Contrails

# ASTRONAUT MANEUVERING UNIT TECHNOLOGY

Peter N. Van Schaik
Air Force Aero Propulsion Laboratory

## INTRODUCTION

Astronaut Maneuvering Unit (AMU) has been the title given personal propulsion systems for astronauts who will venture outside space vehicles to perform maintenance, assembly, surveillance, and repair while in orbit. The requirement for extra-vehicular activities has been derived from studies (Ref 1) of spacecraft that maintain long duration orbits. The orbital time for Project Mercury and Gemini are not of sufficient length to require extra-vehicular activities such as maintenance. In the low orbits, redundancy is the most economical method for safety of flight and mission success. If failure should occur or system degradation begin, manual take-over of the flight systems has been accomplished. In case of severe system malfunction, the spacecraft can be deorbited in one-half to one orbit period. However, as orbits become higher and longer in duration, the ability to accomplish fast retrieval decreases while the need for on the spot repairs become more urgent.

To accomplish extra-vehicular activities personal propulsion systems are required. It is not practical to use handholds or handrails over the surface of the vehicle due to weight and complexity. This complexity arises in the fact that surface protrusions are affected by aerodynamic drag during lift-off and re-entry. Individual propulsion units which are self-contained provide the capability to survey and inspect any portion of his vehicle or a second vehicle thereby increasing his capability manyfold.

There have been many poor or inadequate concepts proposed for EVA travel due to a misconception of the purpose required. Extra-vehicular activities do not involve only straight-line "flying" from point A to point B. To perform maintenance and inspect the surface, the astronaut must maneuver in various planes, curvatures, and angles. This alone defeats most hand-held and unstabilized systems. Systems which have six full degrees of freedom must have some control mode other than just open-loop.

The research systems currently undergoing development are the Modular Maneuvering Unit (MMU), Astronaut Maneuvering Unit (AMU), and Remote Maneuvering Unit (RMU). The remainder of this paper will discuss these current systems, discuss problems being encountered, and discuss design criteria and new subsystems which have great potential.

## CURRENT DESIGNS

The three systems previously mentioned are concepts which have resulted from studies (Ref 2, 3), analyses, and considerable in-house

Approved for Public Release

Contrails

testing. In the early days of exploratory development, a design called the Self Maneuvering Unit (SMU) (Fig 1) was designed and fabricated. This unit was test flown in zero-g aircraft for over 250 Keplarian Trajectories (approx 3000 seconds of weightless time.) The data from these flights, although only qualitative in nature, did demonstrate the concept to be feasible. It showed that a back-pack is out of the way mounted on the back, that one hand can be kept free to absorb small impacts and permit carrying of tools, and that after a training period the man can control and maneuver with sufficient precision to arrive properly at worksites. Straight flights down the aircraft compartment are not sufficient to prove feasibility. Translations followed by 90° and 180° turns, then stopping properly oriented at worksites proved the best demonstration of performance.

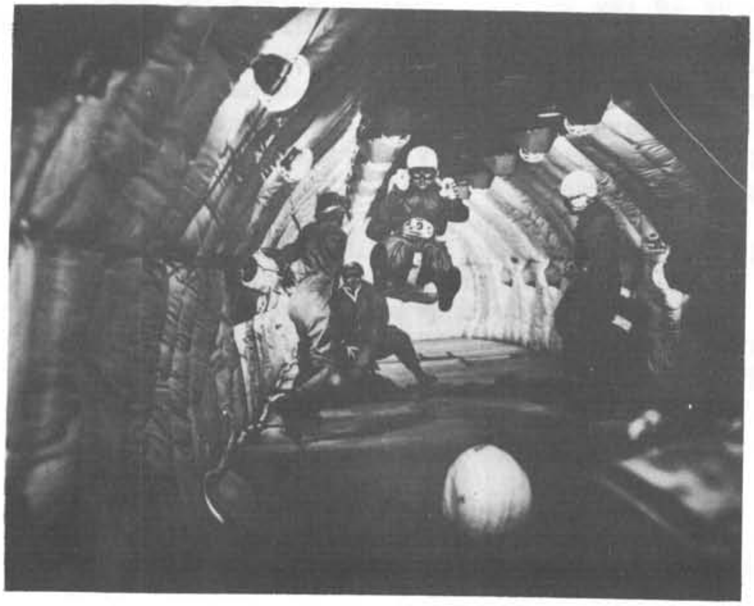

Fig 1 - Self Maneuvering Unit

## Modular Maneuvering Unit

The Modular Maneuvering Unit (MMU)(Fig 2) represents a system based upon the SMU tests and modified to be compatible with the Gemini Spacecraft. The SMU was a general concept using ten (10) nozzles for maneuvering. This was accomplished by three (3) forward and three (3) aft nozzles, two (2) up and two (2) down nozzles. This crotch nozzle proved to be impractical as it provided no redundant features and introduced some cross coupling. The MMU incorporated twelve (12) nozzles which was accomplished by deleting the crotch nozzle and incorporating nozzles on each side of the hips.

