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Astronaut Maneuvering Research Vehicle

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ABSTRACT

The Astronaut Maneuvering Research Vehicle (AMRV) for use in the Skylab Experiment M509, Astronaut Maneuvering Equipment, is described. The AMRV enables investigation of several maneuvering devices and mobility techniques. The AMRV consists of two maneuvering unit configurations; a Hand Held Meneuvering Unit (HHMU) which provides manually oriented variable thrust control and an Automatically Stabilized Maneuvering Unit (ASMU) which provides fixed thrusters and three selectable attitude control and stabilization modes.

INTRODUCTION

The usefulness of providing the astronaut with powered mobility devices for Extra Vehicular Activity (EVA) tasks were initially investigated during the Gemini program. On Gemini IV, a Hand Held Maneuvering Unit (HHMU) was first used by Lt. Col. E. White during an EVA portion of the mission. The HHMU was a relatively simple device consisting of three thrusters and required the astronaut to manually position and aim the thruster with his arm. Then he activated a trigger mechanism to initiate propellant flow at the desired thrust level. On Gemini IX-A, a Modular Maneuvering Unit (MMU) was carried. The MMU was a fixed thruster device worn by the astronaut in the form of a backpack and contained automatic stabilization equipment. Hand controllers were provided on arms extending from the backpack by which the astronaut commanded translation and attitude maneuvers. However, it was discovered that the efforts to prepare for the MMU experiment required more work than had been expected and the unit was never flown. The experiment did demonstrate that the ground based simulations had not sufficiently duplicated the EVA tasks and the difficulties encountered.

Therefore, due to the lack of realistic experience in the handling qualities and performance of astronaut maneuvering aids, an Astronaut Maneuvering Research Vehicle is presently being developed for use in the Skylab Experiment M509, Astronaut Maneuvering Equipment. M509 is an investigation of the utility of several astronaut maneuvering devices and related mobility techniques which will enhance man's operational capability during orbital EVA. The purpose of the experiment is to obtain engineering and human performance data on inflight operations and to gain experience by performing various maneuvering tasks which are representative of future EVA requirements. The experiment is the principal part of a broader program to develop operational EVA maneuvering units and a sound technology base to support future missions.

The M509 concept is to fly the AMRV inside the safe and habitable environment of the Skylab workshop to decouple the maneuvering dynamics from the risks and constraints associated with EVA. Adequate volume is available in the workshop to allow the capabilities and limitations of manned maneuvering to be investigated in a systematic manner.

ASTRONAUT MANEUVERING RESEARCH VEHICLE

A preliminary mockup of the AMRV used for astronaut interface evaluations is shown in Figure 1. The AMRV consists of two maneuvering unit configurations: a Hand Held Maneuvering Unit (HHMU) and an Automatically Stabilized Maneuvering Unit (ASMU).

HAND HELD MANEUVERING UNIT

The HHMU shown in Figure 2, is similar to the units flown during the Gemini program. The HHMU is designed to operate using either gaseous oxygen or nitrogen propellant supplied by the ASMU through a short flexible umbilical. A hand grip trigger actuates propellant flow to the two tractor thrusters which "pull" the astronaut while a selector valve, when actuated by the forefinger, directs the propellant flow to a single pusher thruster which "pushes" the astronaut. The thruster levels are proportional to the trigger displacement with a maximum thrust of approximately three pounds available. By positioning the unit with the hand, maneuvering in six degrees of freedom is possible. It should be noted however, that when translating, if the thrust vector is not aligned through the astronaut system center of mass, rotational accelerations are developed. In addition, since the HHMU cannot produce a pure torque couple, rotational maneuvers will induce some translation acceleration. The HHMU is instrumented with a propellant temperature transducer and two pressure transducers to monitor the propellant dynamics during the experiment and provide data for post-flight analysis.

AUTOMATICALLY STABILIZED MANEUVERING UNIT

The ASMU is the backmounted device shown in Fig. 1 and enables the evaluation of a multiple, fixed position thruster type maneuvering unit containing three unique modes of attitude control and stabilization. It is designed to be flown using either self-contained power and propellant or when supplied from an external source. The features of the ASMU are identified in more detail in Figs. 3 and 4.

