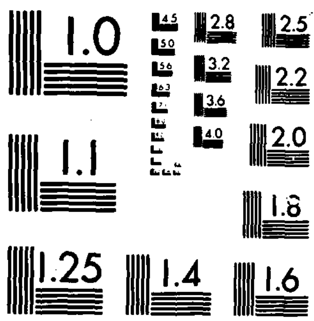
#POST/MILMU VERSION Ø4GF(1134/18Jun84)   SESSION BEGUN @ Ø315 / Ø8 NOV 198
5 SEC +Y TRANSLATION, IRV, W/IMPINGEMENT, BACKUP B CONTROL MODE
RUN Ø



AD-A164 039 A PROPOSED DESIGN FOR AN INTERIM SPACE RESCUE FERRY VEHICLE(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING J D HALSELL DEC 85 3/3

UNCLASSIFIED AFIT/GSO/ENY/85D-2 F/G 22/2 NL

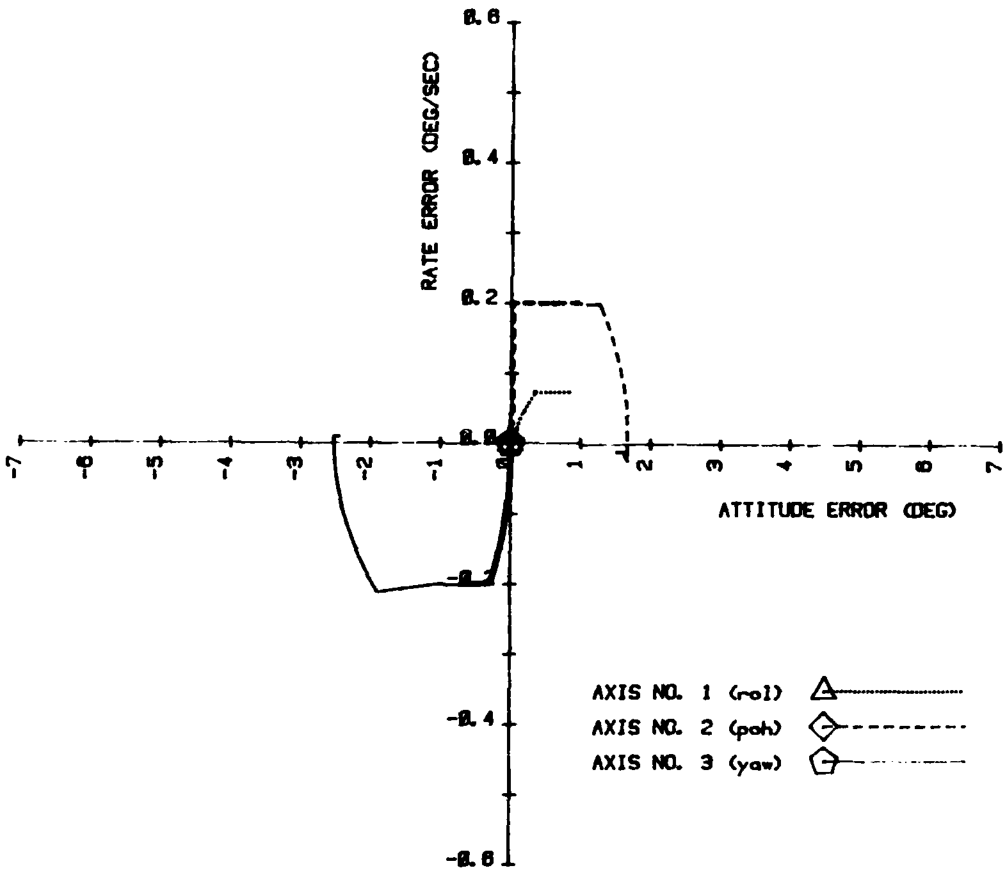
END
FILMED
DTIC



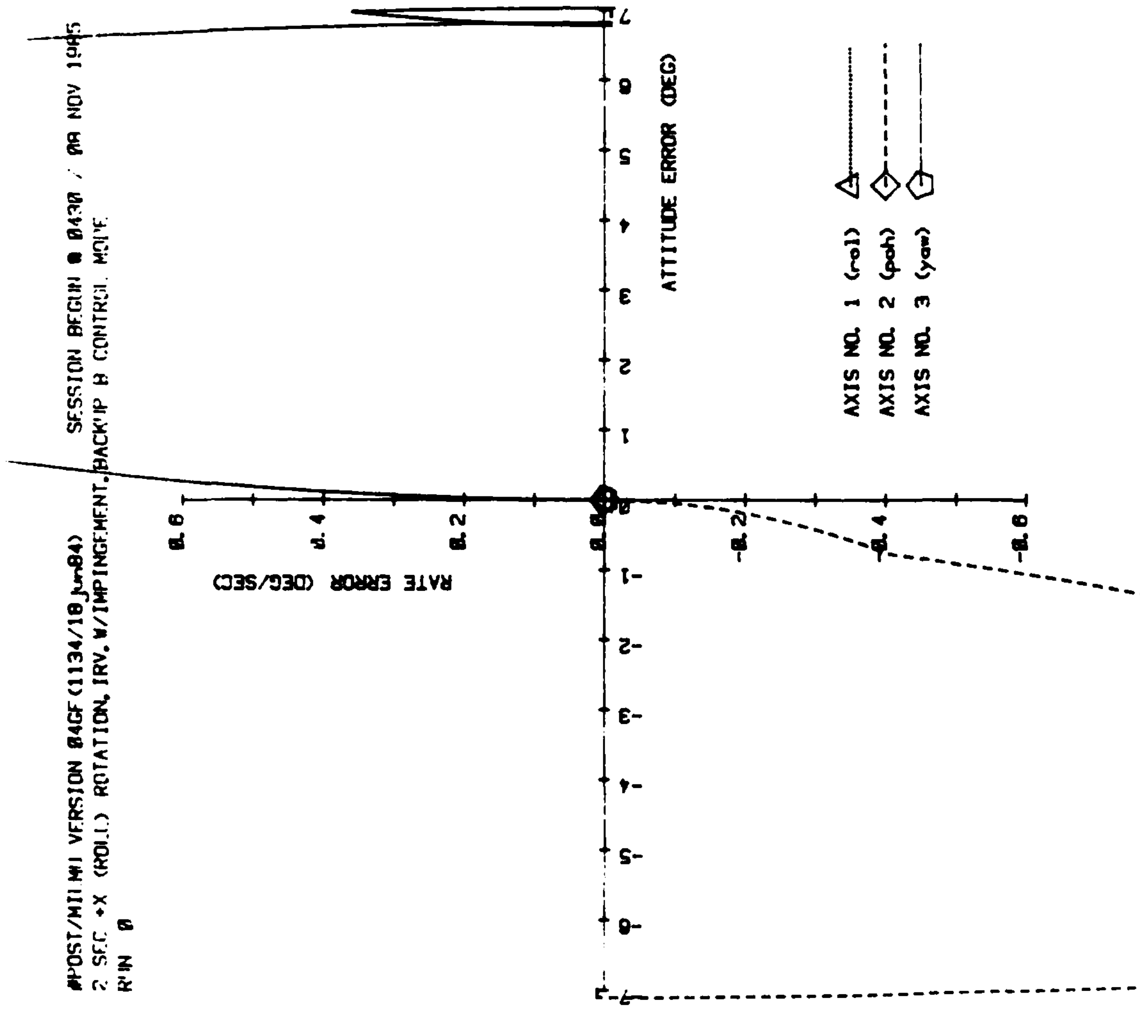
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
PET =      0.320 HHMM.SS          MET =      0.320 HHMM.SS

