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STUDY OF EXTRAVEHICULAR PROTECTION AND OPERATIONS

by P. Iribe and J. A. Lieske

Prepared by
THE JOHNS HOPKINS UNIVERSITY
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extravehicular systems

A B S T R A C T

This report is a study of the requirements placed on extravehicular protection and operation devices by the orbital environment and contemplated orbital missions. The orbital missions studied cover the period 1970-1978 to the extent that they are presently defined. The conclusions favor a suited astronaut supported by propulsion, communication and working aids (non-anthropomorphic suits were not included in this study). Concepts of vehicles satisfying the requirements developed are presented as is the concept of a modularly assembled device which can be modified to best suit specific mission requirements.

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1.0 STATEMENT OF PROBLEM

The purpose of this report is to examine the present state of the requirements that have been assumed for extravehicular activity (EVA) and the state-of-the-art of the hardware solutions so far developed or proposed to meet these requirements. This examination will also suggest possible omissions to the list of requirements and development programs likely to be required for future missions.

The present state of development of EV systems for the astronaut working in orbital space or on the lunar surface consists of individual devices employing hardware which has been in the main developed for other uses. Only 4.0 hours of EV experience ~~has~~ have been accumulated up to the present by the United States so that development of EV hardware based on space experience has not yet begun. The present and most probable future sequence of events in the development of EVA systems is shown in the diagram below.

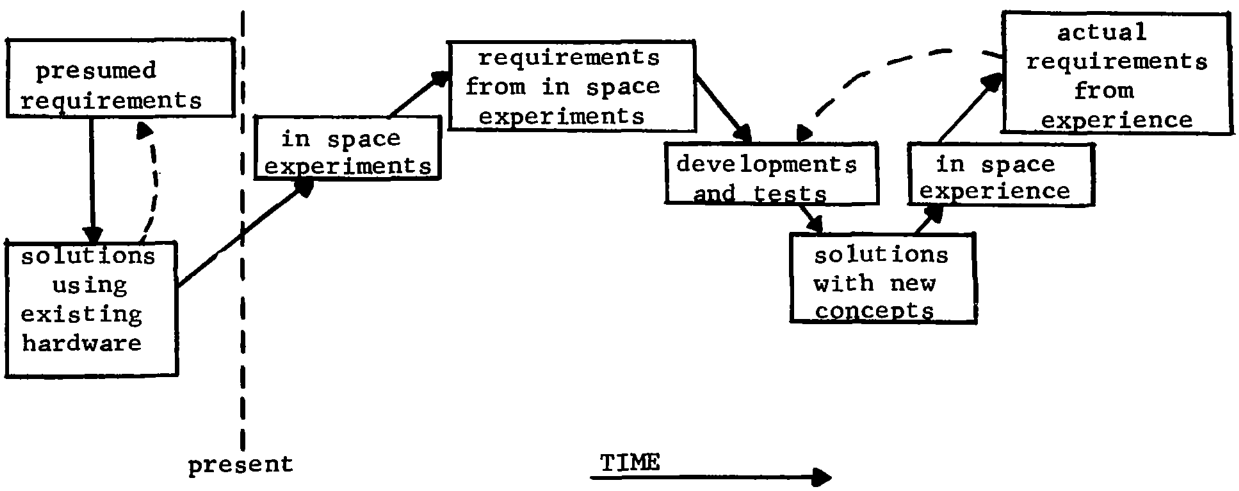


Figure 1.1 Development sequence for EVA systems

This figure points out the vital importance of in space EVA experiments closely related to the contemplated future missions requiring EVA.

2.0 THE CONCEPT OF EXTRAVEHICULAR ACTIVITY - EVA

The execution of the early manned space exploration missions is a prelude to man's most useful role, that of active work outside the main vehicles which have conveyed him into space.

Man's capability in space will be exploited to the fullest when complete use is made of his vast spectrum of combinational capabilities, his ability to analyze, make decisions, reprogram and take appropriate actions. These attributes are best demonstrated in the variety of extravehicular activities demanded by missions contemplated for the future. For these missions the astronauts will also need the best available knowledge, experience, and training.

The original concept of the unencumbered space suited man has had to be replaced by EVA systems whose complexity mirrors that of the tasks proposed in the advanced mission concepts. This study is primarily concerned with the development of these systems for orbital missions. Moon crawlers and rocket harnesses, as well as Martian gliders, will be examined in later studies.

3.0 ORBITAL ENVIRONMENT CONDITIONS

The answers to the mysteries of the environment in space and particularly in orbital space have been diligently pursued since the launching of the first sounding rockets. Extensive literature exists and tremendous earth surface simulation laboratories have answered most of the questions raised in dealing with the environment. However, EVA puts man in such direct contact with the peculiarities of the environment that a review of the aspects pertinent to EVA is necessary in examining EV systems.

The four most important environment conditions which affect an EV system in orbital space are:

1. Mechanics
2. Vacuum
3. Illumination
4. Radiation

3.1 Mechanics

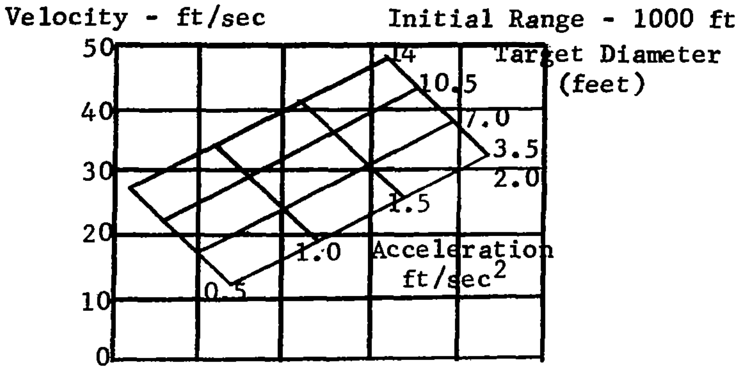
The mechanics of motion and zero "g" environment pose several problems. These are:

1. Scattering of untethered objects
2. Peculiar interobject navigation requirements
3. Changing relative bearings between objects

These effects, in turn, restrict the time available for assembling a unit from scattered objects, require some method of retaining tools and parts, and complicate communications between vehicles.

Textron's Bell Aerosystems Company has conducted simulation studies of EVA missions relating motion mechanics, propulsion, sensor, and display systems to vehicles of the EVA class, both manned and unmanned (Ref. 56). The EVA vehicles they examined ranged from an astronaut maneuvering unit (AMU) to an enclosed non-anthropomorphic structure with a shirt sleeve environment. Simulation runs that were conducted showed a specific relationship between range, closing speed, target size, and acceleration. These results are summarized in Figure 3.1.1 where the intersection of the lines of constant target diameter with a given closing speed determines the minimum acceleration requirements for stopping before reaching the target.

It is expected that maximum closing speeds of 15 to 20 fps will be experienced in the performance of rendezvous maneuvers with ranges from 1000 to 5000 feet. Figure 3.1.1 shows that if this is the case, a minimum acceleration of 0.5 ft/sec^2 would be required to safely approach targets of 10 foot diameter (Ref. 56).



Deceleration Requirements
for EVA Vehicles (Ref. 56)

Figure 3.1.1

Ideally, the characteristic velocity (ΔV) required to translate over a given range is twice the translational velocity. Thus lower velocities imply lower characteristic velocities. Controlling manually, and using proportional navigation Bell Aerosystems Co. (Ref. 56) found from simulation testing that these are practical limits both on velocity and time. For instance, for a maneuver of constant range, characteristic velocity decreases as time allowed for the maneuver increases. This only holds true to a point, however, after which ΔV increases as a function of time. The increase of ΔV as a function of time is due to the combined effects of reduced maneuvering efficiency associated with small translational velocities and increased propellant consumption associated with attitude control requirements for prolonged periods.

Results from simulated maneuvers conducted at Langley Research Center have tended to corroborate the above findings (Ref. 13). One of the more significant observations is that in any realistic extravehicular operation, the astronaut has a definite target at which to aim and should rarely require the generation of large transfer velocities to get to the target. These results also indicate that when the velocity inputs of the astronaut are kept low, a simple low-powered maneuvering system will provide adequate maneuvering and retrieval capability.

3.2 Vacuum

The most important characteristic of the space environment is the vacuum since it affects all extravehicular operations both in orbit and on the lunar surface. The space vacuum is a very restrictive factor in that it:

(a) Forces man into a soft space suit or some other airtight pressurizable enclosure.

(b) Imposes mobility restrictions and often atmosphere losses during an astronaut's movement from one enclosure to another. (Airlock design problem)

(c) Requires radiative heat dissipation. (Conductive heat sinks may be found on the moon)

(d) Necessitates that communication be by wire, contact, or electromagnetic radiation.

(e) Requires, in orbit, reaction against vehicles or expenditure of mass for propulsion.