The unit is secured to the astronaut using a restraint harness and a seat which provides an adjustable position index. The side arms, containing hand controllers, are adjustable in length so that the ASMU can be comfortably flown with the wide anthropometic dimensions existing between all astronauts while wearing either shirtsleeve clothing or a pressure suit. In addition, the arms can be folded down to eliminate interference with the astronaut's mobility when using the HHMU or to provide maximum accessibility while performing tasks at a work site. The left arm contains all control switches and displays that must be readily accessible and visible to the astronaut while maneuvering.

There are five major subsystems contained in the ASMU. These are the Attitude Control, Propulsion, Electrical, Controls and Displays, and Instrumentation Subsystems. The major elements of the subsystem can be seen in Fig. 5 and are described in detail below.

ATTITUDE CONTROL SUBSYSTEM

The Attitude Control Subsystem provides the necessary components to control attitude and attitude rates of the ASMU/astronaut system in three different modes: (1) Direct, (2) Rate Gyro, and (3) Control Moment Gyro. Each mode is readily selectable while flying the ASMU.

Translational Control

Translational control is identical in each of the attitude control modes. On the left arm of the ASMU, a translational controller allows command inputs to be fed to the attitude control electronics assembly which activates the proper thruster valves. Movement of the controller from the neutral position along the longitudinal, lateral, or vertical translation axes results in a continuous acceleration (approx. 0.35 ft/sec^2) along the commanded axis as long as the controller switch is actuated. Upon release, the translation rates developed remain. To arrest any translational velocities, commands in the opposite direction must be made.

Direct Mode

Operation in this mode evaluates the astronaut's capability to control his attitude through visual cues. Rotational commands are developed by displacing the right hand controller approximately 2.5° from the neutral position. The appropriate thrusters operate continuously and provide angular acceleration about the commanded axes as long as the controller is actuated. The rotational accelerations are approximately 13°/sec^2 in roll and yaw and 11°/sec^2 in pitch. Since the angular rates developed will remain if the controller is returned to the neutral position, "reverse" torques must be commanded to eliminate any attitude rates.

Rate Gyro Mode

Operation in this mode evaluates the handling characteristics of a rate-command and attitude hold capability for the ASMU. Automatic stabilization and control is provided using rate gyro sensors and associated control electronics. Actuation of the rotational controller generates a command signal to the control electronics assembly. This signal is compared with the rate gyro outputs and thruster torque commands are issued until the difference between the commanded rate and the rate gyro outputs are nulled. Rates developed are proportional to the controller displacement with a maximum capability of 20°/sec maneuvering.

Upon release of the hand controller, the rotational rates are reduced automatically to essentially zero. A limit cycle is established at this time by summing ASMU attitude with the rate feedback. The attitude is obtained by electronically integrating the rate gyro outputs. The attitude hold is established to within $\pm$ 4 degrees and pulse modulation techniques are used to maintain the limit cycle rate within the minimum impulse to obtain maximum fuel economy.

Control Moment Gyro Mode

Operation in the Control Moment Gyro (CMG) mode is similar to the Rate Gyro mode except that attitude control and stabilization is provided through momentum exchange rather than mass expulsion. The CMG mode allows maneuvering with a smooth solid feel at reduced propellant requirements but an increase in electrical power consumption.

A CMG assembly provides three orthogonal CMG momentum exchange actuators. Each actuator contains two wheels spinning at a constant speed of 22,500 RPM. The spin vectors of each pair are oriented 180 degrees apart such that in the nominal position the net momentum is zero. The wheels are gimballed and mechanically coupled with a sector gear to form a scissored pair. The gimbal is electrically torqued, and when the pair of wheels are not aligned, the sum of the spin vectors result in a net momentum which is transferred into the ASMU/astronaut system.

CMG control is accomplished with a torque balance control concept using the CMG as a dual purpose device (sensor-actuator). This method of rate control relies on the steady state canceling of two torques on the gimbal axis, a load torque and a control torque. Load torque is developed by the

the angular motion of the ASMU about the momentum exchange axis of the CMG scissored pair. The magnitude of the load torque is proportional to the product of wheel momentum, ASMU angular rate, and the cosine of the gimbal angle. The sign is such that this torque alone tends to change the gimbal angle in a direction that reduces the ASMU angular rate.

Displacement of the rotational hand controller from the null generates a command signal to the control electronics. Control torque is produced by the electrical torques about the gimbal axis. The gimbal angle will change and exchange momentum with the ASMU/astronaut system causing the angular rate to increase until the load torque and control torque balance. Maximum steady state maneuvering rates are 5°/sec about each attitude axis with the rate of rotation proportional to the controller displacement. Upon release of the hand controller, the rotational rates are automatically reduced to zero.