MU:RM50      151438          14 -628537253 XYZ    4732.43      0.51      1.12 DXYZ
PL:RM50      151737           0 -628537252 XYZ    4732.40      0.00      1.14 DXYZ

MU DATA $$$$$$$$ H    -89.99 DEC  -72.41 LON    1040 WT     111 ESUN   64.6 BETA
PL DATA $$$$$$$$ H    -89.99 DEC  -72.41 LON      21 WT     111 ESUN   64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00001 ECC   90.00 INC    0.01 RAN -110.73 ARG   20.74 TPA
MU:IMLD $$$$$$$$ HA 99999.90 HP    90.00 INC    0.01 RAN -110.73 ARG   20.74 TRA

MU: M50      1.42 PCH   -5.96 YAW    1.27 ROL  -0.025 RXB  -0.010 RYB   0.010 RZB
MU: MLV      1.44 PCH   -5.96 YAW    1.27 ROL  -0.025 RXB  -0.010 RYB   0.010 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC   90.00 INC    0.00 RAN   90.01 ARG -179.99 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP    90.00 INC    0.00 RAN   90.01 ARG -179.99 TRA

PL: M50  -104.04 PCH   65.12 YAW -101.60 ROL   3.063 RXB   4.620 RYB  -2.620 RZB
PL: PLV  -104.03 PCH   65.12 YAW -101.60 ROL   3.063 RXB   4.620 RYB  -2.620 RZB

MU:CPLV     -0.049       0.002      -0.000 XYZ      0.03      0.51     -0.02 DXYZ
PL:RMLV        299         -14           1 XYZ     -0.03     -0.51      0.02 DXYZ
PL:RMBY        299          17           8 XYZ      0.03     -0.57     -0.01 DXYZ

MU PROPELLANT STATUS ('BUPB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                      OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)              0.00  A TANK       -7.32  B TANK
PRESSURE        (LB/IN^2)         3000.00  A TANK     2835.92  B TANK
PROPELLANT WT   (LB)              15.1154  A TANK     14.5202  B TANK     29.6356 TOTAL

AMOUNT USED     (LB)               0.0000  A TANK      0.5952  B TANK      0.5952 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0315 / 08 NOV  198

5 SEC +Y TRANSLATION,IRV,W/IMPINGEMENT,BACKUP B CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 04GF (1134/18jun84) SESSION BEGUN @ 0330 / . NOV 1985
5 SEC +Z TRANSLATION, IRV, W/IMPINGEMENT, BACKUP B MODE
RUN 0