Approved for Public Release

Fig 2 - Modular Maneuvering Unit

The MMU was further modified by the addition of a chest pack to contain the primary ECS system hardware and emergency oxygen gas. The chest pack also provided a mounting for the status displays and abort alarm indicators. The back pack module contains all other systems for flight. It contains a hydrogen peroxide propulsion system with a total capability of about 3000 pound-seconds of propellent which is expended through the twelve (12) nozzles each having 2.4 pounds of thrust each. It contains a high pressure oxygen bottle which provides the oxygen source to the chest pack during the MMU mission. It contains a pulse modulated stabilization system utilizing three (3) rate gyros for altitude error sensing. This error signal is sent through a logic network to fire or inhibit the twelve nozzles. In addition, the back pack contains a telemetry system for transmitting biomedical data and MMU performance information. A voice transceiver is included for communication of astronaut with the spacecraft. Finally, a battery pack is included to provide self-contained power to all sub-systems. The control system will entail two side arm controllers, one for attitude and one for translation. The controls will be mounted on extendable arms to simplify the interface with the chest pack and suit.

The modifications were necessary due to space limitations which prevented storage of a back-pack in the cockpit. The chest pack, when con-

Approved for Public Release

Contrails

nected to the spacecraft umbilical, serves to provide ECS during egress/ingress permitting external stowage of the back-pack. The chest-pack is also utilized during the MMU flight.

### Astronaut Maneuvering Unit

The Astronaut Maneuvering Unit (AMU) (Fig 3) represents an integrated design based upon the old SMU design. In the AMU, the environmental control system is contained completely in the back-pack. This is obtainable through a closed ECS system of fan-battery or wet-fan types thereby eliminating the need for a chest pack. Obviously without a chest pack, the AMU must be stowed internally in the crew compartment to permit donning and checkout prior to going extra-vehicular. The control system can be obtained through a waist mounted box like the SMU or a multi-freedom control pole.

The AMU is back-mounted utilizing the 12 nozzle configuration and containing 3000-3500 pound-seconds of propellent. It contains the other subsystems such as the closed loop ECS system capable up to 3 hours of outside operation, stabilization using rate gyros, telemetry, voice transceiver, and a self contained power supply. The control was mentioned before.

## CURRENT PROBLEM AREAS

In the development of the MMU and AMU, as well as testing other concepts, certain problem areas have come to light. Many of these have been fixed to satisfy the current system requirements but have not necessarily been solved for future systems. In light of tight schedules and high cost it has not been possible to redesign the system to eliminate the problem but rather the approach is to derive a solution commensurate with the schedule. Bringing these problems to light and discussing them, should permit better solutions in future applications.

### Configuration

The MMU is a good example of configuration problems caused by designing the maneuvering system after the suit and spacecraft were designed. This is not the optimum design practice but it was the only configuration possible in order to even fly. One of the problems has been the suit design. The suit is designed for a semi-reclining astronaut instead of standing. This semi-reclined position causes the back to take on an egg-shaped contour making it extremely difficult to match a back-pack. The only way to circumvent this problem is to mold the pack around the astronaut to further complicate the problem each astronaut has a different back contour requiring adjustments. This molding of the pack makes the pack look bigger and results in packaging efficiency loss. This hunched-over position makes the astronaut's normal line-of-sight at approximately 45 degrees below the normal horizontal. This creates a thrust mis-alignment between the nozzle orientation and the line-of-sight. Obviously, in the weightless space the astronaut will tend to fly with forward being the normal relaxed eye position. This can be partially corrected but often solutions are possible, as we'll see later.