In the event that external torques saturate the CMGs (approximately 55 deg. of gimbal angle), the thrusters are actuated and exchange momentum with the CMGs to reduce the gimbal angle to 30 deg. which enable the CMGs to again provide control. When the CMG mode is not being used, the gimbals are caged and locked with a solenoid actuated pin.

PROPULSION SUBSYSTEM

The propulsion subsystem of the ASMU is designed to operate from either self-contained gaseous nitrogen or gaseous oxygen obtained from the workshop environmental control supply. The former, sized for approximately 20 minutes of "free" flight is provided by a pressure vessel in the ASMU while the latter requires a 30 foot, 1/2 inch umbilical to connect the ASMU with the spacecraft supply.

The pressure vessel is made of unaged 301 cryogenically cold worked stainless steel and enables 1500 cu. in. of gaseous nitrogen to be stored at pressures up to approximately 3,000 psig @ 90°F. The vessel temperature is monitored by a transducer mounted to the outer surface.

A regulator assembly, attached to the pressure vessel, maintains the downstream pressure at 145 psig when the upstream pressure is between 3,000 to 250 psig. The regulator also contains a pressure gauge displaying the vessel pressure, a pressure transducer for inflight instrumentation, a relief valve (vented into thrust neutralizing which has a cracking pressure of 205 psig and becomes fully open at 300 psig) and filters to prevent contaminates from clogging the regulator. The regulator also has provisions for connecting the external propellant supply umbilical.

The pressure vessel/regulator assembly is supported to the ASMU by a quick release mechanism and connected to the propellant distribution manifold by a flex hose/quick disconnect umbilical. This provides the option to either recharge the pressure vessel through the regulator fill port while mounted on the ASMU or to replace it with a spare charged pressure vessel and recharge the depleted vessel at a recharge station provided within the workshop.

Downstream of the regulator, a manifold distributes propellant to the 14 thruster valves controlled by the attitude control subsystem. In the event of a thruster valve failing in the open position, a normally open solenoid operated isolation valve in the manifold can be activated to terminate propellant flow.

Quick disconnects, which are self-sealing and have low release forces, are provided at all propulsion subsystem interfaces. These include the regulator/manifold interface, the remote propellant supply, and the propellant supply to the HHMU umbilical.

ELECTRICAL SUBSYSTEM

The Electrical Subsystem of the ASMU provides the power, circuit protection, and power/signal distribution requirements. The main power source is a 28 volt, 6 amp. hr. nickel cadmium battery which enables the ASMU to be flown approximately one hour. The battery is mounted to the ASMU with manual release fasteners and connectors to allow battery replacement. Additional spare batteries are provided with the experiment hardware as well as a recharge capability within the workshop.

A connector is available to allow operation of the ASMU from an external source of power. It is primarily used during the first 20 minutes to spin up the CMGs and for initial ASMU checkout. The battery may also be recharged while installed in the backpack through this connector.

A power supply within the CMG assembly converts the raw 28 VDC into $\pm$ 5 and $\pm$ 15 VDC required by the control electronics assembly and for instrumentation use.

Circuit protection consists of three circuit breakers and six fuses which isolate a failure without total loss of ASMU power.

The Ground Support Equipment (GSE) connector is used during functional tests and checkout on the ground. Rotational and translational commands can be input from an external source and thruster solenoid valve response verified by monitoring valve signature coil outputs

CONTROLS AND DISPLAYS SUBSYSTEM

The Controls and Displays Subsystem is shown in detail in Fig. 4, and contain the necessary controls/switches requiring activation by the astronaut during flight as well as displaying the ASMU status.

Displays

A dual-scale meter is provided which displays the propellant supply pressure and the battery voltage.

This enables the astronaut to visually determine the amount of propellant and power remaining and identifies when the flight should be terminated to either replace or recharge the pressure vessel or battery.

Two legend lights with redundant bulbs are provided. One light indicates when the CMGs have reached their normal operating speed while the other displays when the CMGs are in a locking sequence.

Switches

Two toggle switches are provided on the left arm of the ASMU. One is used as the master power switch and a similar switch supplies power to the CMG spin motors and torquers. The latter switch enables modes other than CMG to be flown at a reduced power consumption thus extending the battery operating life and flight time.