There are many other minor adverse effects resulting from the vacuum environment; however, for extravehicular operations an effort should be made to take advantage of the vacuum so that it will be as much a tool as possible.

Some of these advantages may be:

(a) Ease of vacuum deposition. (Mirror coatings, changing surface characteristics)

(b) Contact welding of similar metals.

(c) No air drag. (Possibility of erecting flimsy unguyed structures)

Full development of these advantages will require experiments both on earth and in space.

3.3 Illumination

The sources of illumination in near-earth space and on the lunar surface are so extremely different in their intensities that they give rise to serious problems for the EV astronaut.

An important aggravating factor is the changing orientation of the astronaut's field of view. In orbital space, the orbital motion may further complicate the situation by constantly changing the position of illuminating sources and background of the work or objects in the field of view.

Under some conditions the Sun can create hazards to vision and the visual apparatus; filters to compensate for these hazards are not a complete solution as they can lead to insufficient transmission of low level illumination from the work. Certain viewing angles can so reduce the available illumination that familiar objects may be difficult to recognize or may vanish altogether. Certain surfaces do indeed appear to vanish under space illumination.

3.3.1 Optical Hazards (Ref. 69)

When viewed from outside the earth's atmosphere at the earth's orbital distance, the Sun is almost twice as bright as from the earth's surface (7×10^8 ml against 4.4×10^8 ml). In earth-orbital space, the earth's day side is a brilliant surface with a luminance varying from 4.3×10^3 ml to 9.4×10^3 ml. When contrasting these luminances with common objects such as a TV screen (1×10^1 ml), white paper in a good reading light (2×10^1 ml), and a full moon viewed from the earth (8×10^2 ml), one can obtain a fair idea of the intensities to which the eye is exposed. Solar illumination differs from that reflected from the earth in two main characteristics; its energy flux (130 watts per ft^2), and its collimation, which gives the light the characteristics of a laser beam. Suitably aimed and modulated, it can provide an excellent means for emergency transmission of information.

The brilliances have two optical effects. The first is on visual adaptation; the eye, unless shielded and given time to adapt, will not respond to low intensities such as stars. When observing a co-orbital object illuminated on one side by the sun, the other side, even if illuminated by the full moon or by the earth when the albedo is down to

0.39 (no cloud cover), will not be visible to the eye adapted to the bright glare of the sunlit side. Filters do not help since while decreasing the intensity of the sunlit side, the light value of the other side is equivalently diminished so that adaptation will still not detect the weakly illuminated side.

The second optical effect is the potential for retinal burns if the unfiltered sun is in the field of view of the eye for more than a few seconds. Solutions proposed to deal with this problem must take into account the first optical effect described above. Otherwise, the astronaut's work capability may be seriously reduced.

3.4 Radiation

Beyond the protection of the earth's atmosphere, at altitudes in excess of 200 to 300 km, the radiation intensities increase markedly and can vary over a considerable range. The variations are a function of the magnetic latitude, altitude, and solar activity of the past days and weeks. Balloon, rocket, and satellite measurements have not yet yielded enough data to enable the characteristics of the earth's radiation field to be accurately forecast for any combination of the above variables. However, enough is known that a composite picture of the radiation field accurate to one order of magnitude can be assembled. Figure 3.4-1 shows the various major orbital natural radiation phenomena.

The most generally distributed source of radiation is the interstellar cosmic ray radiation, which seems, even with respect to our galaxy, to be nearly isotropic in its origin in the celestial sphere. This field is modified only by the earth's magnetic field, and in Figure 3.4.1 the primary particle flux per square centimeter per second is shown by the dashed lines.

Next in importance is the radiation field of the Van Allen belts. In one location, at 1500 km above the equator, the inner belt reaches a maximum intensity with a flux of approximately 1000 protons per cm^2 per sec of energies greater than 1 Bev. This radiation flux decreases rapidly with changes in altitude and geomagnetic latitude. It is, however, constant in time since these particles are not of solar origin, but apparently consist mainly of cosmic ray albedo protons.

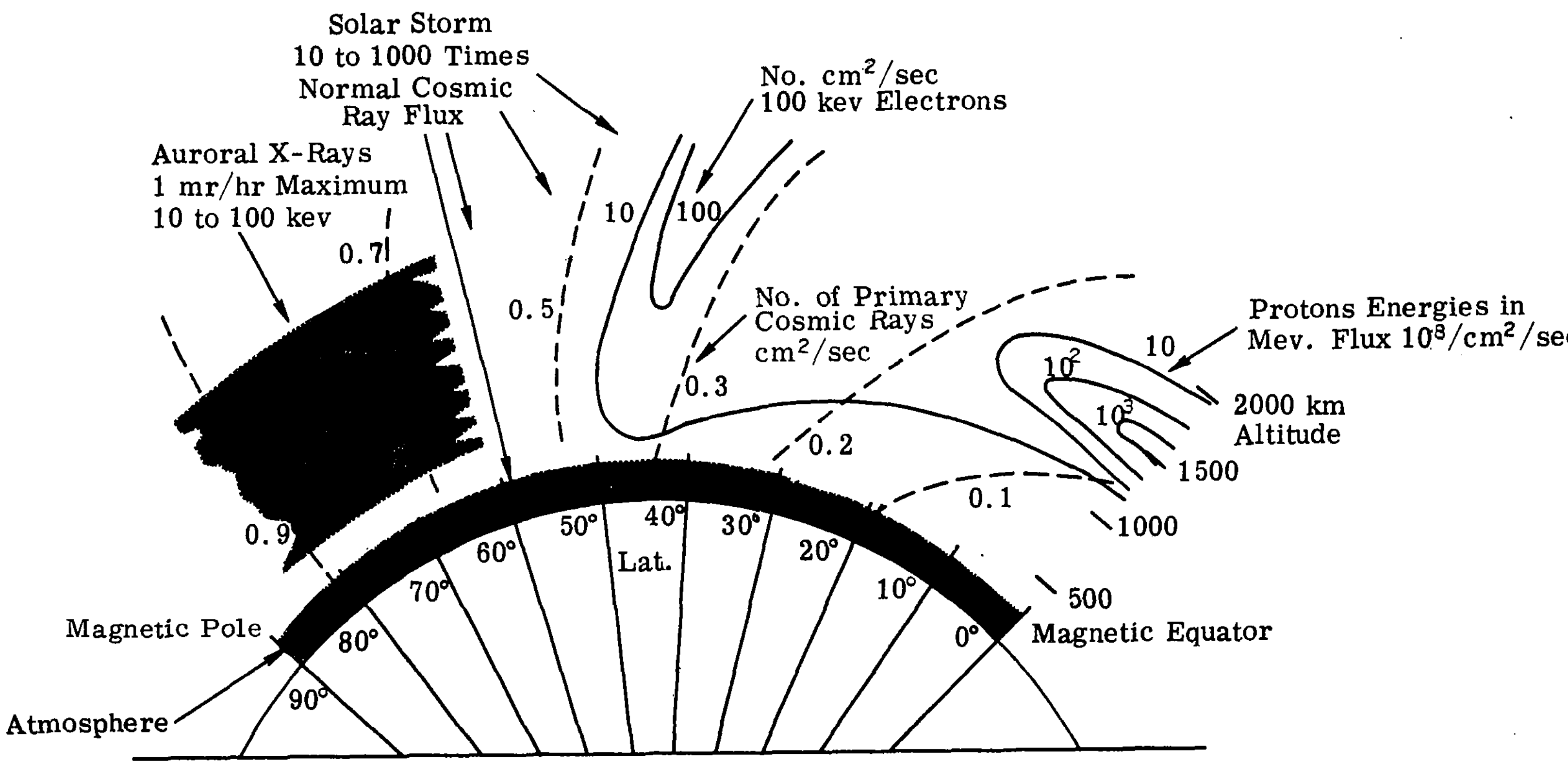


Fig. 3.4.1 RADIATION ENVIRONMENT IN ORBITAL SPACE

The edge of the outer Van Allen shell of magnetically trapped solar plasma is seen in Figure 3.4.1 extending down towards the earth's surface above 30° geomagnetic latitude. The outer Van Allen radiation field may vary by several orders of magnitude as a function of solar activity. The arrival of solar plasma, about a day after a solar flare, distorts the magnetic field of the outer belt dumping its particles in the form of auroral X-rays.

Some solar flares are also accompanied by extreme increases in solar cosmic ray emissions reaching peak values of 1000 times the normal cosmic ray field for several hours. Such events, however, occur only every few years. Ordinary solar storms occurring every few weeks produce a rise of less than 10 times the normal cosmic ray field.

Artificial radiation fields such as those of the Argus experiments have not been indicated. Their strengths are a function of the source characteristics, and special bombs or long lived sources can be designed which could generate fairly intense fields. Nuclear weapon shots which inject particles into the forbidden region between the two belts may produce intense but short lived fields as these particles are rapidly dumped out.