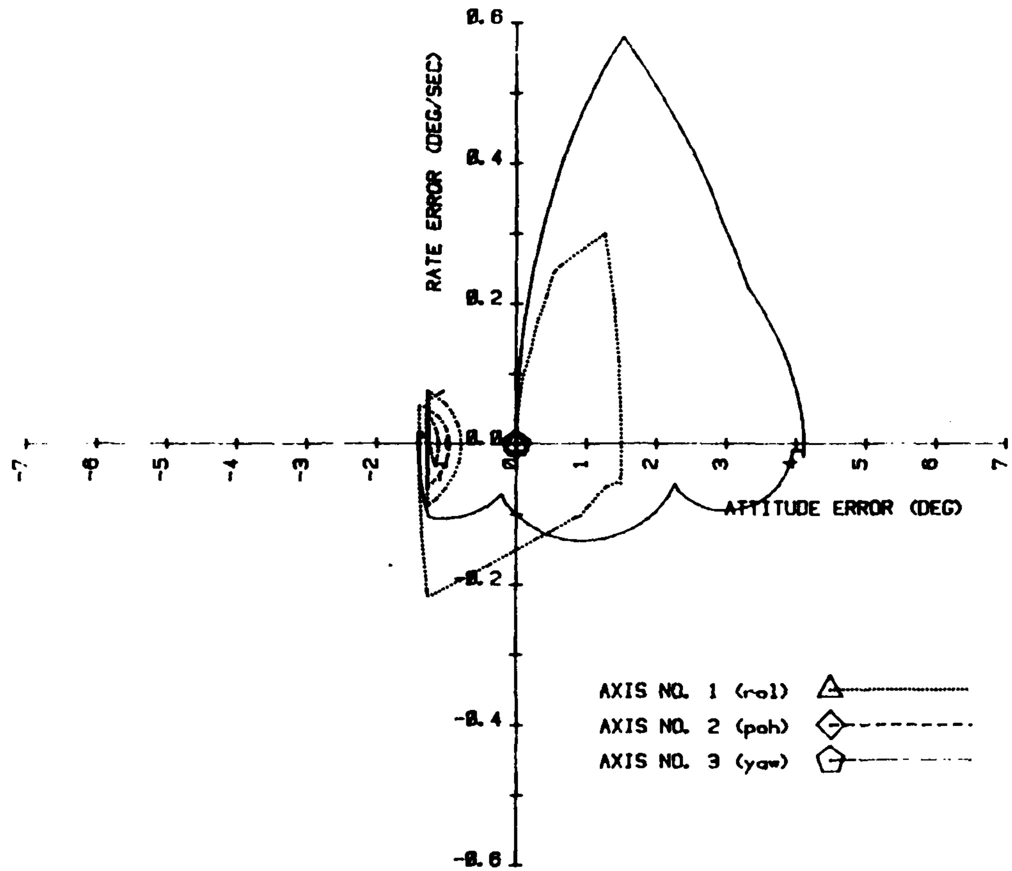
```
PET =      0.270 HHMM.SS          MET =      0.270 HHMM.SS

MU:RM50      127775          -0 -628537247 XYZ    4732.42     -0.01       1.47 DXYZ
PL:RM50      128075           0 -628537257 XYZ    4732.40      0.00       0.96 DXYZ

MU DATA $$$$$$$$ H     -89.99 DEC   -72.39 LON    1040 WT     111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H     -89.99 DEC   -72.39 LON      21 WT     111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00011 ECC    90.00 INC   -0.00 RAN    -4.45 APG  -85.53 TPA
MU:IMLD $$$$$$$$ HA 99989.63 HP     90.00 INC   -0.00 RAN    -4.45 ARG  -85.53 TPA

MU: M50       1.52 PCH    -2.45 YAW     0.84 ROL   0.073 RXB  -0.010 RYB   0.011 RZB
MU: MLV       1.53 PCH    -2.45 YAW     0.84 ROL   0.073 RXB  -0.010 RYB   0.011 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC    90.00 INC    0.00 RAN    90.01 ARG -179.99 TPA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP     90.00 INC    0.00 RAN    90.01 ARG -179.99 TPA

PL: M50     -35.72 PCH    71.30 YAW   176.22 ROL   3.790 RXB   4.507 RYB  -1.673 RZB
PL: PLV     -35.71 PCH    71.30 YAW   176.22 ROL   3.790 RXB   4.507 RYB  -1.673 RZB

MU:CPLV      -0.049      -0.000         0.002 XYZ      0.02      -0.01       0.51 DXYZ
PL:RMLV         300           0           -10 XYZ     -0.02       0.01      -0.51 DXYZ
PL:RMBY         299          13            -3 XYZ     -0.00      -0.06      -0.58 DXYZ

MU PROPELLANT STATUS ('BUPB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                   OPEN  A JETS       OPEN  B JETS
TEMPERATURE      (deg F)          0.00 A TANK       -5.58 B TANK
PRESSURE         (LB/IN^2)     3000.00 A TANK     2874.37 B TANK
PROPELLANT WT    (LB)          15.1154 A TANK     14.6605 B TANK      29.7759 TOTAL

AMOUNT USED      (LB)           0.0000 A TANK      0.4549 B TANK       0.4549 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0330 / 08 NOV 1985

5 SEC +Z TRANSLATION,IRV,W/IMPINGEMENT,BACKUP B MODE

END RUN NO.  0
```