The four-position rotary switch allows the astronaut to select any attitude control modes while maneuvering. The four positions are direct, rate gyro, CMG, and HHMU. When in the HHMU mode, the control electronics inactivate the hand controller signals to assure no inadvertant ASMU thruster action.

Controls

Two controllers, translational and rotational, are located on the arms of the ASMU. These controllers are the Block I models originally developed for the Apollo command module.

The translational controller, located on the left arm of the ASMU, provides a means by which the astronaut requests translational maneuvering. The control is operated using a T-bar handle grip. Moving the grip in a longitudinal, lateral or vertical direction, from its neutral center position, activates a switch which closes circuits in the control electronics and results in accelerations of the ASMU/astronaut system along the desired direction. Rotary motion of the grip, either clockwise or counter-clockwise, close switches which activate the propellant isolation valve and is used in the event of a thruster failure. In addition, a push switch at the top of the T-bar grip is available and is operated by the thumb. The switch is closed when the button is depressed and open when the button is released. While originally provided for communications, it is used for M509 as a marker button, identifying the various segments of a typical maneuver (e.g. attitude orientation, translational transfer, attitude hold, etc.).

The rotational controller, located on the right arm of the ASMU, is a hand operated control assembly containing rotary transducers whose outputs are proportional to the stick deflection. Command inputs are applied to the pitch, yaw, or roll channels and the proper response of the astronaut/ASMU system, with respect to the control mode selected, is provided by the control electronics.

INSTRUMENTATION SUBSYSTEM

The Instrumentation Subsystem contains the necessary sensors and signal conditioning within the ASMU and HHMU to establish operational characteristics of the maneuvering units. Table I shows the instrumentation incorporated in the ASMU which enables, along with subjective comments and photographic documentation, a detailed postflight analysis of the M509 experiment.

The instrumentation outputs are fed to the crystal controlled telemetry transmitter which accepts either 0-5 VDC analog or bilevel inputs. These inputs are sequentially sampled and formatted for transmission to a telemetry receiver located in the workshop. The transmitter uses frequency shift keying modulation with a mark frequency of 26.075 MHz and a space frequency of 25.925 MHz.

CONCLUSIONS

The AMRV Hardware Program is presently in the development stage with the first flight article scheduled to be available early in 1971. However, to accomplish the total M509 experiment objectives, four additional major program elements must be accomplished:

(1) The development of an inflight test plan to cover maneuvering tasks representative of future EVA requirements and the performance of the in-orbit flight tests of the AMRV. The test plan will incorporate Gemini maneuvering unit plans, previous maneuvering unit simulation studies, various simulations in support of the M509 development program, and future EVA mission support requirements.

(2) Gather and analyze data during the preflight and postflight simulations as well as the inflight tests. Similar data will be recorded during ground simulations as during the inflight tests and will be reduced and analyzed to establish the performance of both astronaut and maneuvering unit.

(3) Correlate the ground based simulator data with that obtained during inflight maneuver. This effort will determine the applicability, fidelity, and limitations of various ground based simulation techniques.

(4) Develop a handbook of maneuvering technology which incorporates the handling qualities and performance of each maneuvering technique flown as well as identifying the capabilities and limitations of both the astronaut and the maneuvering unit.

Analysis of the M509 Experiment will provide a valid basis for establishing EVA performance requirements and for estimating consumable requirements of future astronaut maneuvering systems. It will also indicate what man can or cannot be expected to accomplish when assisted with mobility devices. Proven procedures and techniques will be available to support the wide range of future EVA missions.

NOMENCLATURE

AMRV - Astronaut Maneuvering Research Vehicle
ASMU - Automatically Stabilized Maneuvering Unit
CMG - Control Moment Gyro
EVA - Extra Vehicular Activity
GSE - Ground Support Equipment
HHMU - Hand Held Maneuvering Unit
MMU - Modular Maneuvering Unit

ACKNOWLEDGEMENT

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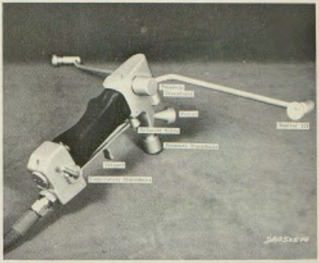

Figure 2. HHMU Mockup.

Figure 1. Preliminary AMRV Mockup.