The radiation fields shown in Figure 3.4.1 play a critical role in the planning of orbital missions. Shielding is required for missions which penetrate the Van Allen belts for lengthy periods, such as weeks or months, and the amount of shielding necessary is a function of the region crossed by the orbital path. Radiation affects both the crew and all materials on board depending on their sensitivity. This fact can play an important role in EV activity where replacement of sensitive materials may be required.

An example is the consideration which must be given to photographic film in the Manned Orbiting Telescope (MOT). Since film is actually a sensitive radiation detector, it must either be heavily shielded or be exposed to radiation danger for a very limited time. It appears that the mission of the MOT would benefit in many ways from being in an orbit as high as the so called stationary orbit. Longer observing times could be used with smaller expenditures of stabilizing propellant, the operation of the telescope doors, which protect the telescope thermally when viewing the earth, would be operated, at the most, once in twenty-four hours instead of 16 times in twenty-four hours for a 90 minute orbit. The major problems are film handling techniques and schedules which can make heavy demands on EVA (Ref. 54).

The soviets have thus far made only brief qualitative statements about the lunar vicinity radiation measured by Luna X. They have reported the existence of surface albedo radiation (produced by the reaction of cosmic rays with lunar surface materials) and of radiation originating in the materials themselves. They conclude that, "Compared with the analogous radioactivity of earth rocks, the observed gamma ray spectrum comes close to the radioactivity of basic rocks - basalts" (Press Release). It thus appears that there are no unusual radiation dangers caused by the lunar surface itself, the main radiation danger being only slightly greater than that observed in free space at the earth's orbital distance from the sun.

4.0 REVIEW OF MISSIONS

Extravehicular activity is intended to play two roles in the space exploration program. The first is to insure the safety and integrity of one's own or primary vehicle, the second is to aid in the accomplishment of many of the important missions of the future, whether in orbit or on the lunar or martian surface.

The orbital missions which appear most likely, at this time, to be implemented during the 1968 to 1980 period are (Ref. 72):

(a) Environment survey
(b) Biomedical experiments
(c) Earth sensing
(d) Orbital operations development
(e) Astronomical sensing

(f) Orbital assembly

(g) Satellite inspection

(h) Orbital launch vehicle assembly

A description of the probable EV scope of each of these missions is given in the following paragraphs which indicate some of the EV operations requirements.

4.1 Environment Survey

Such missions will include the use of all pertinent particle and radiation measuring devices such as have been used on unmanned scientific probes. It is not expected that the measurements will be the sole purpose of a mission, but rather that some environment measurements will be a part of all orbital missions. Special programs will involve manned participation.

These may include measurements in cooperation with surface solar observatories during periods of solar events, the use of special instruments during meteor stream encounters, and a "space weather station" during lunar missions.

The major reasons for EVA in connection with this mission are:

(a) Work involving emplacement of instruments which cannot operate from the pressurized interior of the vehicle (usually because the sensor cannot operate through any type of window).

(b) Deployment of instrument which must be isolated from the vehicle's field of influence by being placed at a distance from the vehicle. This involves supervising the deployment of booms and the installation and check out of the instruments.

(c) The servicing of externally mounted instruments with a limited life (usually due to sensor degradation).

(d) Routine repair and maintenance tasks involving the vehicle and the instruments mentioned above.

4.2 Biomedical Experiments

Such mission objectives will also be included among those of other missions. The principal purpose is to provide for closer and more intensive monitoring of the physiological effect on the astronaut resulting from environment and task variables. Certain missions may involve important modifications of the atmosphere or of the zero or hypogravity schedule. Astronauts engaged in EV experiments and activities may expect to have all meaningful physiological variables constantly monitored and telemetered to the main vehicle.

Some EV experiments may be designed mainly to gather physiological data.

4.3 Earth Sensing

In general, these missions have the greatest payoff potential from the point of view of meteorology, crop planning, agricultural disease and pest control, land development, and other uses as yet unforeseen. Such missions imply the use of imaging sensors over a great part of the electromagnetic spectrum. For those wavelengths which do not penetrate the atmosphere, atmospheric adsorption and scattering or reflecting data would be obtained.

As in environment sensing, the major EVA will be in emplacing and servicing instruments which must be externally mounted because the sensor cannot operate through any pressure sealing window. Externally mounted sensors may require a frequent servicing schedule since they may involve tracking mechanisms exposed to the space environment.

The ability of the astronauts to select ground targets of interest and to participate actively in ground cooperative programs may be of great importance especially in meteorological research.

4.4 Orbital Operations Development

These missions are of immediate and paramount importance in arriving at the requirements for EV systems. They constitute a class of missions which will be carried intermittently over several years. Five typical experiments which will be the subjects of early missions are:

(1) Development of manned locomotion and maneuvering capability.

(2) Emergency techniques, equipment, and procedures for rescue operations.

(3) Development of personnel and cargo transfer operations.

(4) Maintenance and repair techniques.

(5) Extravehicular assembly operations.

These experiments will involve one or two astronauts operating extravehicularly for two to four hours per excursion and may be repeated as the results demand. The variety of subexperiments anticipated at this time is shown in the table below:

(1) Locomotion and Maneuvering

Non-Powered Extravehicular Locomotion

Non-Powered Extravehicular Work Site Anchoring

Non-Powered Extravehicular Attitude Control

Powered Maneuvers at Short Ranges

Powered Maneuvers at Intermediate Ranges

(2) Emergency Techniques

Non-Powered Rescue Operations at Close Range

AMU-Powered Rescue Operations

Tests of Auxiliary Maneuver Devices and Emergency Life Support Methods

Rescue by Emergency "Talk-In" and Remote Control

(3) Transfer Operations

Non-Powered Activities

Powered Cargo Transfer Activities

Crew Transfer with Portable Air-Lock

Verification of Selected Cargo Transfer Techniques

RMU Tests

Crew and Cargo Transfer During Rendezvous

(4) Maintenance and Repair

Basic Behavioral Tasks

Component and Module Replacement

Electrical and Electronics Maintenance

Fluid and Gas System Maintenance

Propulsion System Maintenance

Mechanical System Maintenance

Structural Maintenance

(5) Assembly Operations

Minor Assembly and Erecting Tasks

Assembly of Large Structures

Positioning and Connecting Large Modules

4.5 Astronomical Sensing

The recent failure of the first large unmanned orbiting Astronomical Observatory serves to point up the role of man in a mission with such complex instruments and objectives. This mission will evolve as small telescopes presently carried inside the main orbital vehicle and small externally mounted sensors are replaced with large external telescopes. One concept of an independent external telescope is the 120" diameter mirror telescope vehicle evolved in the Boeing Aircraft Company's funded study (Ref. 54). This study, although not a final detailed design study, can be used to elaborate some of the typical EV tasks involved in operating a large orbiting astronomical observatory.

Figure 4.5.1 shows the general layout of the 120" cassegranian primary and the two secondary mirrors which permit two focal lengths to be obtained.

4.5.1 Focal Length Change

As an example of an extravehicular task the steps required to enter the inner shell telescope structure and change from an F30 to an F15 focal length are examined in detail. The task of changing the secondary mirrors is shown in Figure 4.5.2.

Elapsed Time	Astronaut Activity
000	Move from exterior of cabin to end of extended earth shade. (1/2 ft/sec. = 2 min.)
003	Secure work pack to end of extended earth shade. (Anchor points provided.)
006	Detach connections to work pack. Set up TV monitor.
007	Connect power and communications umbilical lines and check out. (These lines are used throughout the task only if the system provided inside the telescope structure is not operative.)

009	Using handholds provided, enter earthshade to level of telescope door location above secondary mirror spider structure.
010	Connect to MOT Communication system. Examine and report door condition.
012	Turn on lights required for secondary mirror servicing.
012	Activate door opening mechanism. In case of failure use manual mechanism.
014	If interior lights function, secure umbilical line.
015	Enter telescope inner structure using foot and handholds.
017	Close telescope doors.
017	Proceed to level where F15 mirror is secured to telescope tube wall. (Great care is required to pass through 4 arm spider secondary structure.)
020	Connect astronaut restraint. Lock restraint for access to stowed F15 mirror.
021	Disconnect and secure F15 mirror stowage clamps.
022	Position and secure F15 mirror near secondary mirror cell.
023	Unlock astronaut restraint.
023	Astronaut moves to secondary mirror cell service position.
024	Lock astronaut restraint as required for mirror positioning.
024	Position secondary F15 mirror on locating pins and seating flanges.
025	Secure F15 mirror cell to control structure with clamp mechanism.
026	Inspect secondary mirror structure and telescope tube, report to astronaut in instrument cabin.
029	Open telescope doors.
029	Disconnect astronaut restraint.