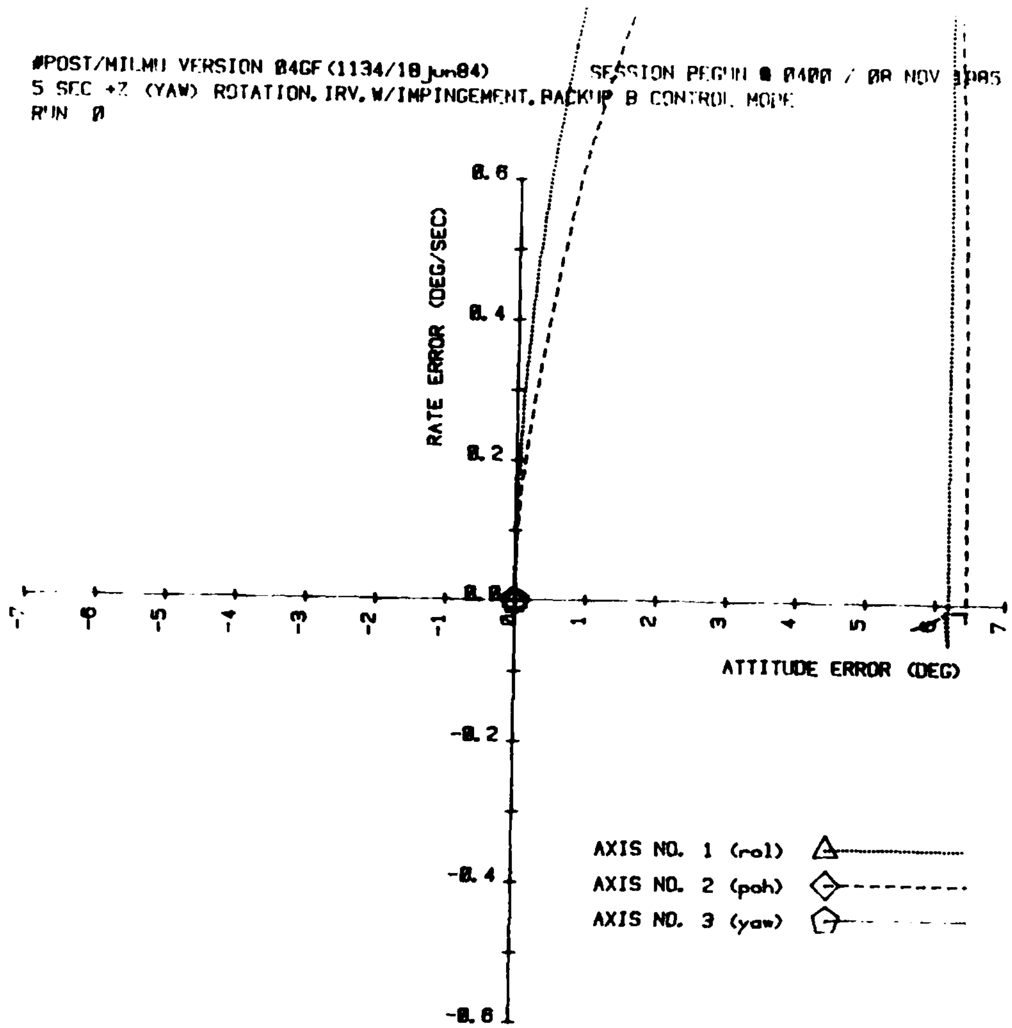
SESSION BEGIN
2 SEC +X (ROLL) ROTATION, IRV, W/IMPINGEMENT, BACKUP B CONTROL MODE
RATE ERROR (DEG/SEC)
ATTITUDE ERROR (DEG)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
AXIS NO. 1 (roll)
AXIS NO. 2 (pch)
AXIS NO. 3 (yaw)

```
PET =      0.260 HHMM.SS          MET =      0.260 HHMM.SS

MU:RM50      123043          -0 -628537259 XYZ    4732.43     -0.01       0.92 DXYZ
PL:RM50      123342           0 -628537258 XYZ    4732.40      0.00       0.93 DXYZ

MU DATA ######### H     -89.99 DEC  -72.39 LON    1041 WT     111 ESUN   64.6 BETA
PL DATA ######### H     -89.99 DEC  -72.39 LON      21 WT     111 ESUN   64.6 BETA

MU:OM50 ######### SMA 0.00001 ECC    90.00 INC   -0.00 RAN  -92.60 ARG    2.61 TRA
MU:IMLD ######### HA ######### HP    90.00 INC   -0.00 RAN  -92.60 ARG    2.61 TRA

MU: M50     -1.71 PCH   -1.13 YAW  -12.60 ROL  15.433 RXB   0.010 RYB  -0.010 RZB
MU: MLV     -1.70 PCH   -1.13 YAW  -12.60 ROL  15.433 RXB   0.011 RYB  -0.010 RZB

PL:OM50 ######### SMA 0.00000 ECC    90.00 INC    0.00 RAN   90.00 ARG -179.99 TRA
PL:IMLD ######### HA ######### HP    90.00 INC    0.00 RAN   90.00 ARG -179.99 TRA

PL: M50    -22.77 PCH   68.86 YAW  160.34 ROL   3.919 RXB   4.459 RYB  -1.504 RZB
PL: PLV    -22.75 PCH   68.86 YAW  160.34 ROL   3.919 RXB   4.459 RYB  -1.505 RZB

MU:CPLV    -0.049      -0.000      -0.000 XYZ      0.03      -0.01      -0.00 DXYZ
PL:RMLV       300           0           0 XYZ     -0.03       0.01       0.00 DXYZ
PL:RMBY       299           8          -7 XYZ     -0.03      -1.80      -2.03 DXYZ

MU PROPELLANT STATUS ('BUPB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS       OPEN  B JETS
TEMPERATURE     (deg F)          0.00 A TANK       -4.80 B TANK
PRESSURE        (LB/IN^2)     3000.00 A TANK     2891.55 B TANK
PROPELLANT WT   (LB)          15.1154 A TANK     14.7230 B TANK      29.8384 TOTAL

AMOUNT USED     (LB)           0.0000 A TANK      0.3924 B TANK       0.3924 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0430 / 08 NOV 1985

2 SEC +X (ROLL) ROTATION,IRV,W/IMPINGEMENT,BACKUP B CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 04GF (1134/18 jun84)   SESSION BEGUN @ 0415 / 08 NOV 1985
5 SEC +Y (PITCH) ROTATION, IRV, W/IMPINGEMENT, BACKUPB CONTROL MODE
RUN 0

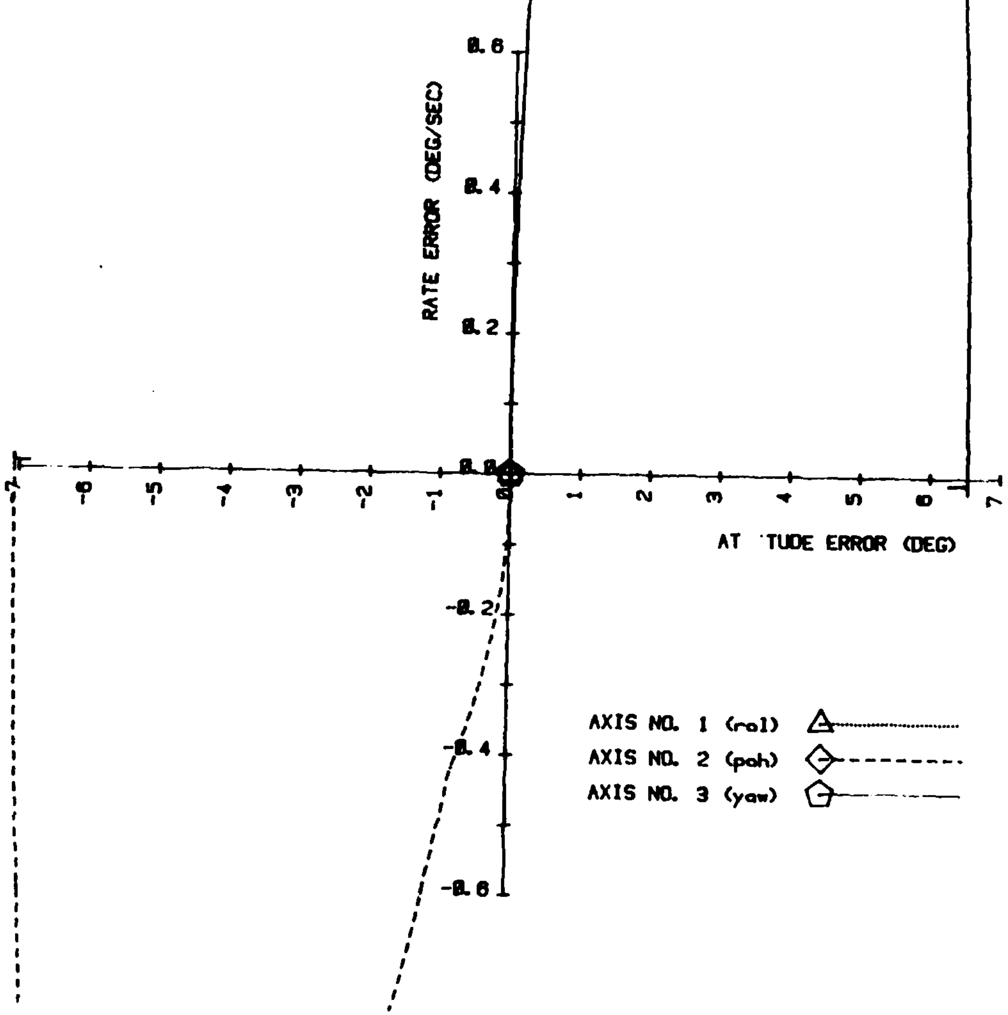