Approved for Public Release

Contrails

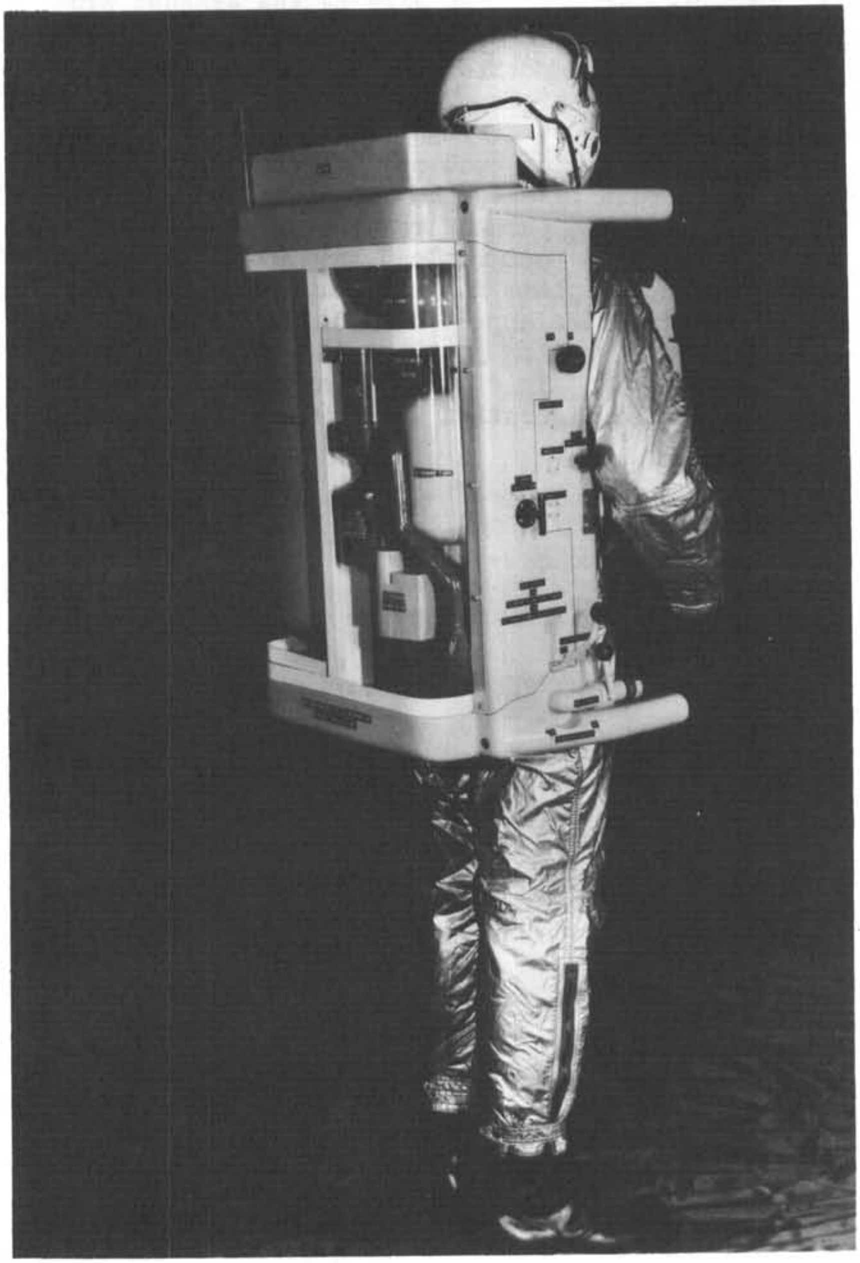

Fig 3 - Astronaut Maneuvering Unit

Another problem in the pack-suit area is the lack of mobility and dexterity. All equipment must be built strong and fool-proof since the astronaut has elephant strength when pressurized. In his attempts to overcome the suit pressure he also can deform fragile controls and cannot perform delicate control movements. Therefore, proportional controls are useless unless they are gross in nature.

Approved for Public Release

Contrails

Plume Heating

The surface heating of the space suit by the exhaust plume has been one area overlooked or over-simplified by many designs. It has become a serious problem in the MMU where the nozzles are anywhere from 3-12 inches from the suit. The plume expansion envelope was analyzed by both mathematical techniques and actual chamber test firings (Ref 4). As there were many unknowns at the time this study was made such as: nozzle design, nozzle locations, suit materials, and thrust levels, the impact of the study was never fully realized. However, as these parameters were defined the problem became more apparent. Many people have been mislead by nozzle firings at atmospheric pressures during which the plume fails to expand as that in a vacuum. The plumes from 5 pound thrusters approach 20 inches in length and 8 inches in diameter causing serious heating problems. Most suits cannot tolerate local heating in excess of 500°F. In figures 4A and 4B typical plumes are shown. As can be seem the AMU configuration with twelve nozzles presents many heat-