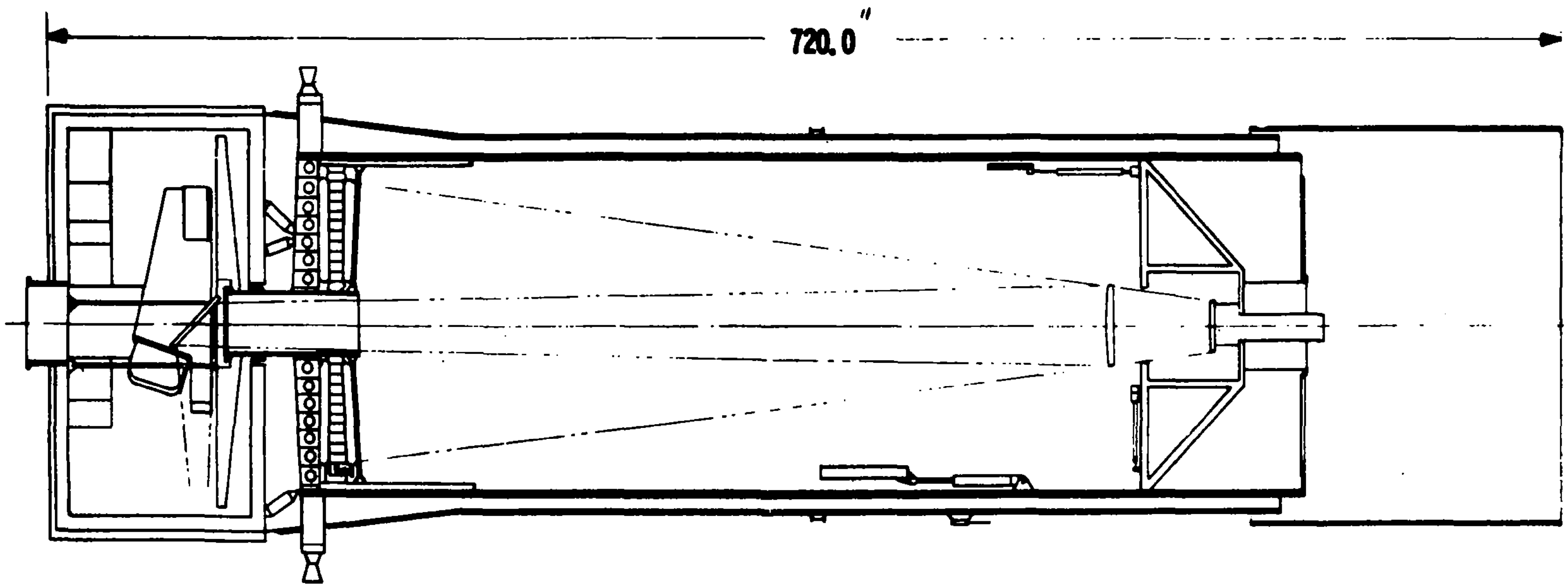


Fig. 4.5.1 MANNED ORBITING TELESCOPE (REF 54)

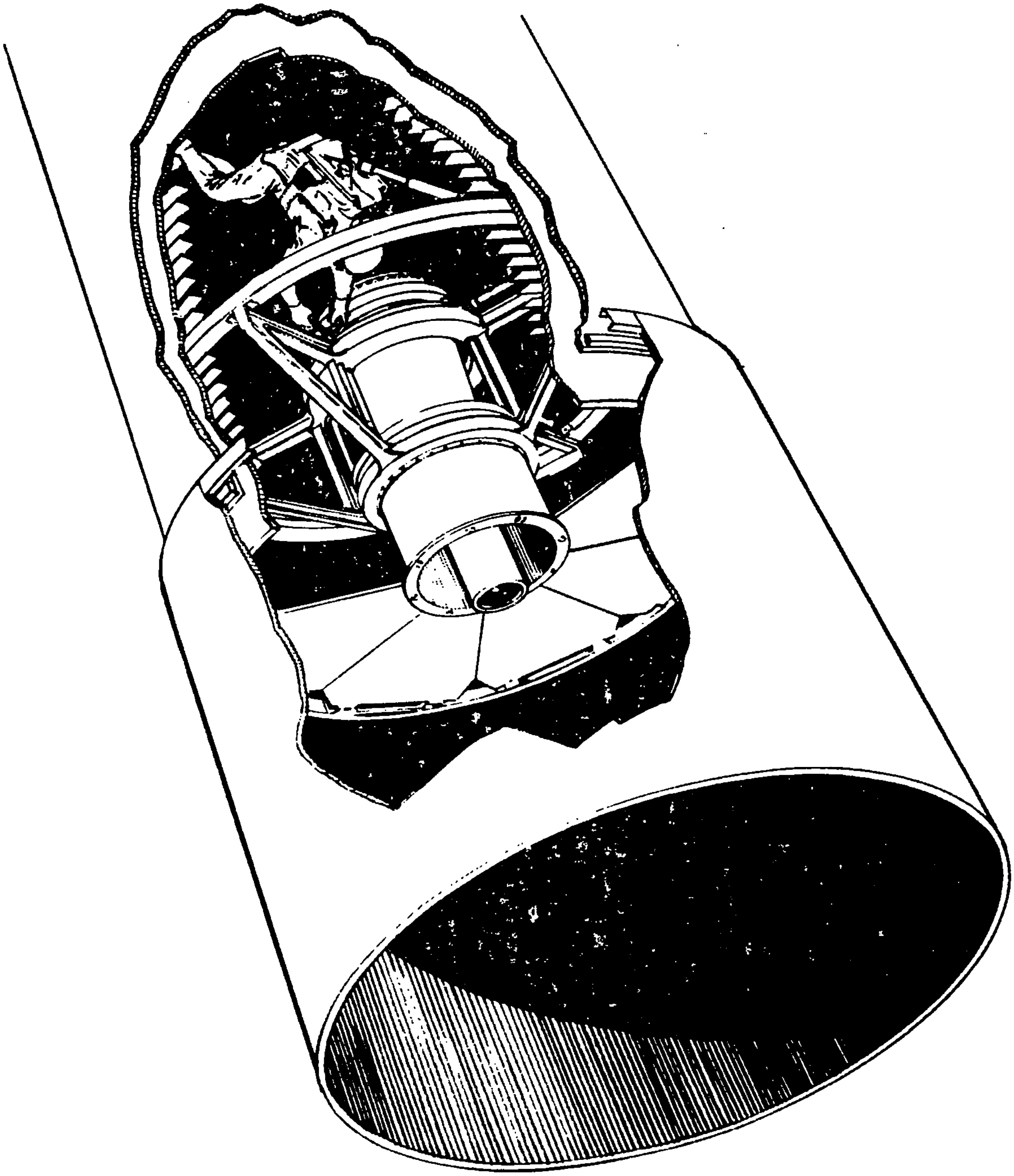


Fig. 4.5.2 FOCAL LENGTH CHANGE (REF 54)

030	Exit from inner shell structure through doors.
033	Turn off secondary mirror servicing lights.
033	Activate telescope door closing mechanism.
033	Inspect earth shade rollers and slides.
034	Secure umbilical line from work pack to suit and connect.
035	Using hand and foot holds in earth shade, return to work pack.
038	Restore work pack connections.
039	Disconnect umbilical line and stow.
040	Proceed to next task.

From the time analysis it is interesting to note that approximately only one-eighth of the astronaut's working time is spent in changing the focal length of the secondary mirror system. Most of the task time is taken up in moving from one location to another and in securing EV work aids. A time breakdown is shown in Figure 4.5.3.

The task of changing from an F30 to an F15 focal length is one example illustrating the limited usefulness of a completely enclosed nonanthropomorphic work boat. Not only is the working volume inside the telescope restricted, (see Figure 4.5.2) but successful completion of the task requires a high degree of astronaut mobility and manual dexterity.

4.6 Orbital Assembly

One of the earliest orbital missions conceived before actual spaceflight, orbital assembly, is still contemplated for large space stations and interplanetary launch vehicles. This mission represents the most ambitious of EV tasks since objects of large mass (100's to 1000's of tons) must be joined with great strength and accuracy. For this purpose there is no doubt that special methods of moving and aligning the subsections with precise control will have to be developed and proved. The same holds true for the fastening or bonding techniques.