```
PET =       1.430 HHMM.SS          MET =       1.430 HHMM.SS

MU:RM50      487440            1 -628537081 XYZ     4732.43       0.01       3.68 DXYZ
PL:RM50      487737            0 -628537081 XYZ     4732.40       0.00       3.67 DXYZ

MU DATA $$$$$$$$ H      -89.96 DEC   -72.71 LON     1041 WT      111 ESUN    64.6 BETA
PL DATA $$$$$$$$ H      -89.96 DEC   -72.71 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00001 ECC     90.00 INC     0.00 RAN  -76.24 ARG  -13.71 TRA
MU:IMLD $$$$$$$$ HA 99999.96 HP      90.00 INC     0.00 RAN  -76.24 ARG  -13.71 TRA

MU: M50   -87.32 PCH   -3.85 YAW     1.28 ROL   0.077 RXB  10.151 RYB   0.010 RZB
MU: MLV   -87.27 PCH   -3.85 YAW     1.28 ROL   0.077 RXB  10.151 RYB   0.010 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC     90.00 INC     0.00 RAN   90.02 ARG -179.98 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP      90.00 INC     0.00 RAN   90.02 ARG -179.98 TRA

PL: M50  -100.51 PCH   12.16 YAW    96.42 ROL   4.454 RXB  -4.124 RYB  -0.808 RZB
PL: PLV  -100.46 PCH   12.16 YAW    96.42 ROL   4.454 RXB  -4.124 RYB  -0.808 RZB

MU:CPLV     -0.049       0.000       0.000 XYZ        0.03       0.01       0.01 DXYZ
PL:RMLV        297          -1          -0 XYZ       -0.03      -0.01      -0.01 DXYZ
PL:RMBY         14          -7        -297 XYZ       52.56      -0.41       2.48 DXYZ

MU PROPELLANT STATUS ('BUPB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                     OPEN  A JETS        OPEN  B JETS
TEMPERATURE      (deg F)            0.00 A TANK        -3.74 B TANK
PRESSURE         (LB/IN^2)       3000.00 A TANK      2915.28 B TANK
PROPELLANT WT    (LB)            15.1154 A TANK      14.8092 B TANK      29.9246 TOTAL

AMOUNT USED      (LB)             0.0000 A TANK       0.3061 B TANK       0.3061 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0415 / 08 NOV 1985