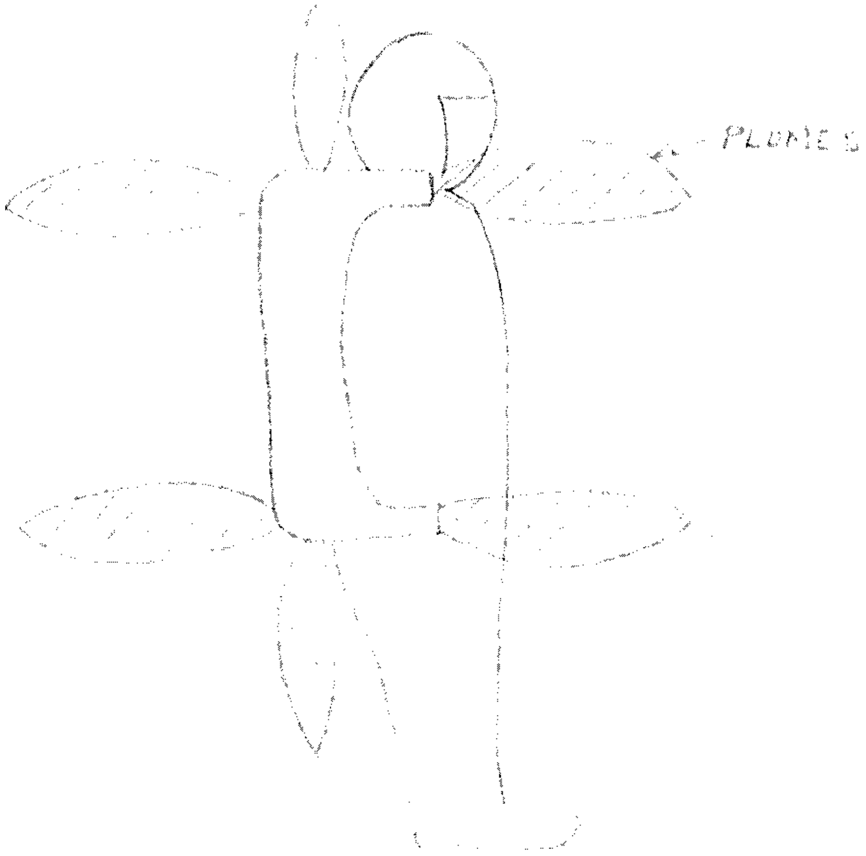

**Fig 4A - Exhaust Plume Outline**
(5# Nozzle, Mach 8 line shown)

Approved for Public Release

Contrails

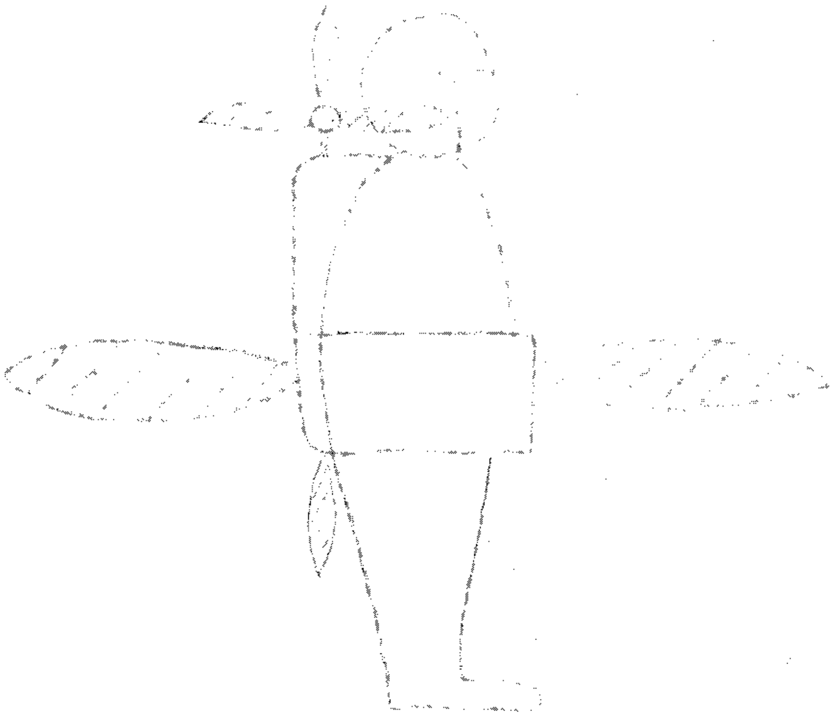

Fig 4B - Exhaust Plume Outline
(Stamp Configuration)

ing areas, particularly on the helmet, shoulder, front and rear legs. The severity of the problem is illustrated below. This pulse is typical of the