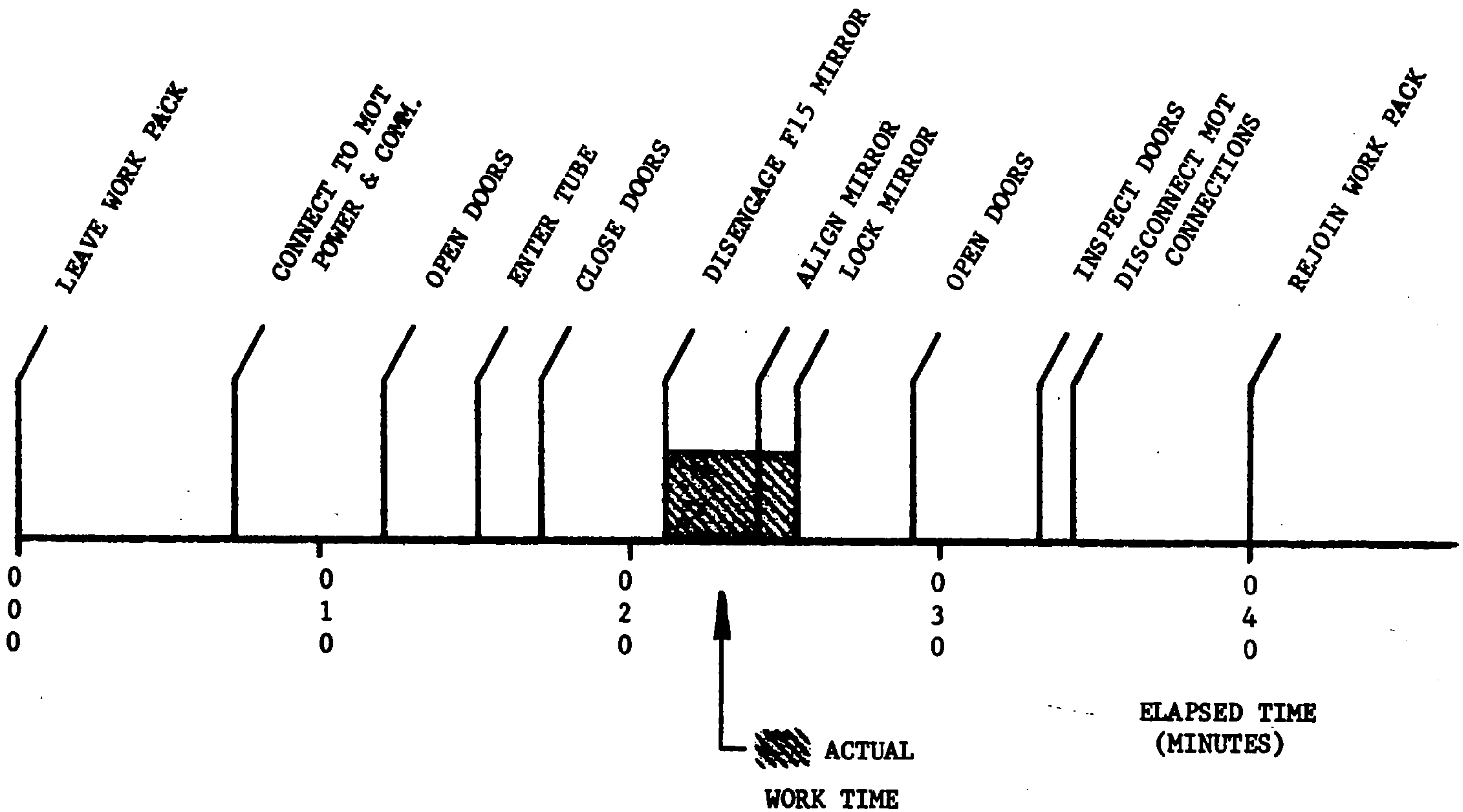


Fig. 4.5.3 TIME BREAKDOWN F30 TO F15 MIRROR CHANGE

An indication of the station assembly process is given by the following sequence of steps:

(1) Injection (position and velocity scatter).

(2) Assembly sequence (assembly window).

(a) Arresting dispersion

(b) Identification and retrieval

(c) Positioning

(d) Fastening

(3) Subsystem installation (except life support).

(4) Subsystem interconnection and checkout.

(5) Life support system installation.

(6) Fuel and stores transfer.

(7) Life support system checkout.

(8) Station operation and control check.

(9) Station placed in ready mode (rendezvous subsystem active).

The principal phases involving EVA are steps 2 through 6 and part of 7. These are briefly discussed in the sequence shown above.

(2.a) Arresting dispersion. Due to the scatter in position accuracy and velocity accuracy, an EV astronaut with a large propulsion capability may be required to bring the station components to within small distances and near zero differential velocity to the main vehicle. An alternate would be to equip each station component with a remotely controlled rendezvous capability.

(2.b) Identification and retrieval. Even though grouped and with small individual differential velocities, the station components must be rapidly assembled at least in rough fashion and fettered to avoid scattering due to the orbital mechanics effects discussed in Section 3.1.

(2.c) Positioning. This is a delicate EV maneuver requiring microthrust control of the EV system to assure correct and safe mating of the station components. This is especially true if these components are equipped with automatically mating electrical and gas or liquid connectors.

(2.d) Fastening. The EV astronaut must activate the automatic fastening devices by using special tools to carry out this task. It is a delicate one since most station components must be fastened with non-leaking joints to satisfy the atmosphere loss limits.

(3) Subsystem Installation. Certain subsystem components may be packaged in locations different from their operational ones. They must be emplaced under conditions similar to the space environment since the assembled station is not pressurized.

(4) Subsystem Interconnection and Check-out. These tasks are also performed under vacuum conditions. However, some subsystems may be of early use such as station illumination, and power source.

(5) Life Support Subsystem Installation. This is probably the most delicate subsystem and may require that other subsystems be available to aid in its installation.

(6) Fuel and Stores Transfer. Items of this type not on board during injection must be transferred. This will require maneuvering the station by means of an EVA system and making the liquid transfer connections.

(7) Life Support System Checkout. Until the life support system is checked out to the extent that an adequate atmosphere is maintained, this task will resemble an EVA.

4.7 Satellite Inspection

Such a mission was desirable since the first Sputnik, however, this type of mission may be only of repetitive interest from a military point of view. It is extremely costly in propulsion requirement and may require an individual launch. In the most extreme case, satellite inspection may involve retrieval of the satellite.

Conceivably, a space hangar may be constructed and pressurized with inert gas so as to make satellite disassembly in space a relatively easy task. The important part of the satellite could then be packaged for return to an earth laboratory.

4.8 Orbital Launch Vehicle Assembly (Ref. 73, 74)

Interplanetary launch vehicle assembly may be more complex than satellite assembly. A recently proposed earth-orbit assembly of a nuclear-propelled Mars exploration spacecraft would require four months of assembly time. The study of an orbital launch facility (OLF) carried out by the Boeing Co. presents the concept of first assembling an orbital launch facility. This facility is similar in its functions to the large gantries in which spacecraft have been assembled and checked out. A five man crew in the OLF then supervises the docking of the various tankers and the interplanetary spacecraft.

In theory, no EVA is planned since all mechanical connections, whether of spacecraft section or of electrical and fuel lines, occur automatically. However, in practice an EVA activity is expected to checkout and correct any malfunctions in these automatic mechanisms. The techniques for the operations involved would be developed in the operations development missions.

4.9 Extravehicular Operations Requirements

The examination that has been made of the mission requirements for EV work shows very clearly what attributes the EV astronaut must have. These are listed below and further defined.

(a) Life support extension

(b) Communications

(c) Mobility - dexterity

(d) Power source

(e) Fixed work base

(f) Tool bin

(g) Work aids

(h) Manipulators

(i) Umbilical capability

(j) Rescue provisions

Life Support Extension

The requirement is for an extension of the life support supplies available in the backpack (Ref. 71). This extension should maintain the backpack when it is interconnected so that a total atmosphere and thermal control time equal to 50% more than the suit discomfort time limit is available to the astronaut.

Communications

Voice communications and physiological telemetry channels available from the standard backpack must be supplemented so that TV can be transmitted when the astronaut is working out of sight. He may also desire to instrument temporarily certain aspects of his work on additional telemetry channels. Low frequency or acoustic transducer equipment may be required when astronauts must communicate from opposite sides of a large booster while assembling an interplanetary launch facility.

Mobility - Dexterity

The mission analyses so far conducted show that mobility and dexterity are unavoidable requirements. The narrow passage through the secondary mirror spider structure in the MOT will permit only an astronaut with a minimum of equipment to pass through (Ref. 54). Similar situations exist in assembling a radio telescope or a launch facility. Dexterity is always required in precision assembly, a task which cannot be easily mechanized.

Power Source

Space tool kits such as that developed by the Martin Company required power to operate the tools (Ref. 49, 70). Power may also be required to fasten the surface adhesives, and to illuminate the work. There may be demands for large amounts of power over short periods, say, for resistance welding. This could be furnished by a turbo generator.

Fixed Work Base

In many instances the astronaut will be working on the exterior of a vehicle. He must be provided with a body restraining device on which he can react the work forces he requires. It would be most convenient if his device also provides him with the other EV requirements in this list.

Tool Bin

The astronaut may require a variety of tools for his tasks. He must be provided with easily accessible means for storing these as well as with containers, or mechanical or magnetic restraints to retain tools and parts in current use.