5 SEC +Y (PITCH) ROTATION,IRV,W/IMPINGEMENT,BACKUPB CONTROL MODE

END RUN NO.  0
```


#POST/MILMU VERSION 04GF (1134/18 Jun84)
SESSION BEGUN @ 0400 / 08 NOV 1985
5 SEC +Z (YAW) ROTATION, IRV, W/IMPINGEMENT, BACKUP B CONTROL MODE
RUN 0
RATE ERROR (DEG/SEC)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
ATTITUDE ERROR (DEG)
AXIS NO. 1 (rol)
AXIS NO. 2 (pch)
AXIS NO. 3 (yaw)

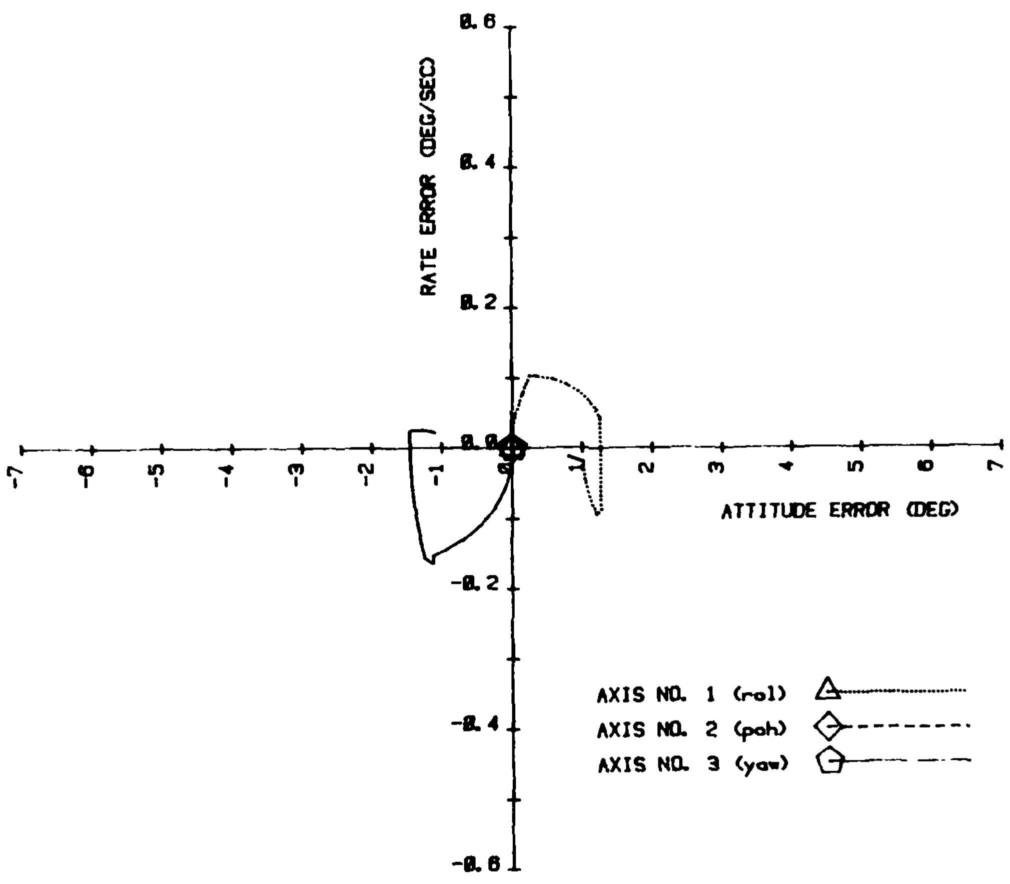
```
PET =       0.340 HHMM.SS          MET =      0.340 HHMM.SS

MU:RM50      160902           -0 -628537251 XYZ    4732.42      -0.00       1.19 DXYZ
PL:RM50      161202            0 -628537250 XYZ    4732.40       0.00       1.21 DXYZ

MU DATA ******** H      -89.99 DEC   -72.42 LON     1041 WT      111 ESUN    64.6 BETA
PL DATA ******** H      -89.99 DEC   -72.42 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 ******** SMA 0.00001 ECC    90.00 INC    -0.00 RAN -114.14 ARG    24.15 TRA
MU:IMLD ******** HA 99999.89 HP     90.00 INC    -0.00 RAN -114.14 ARG    24.15 TRA

MU: M50  -173.42 PCH   -4.18 YAW  176.22 ROL  -0.035 RXB  -0.010 RYB   6.988 RZB
MU: MLV  -173.41 PCH   -4.18 YAW  176.22 ROL  -0.035 RXB  -0.010 RYB   6.989 RZB

PL:OM50 ******** SMA 0.00000 ECC    90.00 INC     0.00 RAN   90.01 ARG -179.99 TRA
PL:IMLD ******** HA ******** HP     90.00 INC     0.00 RAN   90.01 ARG -179.99 TRA

PL: M50  -116.83 PCH   55.63 YAW  -84.89 ROL   2.808 RXB   4.569 RYB  -2.952 RZB
PL: PLV  -116.81 PCH   55.63 YAW  -84.89 ROL   2.808 RXB   4.569 RYB  -2.952 RZB

MU:CPLV     -0.049      -0.000      -0.000 XYZ       0.03      -0.00      -0.02 DXYZ
PL:RMLV        299           0           1 XYZ      -0.03       0.00       0.02 DXYZ
PL:RMBY       -296          19          37 XYZ       2.36      36.12       0.08 DXYZ

MU PROPELLANT STATUS ('BUPB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                   OPEN  A JETS       OPEN  B JETS
TEMPERATURE     (deg F)           0.00 A TANK       -4.30 B TANK
PRESSURE        (LB/IN^2)      3000.00 A TANK     2902.83 B TANK
PROPELLANT WT   (LB)           15.1154 A TANK     14.7641 B TANK      29.8794 TOTAL

AMOUNT USED     (LB)            0.0000 A TANK      0.3513 B TANK       0.3513 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 0400 / 08 NOV 1985