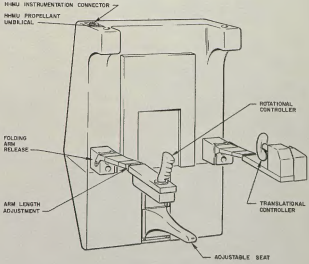

Figure 3. ASMU External Configuration (Front View).

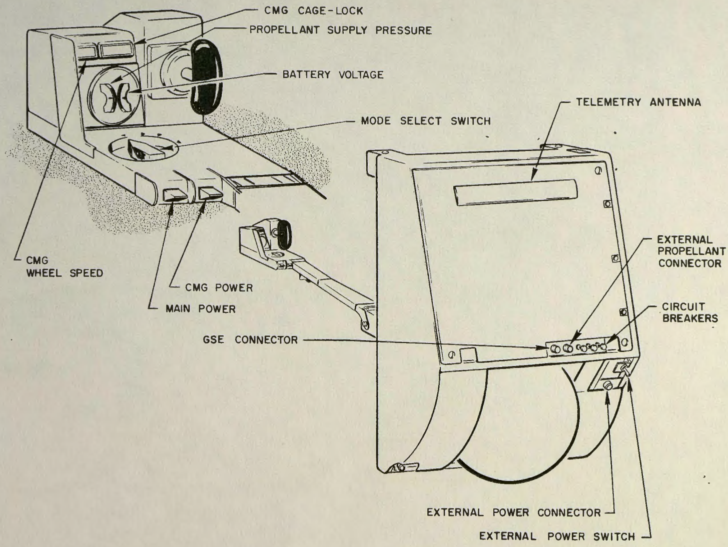

Figure 4. ASMU External Configuration (Rear View).

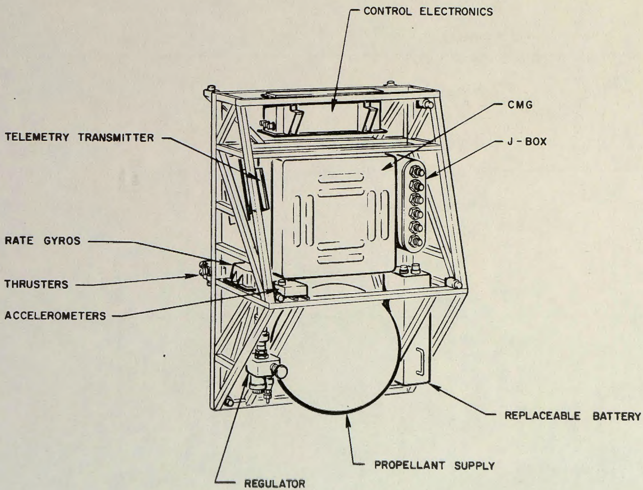

Figure 5. ASMU Inboard Profile

MEASUREMENT DESCRIPTION	MEASUREMENT RANGE	MEAS. TYPE
Rotational Commands (3)	0 to ± 12.75°	Analog
CMG Gimbal Angle (3)	0 to ± 60°	Analog
Tank Pressure	0 to 4000 psi	Analog
Tank Temperature	-50 to +150°F	Analog
ASMU Manifold Temperature	-50 to +150°F	Analog
ASMU Manifold Pressure	0 to 300 psig	Analog
HHMU Tractor Mode Pressure	0 to 300 psig	Analog
HHMU Pusher Mode Pressure	0 to 300 psig	Analog
HHMU Manifold Temperature	-50 to +150°F	Analog
Linear Acceleration (3)	0 to ± 0.05 G's	Analog
CMG Wheel Speed (6)	16,000 to 24,000 RPM	Analog
High Range Rate (3)	0 to ± 50°/sec	Analog
Low Range Rate (3)	0 to ± 2.5°/sec	Analog
ASMU Bus Current	0 to 25 AMPS	Analog
AMSU Bus Voltage	0 to 40 VDC	Analog
Thruster (14)	ON-OFF	Bi-level
Mark Button	ON-OFF	Bi-level
Translational Commands (6)	ON-OFF	Bi-level
Mode Position A	ON-OFF	Bi-level
Mode Position B	ON-OFF	Bi-level
CMG Lock Status	ON-OFF	Bi-level
Rate Gyro SMRD	ON-OFF	Bi-level

Table 1 - ASMU Instrumentation