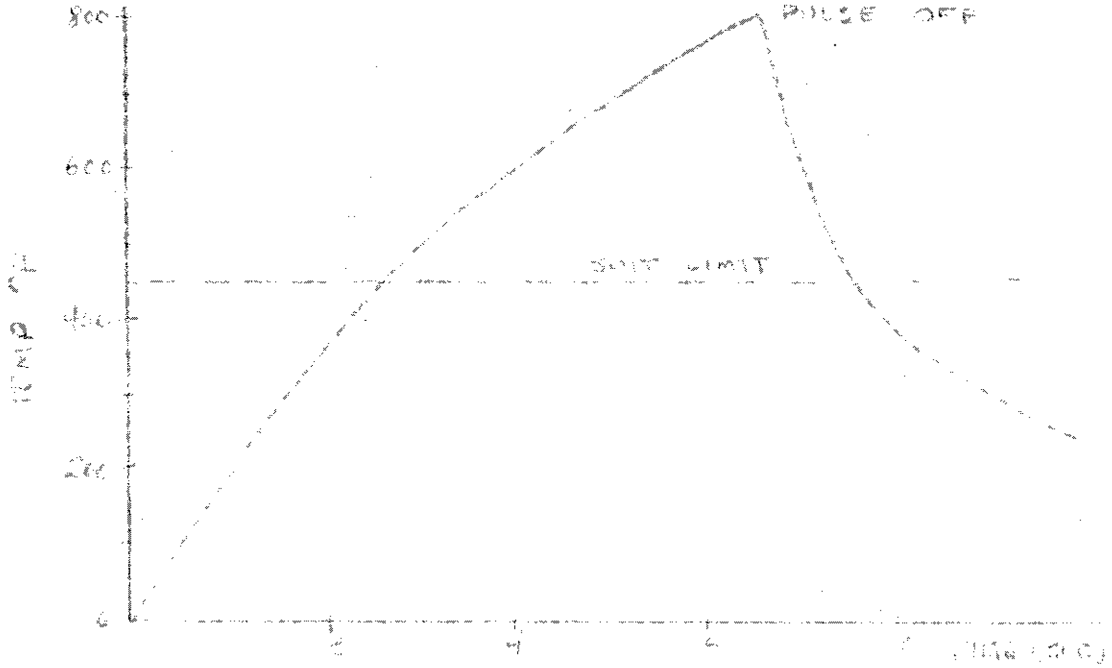

Fig 5 - Heating Rate on Suit Surface

Approved for Public Release

Contrails

normal translation pulses although the maximum time (counting thrust on for forward and retro) may reach 12 seconds.

## Stabilization

Early studies of the SMU (Ref 2) and in-house testing (Ref 3) determined that stabilization is required when complicated maneuvers, such as required during extra-vehicular maintenance, and for relatively long translations are attempted. This conclusion was primarily based on the fact that visual reference from stars were not obtainable and that once man loses the target he can no longer detect the difference between pitch motion and vertical movement. The same occurs in the other axis. Space flights that have occurred since these original studies and tests have confirmed that stars are visible and can be used as references. In addition, additional zero-g testing has shown that man after considerable training can fly most short translationals in "open-loop". It may now be possible to modify the control and stabilization system from full control to a partial control system. By partial control it is meant that the stabilization system prevents the astronaut from going out of control but in normal flight does not interfere.

The SMU experimental maneuvering unit, utilized off-on jets and an amplitude type control system as shown below. This system never worked

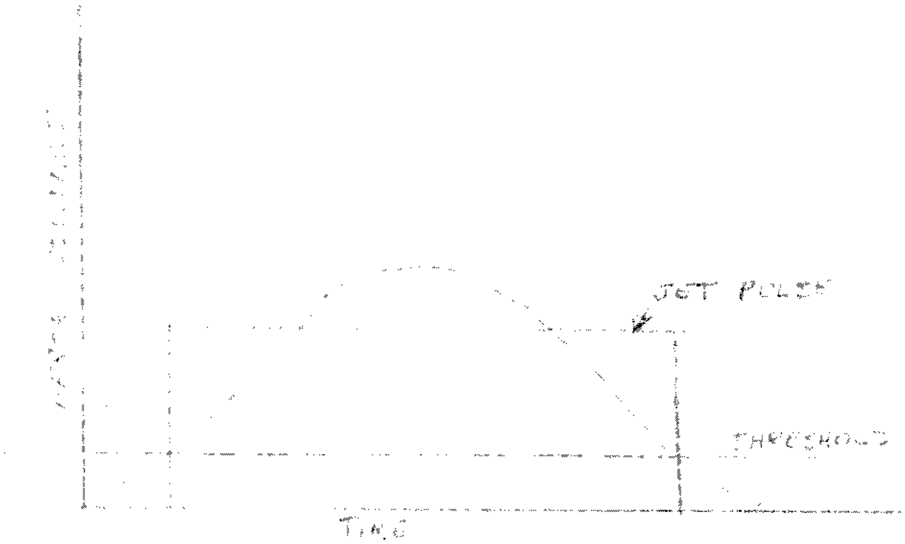

Fig 6 - Pulse Plot

properly because with the one size pulse the system went into oscillations. This was due to the large pulse still being on as the error approached the threshold which drove the SMU past zero. The new system being used in the Modular Maneuvering Unit (MMU) and Remote Maneuvering Unit (RMU) is called a pulse ratio system using a pulse modular. This is illustrated below.