5 SEC +Z (YAW) ROTATION,IRV,W/IMPINGEMENT,BACKUP B CONTROL MODE

END RUN NO.  0
```

#POST/MILMU VERSION 84GF(1134/18jun84)   SESSION BEGUN @ 234 / 07 NOV 1985
1 SEC +X (ROLL) ROTATION, IRV, W/IMPINGEMENT, SATELLITE STABILIZATION CONTROL MODE
RUN 0

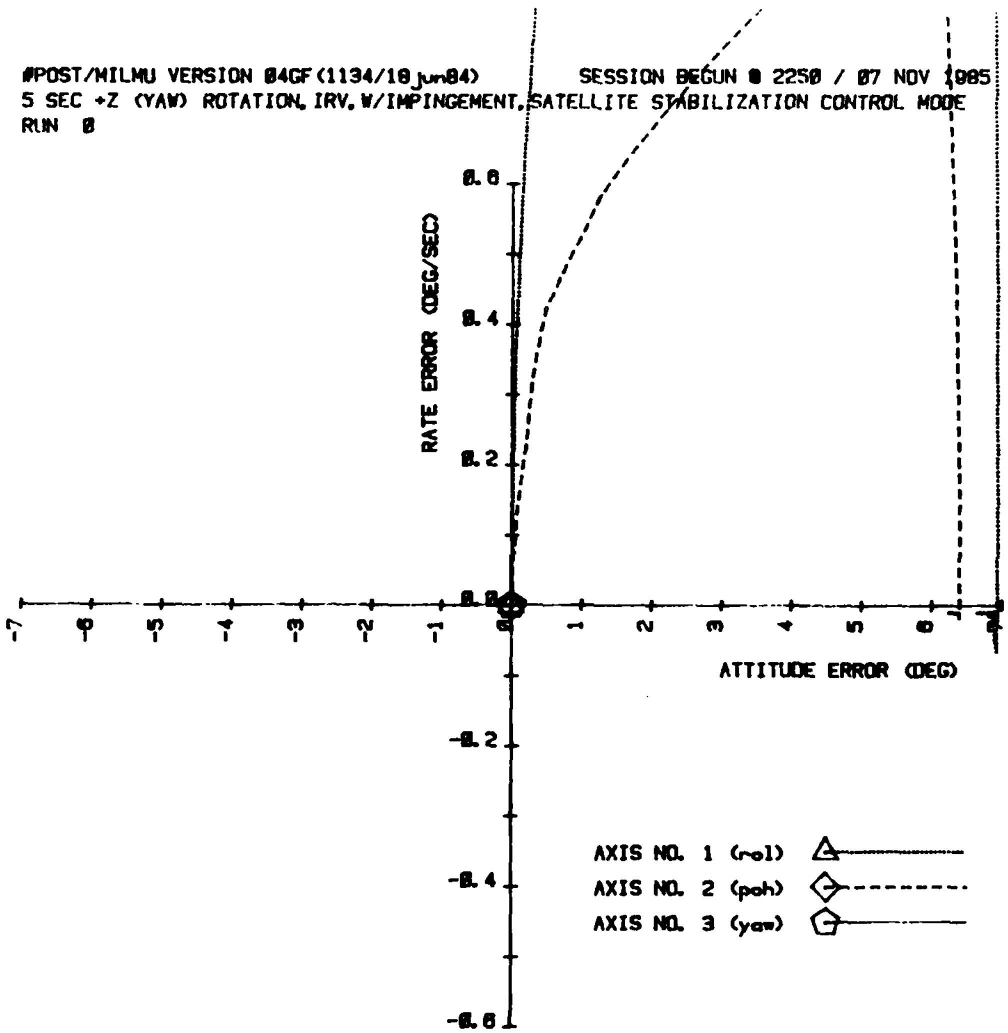


```
PET =       0.350 HHMM.SS          MET =       0.350 HHMM.SS

MU:RM50      165634           0 -628537249 XYZ     4732.39      -0.04       1.29 DXYZ
PL:RM50      165934           0 -628537248 XYZ     4732.40       0.00       1.25 DXYZ

MU DATA ######## H      -89.98 DEC   -72.43 LON     1041 WT     111 ESUN    64.6 BETA
PL DATA ######## H      -89.98 DEC   -72.43 LON       21 WT     111 ESUN    64.6 BETA

MU:OM50 ######## SMA 0.00001 ECC    90.00 INC    -0.00 RAN    17.47 ARG -107.45 TRA
MU:IMLD ######## HA 99998.68 HP     90.00 INC    -0.00 RAN    17.47 ARG -107.45 TRA

MU: M50     -1.11 PCH    -0.79 YAW  127.76 ROL  14.701 RXB   0.010 RYB  -0.010 RZB
MU: MLV     -1.10 PCH    -0.79 YAW  127.76 ROL  14.701 RXB   0.010 RYB  -0.010 RZB

PL:OM50 ######## SMA 0.00000 ECC    90.00 INC     0.00 RAN    90.01 ARG -179.99 TRA
PL:IMLD ######## HA ######## HP     90.00 INC     0.00 RAN    90.01 ARG -179.99 TRA

PL: M50  -120.77 PCH    50.95 YAW  -78.80 ROL   2.660 RXB   4.531 RYB  -3.145 RZB
PL: PLV  -120.75 PCH    50.95 YAW  -78.80 ROL   2.660 RXB   4.531 RYB  -3.145 RZB

MU:CPLV     -0.049       0.000      -0.000 XYZ       -0.01      -0.04       0.04 DXYZ
PL:RMLV        300          -0           0 XYZ        0.01       0.04      -0.04 DXYZ
PL:RMBY        300          -7           0 XYZ        0.01       0.02       1.78 DXYZ

MU PROPELLANT STATUS ('STAB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                  OPEN  A JETS       OPEN  B JETS
TEMPERATURE     (deg F)         -2.63 A TANK       -2.63 B TANK
PRESSURE        (LB/IN^2)     2940.17 A TANK     2940.17 B TANK
PROPELLANT WT   (LB)          14.8994 A TANK     14.8994 B TANK      29.7989 TOTAL

AMOUNT USED     (LB)           0.2160 A TANK      0.2160 B TANK       0.4319 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @  234 / 07 NOV 1985

1 SEC +X (ROLL) ROTATION,IRV,W/IMPINGEMENT,SATELLITE STABILIZATION CONTROL MODE

END RUN NO.  0
```

5 SEC +Y (PITCH) ROTATION, IRV, W/IMPINGEMENT, SATELLITE STABILIZATION CONTROL MODE
RUN 0



```
PET =      0.380 HHMM.SS          MET =      0.380 HHMM.SS

MU:RM50      179834          -0 -628537228 XYZ     4732.47      -0.01       1.87 DXYZ
PL:RM50      180131           0 -628537244 XYZ     4732.40       0.00       1.36 DXYZ