Work Aids

Every means possible must be developed to supplement the abilities of the astronaut and to overcome difficulties imposed by the spacesuit or other characteristics of space operations. Aids at present under consideration include strength or mobility amplification by means of a powered exoskeleton (Ref. 34), and the use of remote control manipulators.

Manipulators (Ref. 31, 4, 7, 9, 18, 21)

Manipulators have been developed primarily to meet the needs of the AEC. However, their potential applications underseas and in space may bring about a much needed increase in their performance.

Generally, manipulators can be classified as either rate controlled or position controlled. In rate control, the velocity of the controlled element is a function of the setting of the controlling element; in position control, the controlled element follows the position of the controlling element. Although rate control manipulators have a degree of fidelity better than that of the human hand, they are very slow in achieving a desired position or orientation. On the other hand, position controlled manipulators can achieve a desired position almost as quickly as the human hand can move. However, their fidelity is not as good as that of the human hand. For the types of tasks that manipulators will be called on to perform in space operations, it appears that the position control is the most desirable, even though the required working volume of the controlling element is larger. This is particularly true in fastening and clasping operations.

The main utility of manipulators for space applications lies in fastening and clasping operations. For instance, it is well within the capability of present remote control manipulator systems to fasten a space work platform to the vehicle to be worked on. Another useful application of existing manipulators would be to position work or tools so that the astronaut can work on or with them.

However, manipulator systems cannot be expected to perform intricate tasks as the human hand. This is due in large part to the lack of fidelity, force reflection, and limited number of degrees of freedom. While the human hand has approximately 35 degrees of freedom, most manipulators are limited to seven. Other problems which limit at the present the use of manipulators in space are size and reliability.

Umbilical Capability

The astronaut may often be required to work in areas of restricted access similar to that illustrated in the telescope analysis. He must, therefore, be able to disengage himself from his main EV device and proceed with only the unavoidable encumbrance of his life support system or umbilical line. He may also require a power and communication umbilical line and certainly a tether when not enclosed in a structure.

Rescue Provision

A very desirable requirement of the extravehicular device is the ability to return an unconscious or incapacitated astronaut to the main vehicle. An orientation and remote control propulsion capability is required.

5.0 SPECTRUM OF EVA SYSTEMS

An extravehicular system is in fact a small spacecraft operating only in orbit, on the lunar surface, or on the surface of some other body at a limited distance from a main vehicle and for a short period of time. The time may conceivably be as long as a few days, but is usually measured by the number of hours in a working period.

There exists a definite family of types of EVA systems classifiable according to size, complexity, and endurance of the system. Figure 5.1 shows the principal types. These can be identified with the following prototypes:

5.1 The Spacesuit with Backpack Life Support System

The astronaut may carry some basic tools or special devices to accomplish some specific task. In orbit, the operational time will be determined by darkness, (45 minutes below the Van Allen belt) otherwise it will be determined by suit discomfort (2 to 4 hours).

5.2 The Non-Anthropomorphic Spacesuit

This is a concept which has not yet been demonstrated, but which holds much promise both in orbit and on the lunar surface. Different basic designs may be adopted, but the principal attribute is the avoidance of most of the disadvantages of the man-fitting spacesuit.

The present spacesuit suffers from the following difficulties:

(a) Limited comfort time

(b) No provisions for feeding

(c) Limited waste disposal

(d) Cannot be repaired by wearer

A non-anthropomorphic suit overcomes these difficulties by providing the astronaut with room enough to free himself from the appendages he uses in working.

He can thus take care of his needs and rest if he wishes. This room also provides him with rescue room capability - a very important advantage. The feasibility of such an EV system should be urgently pursued and demonstrated.

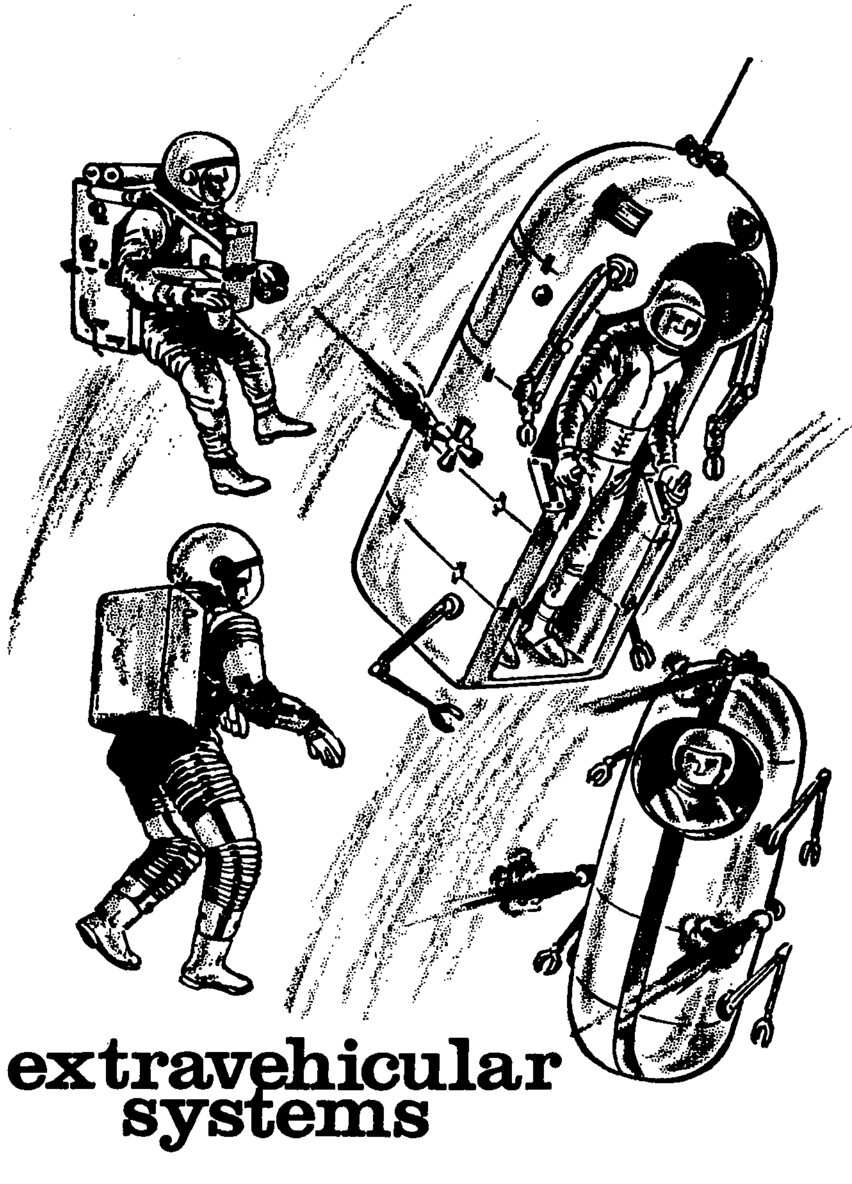


Fig. 5.1

5.3 <u>Spacesuit with Backpack Maneuvering Unit and Life Support System</u>

The astronaut may carry a variety of tools or special devices for space operations or rescue.

The operational time is determined by life support and propulsion requirements (3 - 4 hours).

5.4 <u>Spacesuit with a Work Platform Incorporating Extensive Maneuvering and Life Support Capability</u>

The platform would be equipped with a complete set of tools, working aids, and spares suitable to the particular task requirements. Rescue equipment would also be carried.

Several sizes of platforms can be designed. Some should offer protection from meteoroids and radiation. The platform may have inertial reference on board. It should have the capability of being maneuvered remotely and retrieved by the main vehicle if the platform occupant is incapacitated or if the platform is unoccupied.

The operational time is determined by the time permissible in a pressurized spacesuit.

An example of a work platform is shown in Figure 5.1. The astronaut operates in a spacesuit exposed to the space environment. Some micrometeor and radiation protection is afforded by the platform, but its main functions are to provide:

(1) Increased propulsion capability
(2) Increased tool storage
(3) Increased mechanical aids
(4) Increased guidance and stabilization
(5) Ability to anchor at work place
(6) Work illumination
(7) Heavy duty power supply
(8) TV camera and telemetry channels
(9) Umbilical power and communications for remote operations
(10) Ability to be recalled from main vehicle

Other functions can be devised for special operations.

The astronaut can exit from the front with his life support backpack and operate at umbilical distance. The astronaut is restricted in the platform by a belt which permits him to work with very little leg exertion.

5.5 Work Boat With Pressurized Compartment Enclosing Spacesuited Astronaut

The work boat has propulsion, maneuvering, and life support capability in excess of the work platform. The concept may be realized in a variety of designs; the more complex ones would house two astronauts with airlocks permitting in and out operations.