Approved for Public Release

Contrails

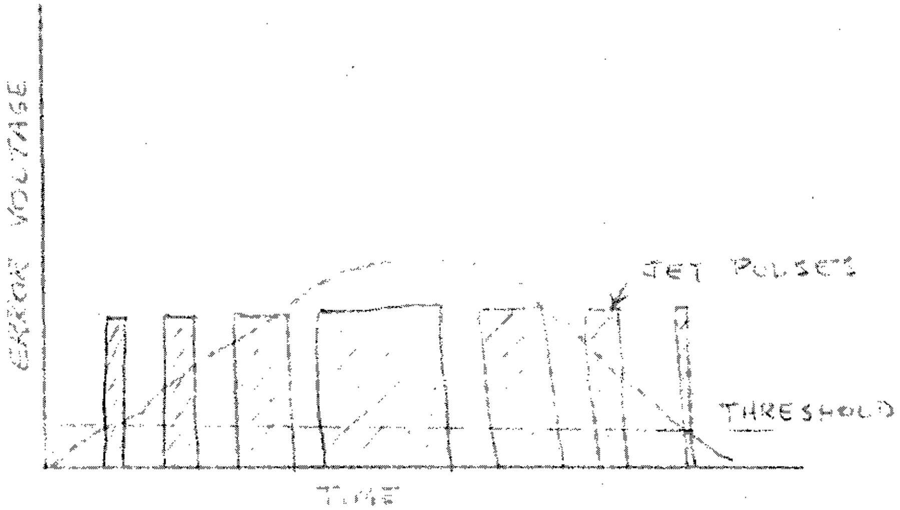

Fig 7 - Pulse Plot

This system has resulted in considerable propellent savings due to pulses being proportional to error and the elimination of oscillations. In the pulse modulation system the pulse width and frequency varies with attitude error with the limit cycling pulse being near the minimum bit size.

Both of the above systems represent full control stabilization since the control develops as limit cycling and after exceeding a 2-5 degree deadband.

Redundancy

System redundancy to an area commonly overlooked in many proposed designs. Redundancy of function is required for maneuvering units to achieve the safety of flight reliability required to fly without tetherlines. It is emphasized that the requirement is for "redundancy in function" not duplicate hardware. This is important in order to reduce weight and volume.

The current maneuvering unit design, including the MMU, has taken on the duplicate hardware approach. This came about trying to make the first "man in space" flight a complete success. The MMU essentially contains two complete propulsion systems (except for tanks), two stabilization systems, two power supplies, two electrical circuits, etc. This makes the unit quite safe but at the same time makes the unit considerably heavier and larger.

On future systems a new philosophy is required in order to reduce weight and volume and yet maintain a highly reliable, safe unit. This philosophy should comprise three basic ideas, such as

1. Redundancy by function

Approved for Public Release

Contrails

2. Expendables sized for moderate mission with recharging capability

3. Systems not falling into 1 above, should have redundancy to return to spacecraft only.

These will be discussed further in the paper. The main reason for this philosophy is to derive a smaller maneuvering unit that can be easier stored, weightless, be safe, and provide all function requirements.

## DESIGN CRITERIA

With all the studies and tests being conducted by various Air Force agencies and NASA in the maneuvering unit area, it appears time for a review of the design criteria is in order. Many people including the Aero Propulsion Laboratory personnel are looking for a "simple, reliable, and lightweight" manned maneuvering unit. However, at the same time the unit must be capable of accomplishing a reasonable mission. Table 1 shows in condensed form the current system capability and future design which is near to state-of-the-art. It is pointed out that the future system criteria is a recommendation and any other system which provides this capability should be satisfactory. Each of these areas will now be discussed to provide a better insight into the reasoning for the parameter selection.

### Configuration

Future AMU's should be a single integral pack being either a back-pack or back-waist pack. There is no need or requirement for a chest pack. The ECS is integral with the back module. Ingress/egress can be accomplished by storing the complete pack in the spacecraft where donning-doffing can occur. If for some reason this procedure is unsatisfactory a short umbilical can be used to reach the spacecraft exterior.

The primary pack shape factors should be egressing through a 34-inch diameter hatch and the exhaust plume heating problem. If solution to plume heating cannot be obtained with the back-pack, then other configurations should be considered. A third consideration for pack consideration is plume impingement on the work surface. Special provisions may have to be made to permit backing away from work areas at a very slow rate to prevent damage to the surface.