MU DATA ######## H      -89.98 DEC   -72.44 LON     1041 WT      111 ESUN    64.6 BETA
PL DATA ######## H      -89.98 DEC   -72.44 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 $$$$$$$$ SMA 0.00011 ECC     90.00 INC    -0.00 RAN   -15.82 ARG   -74.17 TRA
MU:IMLD $$$$$$$$ HA 99991.45 HP      90.00 INC    -0.00 RAN   -15.82 ARG   -74.17 TRA

MU: M50    -59.89 PCH     0.11 YAW    -0.91 ROL   -0.011 RXB    9.041 RYB    0.022 RZB
MU: MLV    -59.87 PCH     0.11 YAW    -0.91 ROL   -0.011 RXB    9.041 RYB    0.022 RZB

PL:OM50 $$$$$$$$ SMA 0.00000 ECC     90.00 INC     0.00 RAN    90.01 ARG -179.99 TRA
PL:IMLD $$$$$$$$ HA $$$$$$$$ HP      90.00 INC     0.00 RAN    90.01 ARG -179.99 TRA

PL: M50  -128.57 PCH    34.80 YAW   -66.27 ROL    2.264 RXB    4.351 RYB   -3.662 RZB
PL: PLV  -128.56 PCH    34.80 YAW   -66.27 ROL    2.264 RXB    4.351 RYB   -3.662 RZB

MU:CPLV     -0.049      -0.000       0.003 XYZ        0.07       -0.01       0.52 DXYZ
PL:RMLV        298           0         -17 XYZ       -0.07        0.01      -0.52 DXYZ
PL:RMBY        135           4        -266 XYZ       41.40        0.01      21.06 DXYZ

MU PROPELLANT STATUS ('STAB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                      OPEN   A JETS        OPEN  B JETS
TEMPERATURE     (deg F)             -1.65 A TANK         -1.65 B TANK
PRESSURE        (LB/IN^2)         2962.36 A TANK       2962.36 B TANK
PROPELLANT WT   (LB)              14.9797 A TANK       14.9797 B TANK      29.9593 TOTAL

AMOUNT USED     (LB)               0.1357 A TANK        0.1357 B TANK       0.2714 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)        SESSION BEGUN @ 2300 / 07 NOV 1985

5 SEC +Y (PITCH) ROTATION,IRV,W/IMPINGEMENT,SATELLITE STABILIZATION CONTPOL MODE

END RUN NO.  0
```



#POST/MILMU VERSION 04GF (1134/18 jun84)
SESSION BEGUN @ 2250 / 07 NOV 1985
5 SEC +Z (YAW) ROTATION, IRV, W/IMPINGEMENT, SATELLITE STABILIZATION CONTROL MODE
RUN 0
RATE ERROR (DEG/SEC)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
ATTITUDE ERROR (DEG)
AXIS NO. 1 (rol)
AXIS NO. 2 (pch)
AXIS NO. 3 (yaw)

```
PET =       0.300 HHMM.SS          MET =       0.300 HHMM.SS

MU:RM50      141974         -13 -628537258 XYZ     4732.46      -0.51       0.84 DXYZ
PL:RM50      142272           0 -628537254 XYZ     4732.40       0.00       1.07 DXYZ

MU DATA ######## H      -89.99 DEC  -72.41 LON     1041 WT      111 ESUN    64.6 BETA
PL DATA ######## H      -89.99 DEC  -72.41 LON       21 WT      111 ESUN    64.6 BETA

MU:OM50 ######## SMA 0.00006 ECC    90.00 INC    -0.01 RAN -149.85 ARG    59.86 TRA
MU:IMLD ######## HA 99997.14 HP     90.00 INC    -0.01 RAN -149.85 ARG    59.86 TRA

MU: M50   179.69 PCH  -64.28 YAW  174.95 ROL  -0.010 RXB  -0.010 RYB   9.909 RZB
MU: MLV   179.70 PCH  -64.28 YAW  174.95 ROL  -0.011 RXB  -0.010 RYB   9.909 RZB

PL:OM50 ######## SMA 0.00000 ECC    90.00 INC     0.00 RAN    90.01 ARG -179.99 TRA
PL:IMLD ######## HA ######## HP     90.00 INC     0.00 RAN    90.01 ARG -179.99 TRA

PL: M50   -82.66 PCH   71.12 YAW -128.23 ROL   3.367 RXB   4.605 RYB  -2.224 RZB
PL: PLV   -82.65 PCH   71.12 YAW -128.23 ROL   3.367 RXB   4.605 RYB  -2.224 RZB

MU:CPLV     -0.049      -0.002      -0.001 XYZ       0.07      -0.51      -0.23 DXYZ
PL:RMLV        298          13           4 XYZ      -0.07       0.51       0.23 DXYZ
PL:RMBY       -141         262          25 XYZ      44.91      24.04       0.28 DXYZ

MU PROPELLANT STATUS ('STAB' JET SELECT OPTION, CROSSFEED 'OFF')

ISOLATION VALVE                 OPEN  A JETS        OPEN  B JETS
TEMPERATURE     (deg F)        -2.72 A TANK        -2.25 B TANK
PRESSURE        (LB/IN^2)    2938.22 A TANK      2948.87 B TANK
PROPELLANT WT   (LB)         14.8924 A TANK      14.9309 B TANK      29.8233 TOTAL

AMOUNT USED     (LB)          0.2230 A TANK       0.1845 B TANK       0.4075 TOTAL


#TRAJ/MILMU VERSION 04GF(1134/18jun84)       SESSION BEGUN @ 2250 / 07 NOV 1985

5 SEC +Z (YAW) ROTATION,IRV,W/IMPINGEMENT,SATELLITE STABILIZATION CONTROL MODE

END RUN NO.  0
```

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VITA

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