The work boat is versatile and can be fitted with tools, work aids, and replacement units suitable to the capabilities of its manipulators. It should have the capability, in the more elaborate versions, of commanding by telemetry specially designed programs or devices in other vehicles or tools. Special provisions for rescue missions would be incorporated. There will also exist the capability of transmitting sensor outputs, including television, relating to the task performed to the main vehicle or to earth.

Operational time will extend from one to several days depending on the design.

6.0 POSSIBLE USEFUL EVA AIDS

One of the most interesting concepts to emerge in connection with EVA is that of furnishing the astronaut equipment which will greatly increase his effectiveness.

There are essentially two classes of such aids: one which enhances his strength or dexterity by giving him power assistance or a greater number of arms, and one which enhances his memory and judgment capability by giving instant access to authoritative engineering and scientific personnel.

The aids considered in the present study are listed below:

6.1 Manipulators
6.2 Exoskeleton
6.3 Prostheses
6.4 Special tools
6.5 Illumination
6.6 Local television

6.1 Manipulators

If the astronaut is to remain within a hard walled capsule totally encapsulated for the duration of the EVA,manipulators are mandatory. Manipulators may also be of use as extra arms on a work platform or backpack. Current developments in manipulators are reviewed below.

6.1.1 Hot Cell Manipulators

Past experience with manipulator systems in hot cell environments indicate that a practical manipulating device must satisfy three minimal requirements. They are the ability of the manipulator hand to: (1) assume any given position within its operating volume, (2) assume a continuous range of attitudes at any point, and (3) be able to line up and grip objects of various shapes. For a manipulator arm to meet all three of these requirements, a minimum of 7 degrees of freedom is necessary. By comparison, the human arm-hand combination has approximately 35 degrees of freedom. Hence, the human arm and hand has not been duplicated. To date, one of the most intricate mechanical hand-arm combinations ever built is General Electric's "Handyman". It has 10 degrees of freedom - 6 degrees of freedom that allow positioning the hand at any point in any attitude, and an articulated tong with 4 degrees of freedom.

6.1.2 Classification

Power: With respect to the power used at the working end of the manipulator, manipulators are classified as manual, electrical, hydraulic, and pneumatic. No decision can be reached at present as to which is best for space usage. Hydraulic manipulators are undergoing a major development phase for undersea operations. Their ready made sealing advantages, lack of lubrication requirement, and excellent control, make them a good candidate.

Configuration: To date many of the manipulator designs have been of the shoulder-elbow-wrist configuration. They are usually based on a given coordinate system - rectilinear, cylindrical, or spherical, or combinations of all three. The design of the gripping mechanism appears to be dependent on its specific use.

A recent innovation in the design of manipulators which may prove useful in space operations is the interchangeability of limbs. Thus, if a malfunction should occur in the manipulator arm, it can be removed for repair in a more hospitable maintenance environment.

So far, existing manipulators have been designed to duplicate the physical characteristics of the human hand. Since this anthropomorphic approach is limited by the number of degrees of freedom of the manipulator, it has been suggested that future system components be designed to simplify manipulator handling rather than manned handling. This philosophy may also be reflected in corresponding designs for controls. Thus, glove-like controls which effect corresponding motion in the master arm may be eliminated in favor of nonanthropomorphic controls.

Control: Control means are usually of two types, position control and rate control. In position control, the controlled element follows the position of the controlling element; in rate control, the velocity of the controlled element is a function of the setting of the controlling element.

To free the operator's hands and arms for the performance of other tasks, it has been suggested in Reference (1) that other body members, such as the feet, might be used to control or dictate corresponding slave hand and arm motion. This concept, among others, is being investigated in the field of prosthetics.

Feedback: Because of a lack of force feedback and proprioceptive information any discussion of remote handling equipment must cover the problem of visual access. Direct viewing is the simplest, but there are many problems such as glare and reflection in monitoring a task through a window port. However, there are extremely difficult problems associated with indirect visual access via closed-circuit television such as focusing, light, and movement relationships. Three-dimensional viewing appears to be necessary for remote handling in space. Stereotelevision has been used with great success in hot cells, and in the absence of direct visual access may provide satisfactory visual feedback for space applications.

6.1.3 Current Manipulators

There are two distinctly different types of manipulators presently in use in hot cells.

The manually powered, position controlled manipulator with force reflection is based primarily on a spherical coordinate system. It is usually operated on a master-slave principle. That is, it has a slave arm for performing the work in a hostile environment and a similarly shaped master arm controlled by the human operator. The two arms are mechanically connected so that the slave arm follows the motions of the master arm, and the load forces are reflected to the master arm. Although the mechanical master-slave manipulator is a useful tool for handling radioactive materials, there are a number of disadvantages which limit its usefulness. One obvious limitation is that it is useless for applications where it cannot reach or where the load forces are beyond its capability. However, for orbital space applications the load force problem largely disappears. What is needed is an electric brake to damp extraneous motions. Other necessary innovations are improved handles, better tools, and boost force capabilities.

The electric motor-slave manipulator is a velocity-controlled, unilateral, electric manipulator. It is based on combinations of rectangular, cylindrical, and spherical coordinate systems. Usually it consists of a mechanical arm with seven or more independent motions, a pair of tongs for gripping objects, a support system, and a control box or console. Each motion of the working mechanical arm is controlled with an electric motor. These motors are controlled by switches or proportional controls in the control box and moved by a human operator. To date, the main deficiency in rate controlled manipulators has been in guiding operations where other than straight line paths are to be followed. According to Donald Melton, President of Programmed and Remote Systems Corporation, St. Paul, Minnesota, this difficulty can be overcome by an auxiliary control system. The auxiliary control system consists of a supplemental position control system, whereby the motions of the manipulator follow the motions of the operator and arm. With this addition, any angular orientation can be established and maintained between the controller and the manipulator (Ref. 7). One of the main advantages of this system is that the auxiliary controller can be used interchangeably with the standard rate controller. In other words, the auxiliary control system allows position control in addition to rate control.

Two advantages of an electric motor-slave over mechanical manipulators are:

(1) An electric motor-slave can be mounted on a movable support or another vehicle so that the slave arm can manipulate throughout a much larger working volume and approach the work from various directions.

(2) The slave arm can work in a vacuum or a controlled atmosphere with only telemetry or an electric cable needing to be sealed.

6.1.4 <u>Problems (Refs. 10, 21, 31)</u>

One of the major problems of manipulator systems is associated with feedback, especially visual feedback. The problems of visual feedback in space include; empty field myopia, unstructured visual field, intensive glare, unidirectional illumination producing extreme contrasts and fluctuations between brightness and darkness. One solution might incorporate the use of artificial lighting and, if necessary, television systems. However, existing television systems suffer from lack of a defining gray scale and the inability to look into cracks, crevices, and into or around objects. For this reason a number of remote viewing improvements are suggested.

Possible Improvements in TV Viewing:

Probably the most notable improvement in operator viewing would be the incorporation of a three dimensional TV system. In many instances a three dimensional effect to the operator can be provided by dual TV cameras. The advantage of the three dimensional effect lies in its contribution to the operator's depth perception, both by presenting two separate images to the eyes (retinal disparity) and through the proprioceptive sense of eye convergence. However, it is not sufficient to have the visual information from the two viewing angles presented on two separate monitors which require viewing of first one and then the other to obtain the desired information. Rather, this information must be displayed in such a manner that each of the operator's eyes may see the visual presentation of only one of the two cameras or optical paths. There are several different methods of achieving this using various combinations of equipment. Either two cameras or a single camera may be used to simultaneously or sequentially present visual information gathered from two viewing angles. Through use of polarization techniques, the composite picture, obtained from either a one or two camera system, may be separated into the two views obtained for each of the viewing angles, with each eye perceiving only one of these views.

Another factor which could provide additional visual clues to the operator is that of color. Maximum benefits from the use of color could be attained by adding color to portions of the assembly to make them stand out in the operator's view. With or without special color provision, the use of color viewing systems would provide the operator with additional information about the object.

Two means which could be incorporated to change the angle of view are the use of booms and manipulator wrist mounted TV. Trends toward camera miniaturization make both concepts possible in a manner which would provide a minimum of interference with other equipment. These cameras would supplement, rather than replace the cameras, providing an overall view of the operation.

Finally, a basic method to increase the detail of the monitor presentation is to increase the number of lines of scan per frame. Although the increase in detail is not in direct proportion to the number of lines per frame, there is a noticeable increase in the detail presented by high resolution equipment, particularly of fine vertical lines.

Direct Viewing: A Comparison With 2D and 3D TV Viewing

When direct viewing is possible, sunshades and filters may be required. A recent study comparing direct viewing with two dimensional and three dimensional TV viewing has shown that:

(1) Subject performance under the direct viewing condition is significantly faster than that obtained under either of the video conditions.