### Propellent

There are approximately five propellents which will give the necessary total impulse while maintaining a reasonable size package. The first is hydrogen peroxide as being used in the MMU. Its main problems are its storability and ACL. For long missions, it will require substantial thermal control to prevent freezing or decomposition. Hydrazine is considerably better from the storage standpoint, higher specific impulse, and handling qualities. It does however have a higher plume temperature (1800°F). One promising variation is hydrazine diluted with ammonia which reduces the plume temperature and specific impulse. The final pro-

Approved for Public Release

Contrails

Table 1 - AMU DESIGN CRITERIA

| Item | Current System | Future Systems |
|---|---|---|
| 1. Configuration | Back-pack molded to suited astronaut. Includes chest pack. Arms used for two separate controls | Back-mounted or combination back and waist (Ref 4). No chest pack - one integral module. One or two arms free |
| 2. Propellent | Hydrogen peroxide | Hydrazine, Hydrazine ammonia mix, solid propellents. |
| 3. Total Impulse | 3000 lb - sec plus 500 lb - sec reserve | 2500 lb - sec plus 300 lb - sec reserve. |
| 4. Nozzles | 12 at 2.4 pounds thrust each. Four forward (2 fire & 2 reserve) four aft (2 fire & 2 reserve), two-up and two-down | 12 at 1 pound thrust each. Four forward (all fire), four aft (all fire), two-up, two down. The back-waist unit would ease 2 forward at 2 pounds each), 2 aft at 2 pounds each, two up and two down at 1 pound each, and attitude control thrust |
| 5. ECS | Semi-open system in chest pack, bottle supply in back-pack. Duration one hour | Closed loop fan or water transport system in back module. Duration 2 hours. |
| 6. Stabilization | 3 rate gyros, logic, and pulse modulator. Limit cycle operation Dead band ±2 degrees, attitude rates 15°/sec | Control moment gyros and simple logic. No limit cycle. Jet actuation ±2-4 degrees, attitude rates 10-15 degrees/sec. |
| 7. Power (Battery) | Main batteries ±28VDC<br>Stab batteries ±16VDC | Main battery ±28 VDC |

Approved for Public Release

Contrails

Table 1 - CRITERIA (Cont'd)

| Item | Current System | Future Systems |
|---|---|---|
| 8. Telemetry | | Same plus remote control requirements |
| 9. Tetherline | 200 foot soft line | None |
| 10. Redundancy & Reserve | | |
| a. Propulsion | Primary & secondary systems manual switched | Single system with electrical cut-off for on nozzle failure |
| b. Total Impulse | 500 pound-sec | 300 pound-sec |
| c. ECS | 10 minute emergency | 10 minute emergency |
| d. Stabilization | Back-up system | Open-loop |
| e. Power | Back-up batteries | Reserve battery to return to spacecraft |
| f. Failure | Tether | Remote control |
| 11. Abort Alarm & Displays | Mounted on Chest Pack | Wrist mount or digital display on helmet |
| 12. Flight Control | Side-arm controls | One-hand control or voice controller |

Approved for Public Release

Contrails

pellents which appear attractive for this application is the solid propellent capsules (Cap Pistol) and solid charges fired into a chamber which provides gas for the system.

## Total Impulse

Mission analysis and simulated flight tests have indicated that for a moderately active mission 2500 pound-seconds will suffice. The 300-pound-second reserve takes care of contingencies and provides "return to spacecraft fuel." Any additional mission requirements can be achieved by refueling.

## Nozzles

Assuming for this discussion the 12 nozzle back pack is maintained, each nozzle should have one (1) pound of thrust. The forward thrust would be 4 pounds (4 nozzles x 1 lb T). This is nearly identical to the MMU which uses 2 thrusters at 2.4 pounds each for 4.8 total. Although the MMU uses the other thrusters as reserve redundancy, future systems should use all thrusters. Redundancy can be achieved by a special wiring procedure so that failed thrusters can be cut-out electrically in diagonal pairs thus accomplishing same thing as the MMU. This concept is illustrated below.

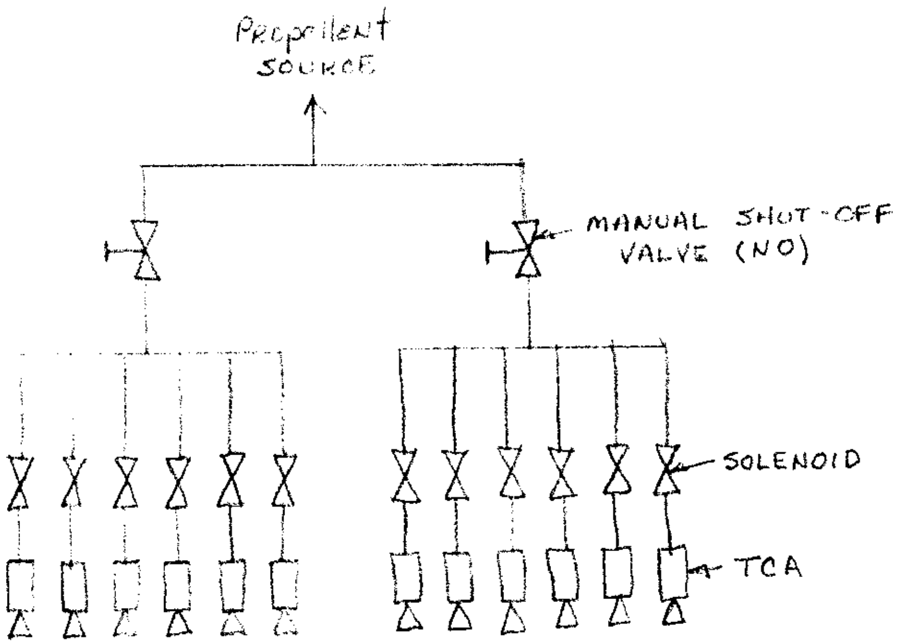

Fig 8 - Propulsion Schematic

Approved for Public Release

## ECS

All studies of environmental control systems for AMU's have shown either the closed loop fan system or the water transport system best for the AMU when mission time exceeds 1-2 hours. The two (2) hour time has been selected because it is compatible with mission accomplishment and the astronauts physiological performance. Although data is considerably lacking on man's degradation per hour worked while extra-vehicular, it is reasonable to estimate that two (2) hours continuous work will be very tiring for the astronaut. It seems also reasonable to believe that there is no work requirement which requires the astronaut more than 1-2 hours at any one time. He can return to the spacecraft to reservice expendables and attain a brief rest.

## Stabilization

Control moment gyros cannot be built large enough to provide complete stabilization because they will become too large and heavy. However, suppose they were only capable of 4-5 slugs of control in a 11.5 slug man-pack system. It would control small moments and act as a dampener for large moments. After exceeding a certain deadband the jets would turn on to prevent large excursions. Such a system appears advantageous and feasible but needs study and analysis.

## Tetherline

The idea of using a tetherline for emergency recovery has not proven successful to date due to space dynamics which won't be discussed here. However, one concept which has not received attention to date is remote control for emergency recovery. This may not be too difficult to achieve since a telemetry system is already aboard the AMU. A trade-off study is needed to weight the feasibility and practicability of a three-body tether scheme as opposed to remote control.

## Abort Alarms and Displays

The displays and alarms are still a firm requirement even though no chest pack is required. However, the displays must be limited to only those critical to EVA flight such as fuel quantity, $O_2$ quantity, $CO_2$, etc. and subsystem failure alarm. There are two possible schemes available. One is a wrist mounted display which can be read by the astronaut. A second is a modular digital light display which can be mounted to the helmet like a voice microphone. The critical parameters could be presented at some sampling rate and read by the astronaut at periodic intervals. Failure, malfunction, or low expendables could be immediately brought to his attention by flashing red. Both these method need further analysis.

## Flight Controls

A flight controller which appears attractive for the AMU is a voice controller. This is simplified from previous studies (Ref 6) where the commands are narrowed to six or eight distinct commands instead of the

Approved for Public Release

Contrails

whole English language. This simplified system could be made in a small package for the AMU.

## CONCLUSIONS

As can be seen from the discussions in this paper, the future AMU's should contain the bare minimum in capability so that size and weight can be minimized. Added capability can be accomplished by returning to the spacecraft for reservicing and recharging.

It also can be seen that the MMU design is not recommended completely for future systems. New technology is available for improving system and subsystem design. These new items should be investigated immediately so most of them can be incorporated as soon as possible.

The discussion of current problems was discussed to bring everyone up to date and encourage new and different solutions. The MMU still will be the first manned extra-vehicular flight and will be a stepping stone to bigger and better missions in the future.

Approved for Public Release

Contrails

## BIBLIOGRAPHY

1. Bell Aerosystems Company, Study of Space Maintenance Techniques, ASD TDR 62-931, Wright-Patterson Air Force Base, Ohio. May 1963

2. Ling-Temco-Vought, Self-Maneuvering Units for the Orbital Maintenance Worker, ASD TDR 62-278, Wright-Patterson AFB, Ohio. August 1962.

3. Van Schaik, P. N., Astronaut Maneuvering Unit Test Results, ASD TDR 63-71, Wright-Patterson AFB, Ohio. March 1963.

4. Ling-Temco-Vought, Integrated Back-Pack Maneuvering Unit Propulsion Study and Exhaust Plume Heating Study, ASD TDR 63-729, Wright-Patterson Air Force Base, Ohio. Sept 1963

5. Van Schaik, P. N., Multi-Purpose Propulsion Units for Space Maintenance, Technical Paper presented at AIAA Conference. April 1965

6. Honeywell, Inc., Study of an Attitude Control System for the Astronaut Maneuvering Unit, NASA Report NASA CR-198. July 1964

Approved for Public Release