(2) No significant differences exist between performance under the 3D and 2D video conditions when the 3D video display exhibits relatively poor resolution.

It must be noted, however, that visual conditions on earth differ from space because of the high diffusive property of the earth's atmosphere. For this reason, it will be even more difficult in space to distinguish depth by gradations of a defining gray scale. Therefore, it is expected that in space a high resolution 3D display system using color transmission will prove superior to a comparable 2D display system.

Remaining Problems:

The problems of extreme temperature fluctuations, high-energy radiation, and micrometeorite collisions can be overcome if the necessary components and materials are properly chosen. However, existing manipulators fall far short of the human hand working directly with tools, because of the lack of sensory feedback and manipulator mobility constraints.

Companies presently working on improvements in manipulator systems include General Electric, American Machine and Foundry, Westinghouse, and Programmed and Remote Systems Corporation. In addition, Argonne National Laboratory is designing and developing a space manipulator system under contract to Huntsville. A manipulator development program which will also have significant bearing on space application will be conducted at facilities being constructed at Jackass Flats, Nevada. These facilities are being designed to satisfy the initial planning and unique requirements set by nuclear rocket engine testing.

6.1.5 Recommendations and Conclusions

On the basis of the reports examined in this survey, a prevailing school of thought favors designing the manipulator system to fit the required task. Since most of the existing manipulator systems have been specifically designed for hot cell operations, it seems evident that considerable research and development is necessary in the field of space manipulators. A pessimistic conclusion may well be that at the present time the uses of existing manipulators in space are restricted to:

(a) Fastening a work platform to the vehicle on which work is to be done;

(b) Positioning work so that the astronaut can work on it.

With modifications on existing space components, limited assembly operations may be possible. These modifications would take into account present manipulator capabilities.

Two system approaches for research and development of space manipulators may be necessary. One would concentrate on near-future mission requirements, taking into account the limitations of present manipulator capabilities. With this approach space components could be designed to simplify manipulator handling rather than manned handling. The design modifications should also be the same for the variety of space systems on which use of manipulators is contemplated. The other approach would be to consider more demanding tasks whose performance would require significant improvements in the state-of-the-art of manipulator systems. This latter approach would develop methods and procedures for space assembly operations and other future EV tasks which present existing manipulator systems cannot perform.

6.2 *Exoskeleton (Ref. 34)*

The exoskeleton concept utilizes a jointed framework external to the human body which follows the movements of the human body. In operation, powerful motors at the joints would produce, by as much as an order of magnitude, far more power than human muscles. Thus while wearing such an exoskeleton, a man could lift 1500 lb. loads or he could exert very large pushing or bending forces.

An extension of this concept is to telemeter the position and joint movement of one master exoskeleton to another unoccupied one. The second one can be made, say, ten or more times larger than the first and contain the master in its head. A man could, in this fashion, stride through a forest clearing a path by hand-pulling large trees from the ground as if they were daisies and smoothing a road as though playing in a sand castle.

The concept thus stated is very attractive. It is being worked on at Cornell University under Navy Contract No. Nonv-3830(00). The General Electric Company occasionally issues publicity indicating they are also developing a similar concept. Neither one at this time seems to have progressed beyond an unpowered mock-up stage. There are many difficulties associated with developing a useful device of this type. Some of these difficulties are listed below:

(1) Development of small powerful motors.

(2) Duplicating motions of human joints.

(3) Protecting human body from exoskeleton.

(4) Providing correct sensory feedback.

(5) Providing a large dynamic range.

These problems represent extensive development efforts in obtaining reliable solutions. There is also the possibility that the final version may be so complex that special tools such as fork lifts or bulldozers remain more convenient solutions.

In orbital space, the necessity for using ones legs is not clear cut so that the exoskeleton represents a special case of a manipulator which has been discussed in 6.1. On the lunar surface, man is more troubled by an instability problem than a lack of power to walk. Hence, even as a walking aid, the exoskeleton concept may not be of great use. However, its versatility may be of use on the moon; its future development should be followed for this reason.

6.3 Prosthetics

It has been suggested that with advances in the art of prosthetics, particularly in the control connections to prosthetic appliances, the EVA astronaut could be given equipment which would greatly increase his efficiency.

A major distinction must be made here as to whether one wishes the astronaut to operate this extra equipment simultaneously or sequentially with equipment he is operating with his hands. If it is desired to operate a pair of manipulators at the same time as gloved hands; then the control connection problem, familiar in prosthetics, exists in full with the added question of whether an astronaut can be trained to direct the different motions of a pair of manipulators at the same time as he is performing tasks with his hands. It is questionable whether this is either necessary or possible.

If, on the other hand, it is sequential operation which is desired then manipulators such as suggested in the design shown in Figure 8.0.1 can be used to assist the gloved hands or another pair of manipulators. The man machine connection problem in prosthetics definitely plays a role in EVA. Thus the ability to operate the propulsion system or to position lights or TV while making use of one's hands on another task is most desirable. Voice control of propulsion is discussed in Ref. 35. This system frees the astronaut's hands of the propulsion control task.

Many other methods of non-manual control are available. For instance, in orbit, the feet are of little use and could be employed for command purposes. Facial muscles are also well adapted to this purpose. Future advances in the field of prosthetics control may eventually permit direct electrical connection to nerves for control purposes.

A survey program in this area would be extremely rewarding. However, there is also the problem of educating the astronaut to be capable of this type of multiple performance, and the limiting factor may well be found in the learning capability and reliability of the astronaut.

6.4 Special Tools (Ref. 70)

A tool kit developed by the Martin Company of Baltimore, Md. (Ref. 70) shows that it is possible to design low torque tools which can be operated in space. The complications imposed in space stem from the fact that the tasks must be done (1) in a pressurized spacesuit, (2) under gravity conditions which distort the mechanical relationships a worker is accustomed to using on earth, (3) under visual conditions of extreme contrast and glare, and (4) under logistic restrictions which preclude replacement of items accidentally dropped or damaged during the work.

The common tools which have been modified will now be tested in space experiments, and further developments can then take place. An important consideration in special tool development is the development of tools for manipulator usage.

6.5 Illumination Aids (Ref. 69)

The best illumination aid for a worker who requires it for work situated within his reach consists of two light sources on either side of his helmet and at eye level.

In studies and simulations made by the Douglas Aircraft Co. in connection with the MOL Program (Ref. 69) the following recommendations have been made:

(a) The eye must be protected against irradiation by raw sunlight, directly or indirectly (from mirrors, chrome, etc.)

(b) Highly polished surfaces are to be avoided - first, because of their potential for glare reflection, and second for their tendency to seem invisible because they reflect space thus masking their contours.

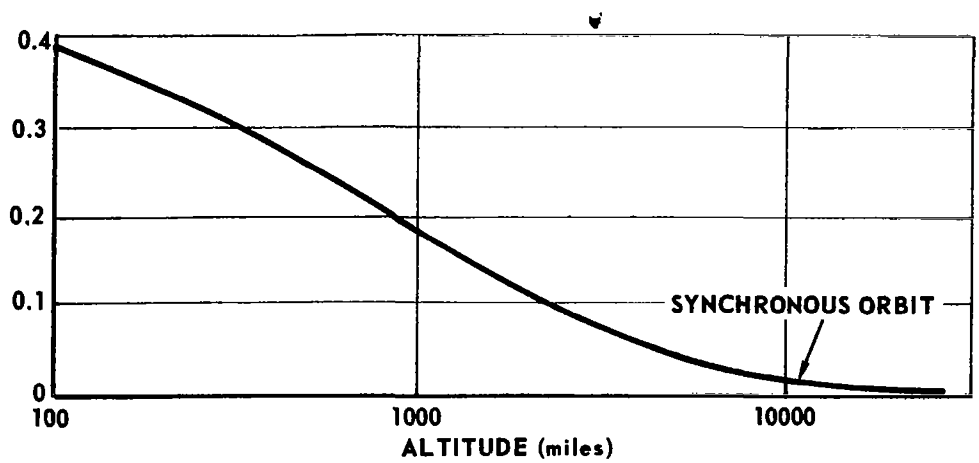
(c) Gloss paints have strong glare hazards, but are superior to polished surfaces. This is due to the scattering caused by particles in the paints.

(d) Matte finishes provide good visibility, but attenuate the light reflected.

(e) Extremes of reflectance on an object should be avoided to aid in recognition.

(f) Generalized light scattering and fill lighting should be provided to enhance outline and contour definition. More than one light source is required to produce a "natural" perception.

(g) Contours can be defined by occultation. For instance, by holding the object to be viewed between the observer and an illuminated field such as the earth or the spacecraft. The percentage of the celestial sphere occupied by the earth is shown in the figure below:



FRACTION OF THE CELESTIAL SPHERE
SUBTENDED BY THE EARTH VERSUS ALTITUDE

Application of these recommendations can be accomplished by using, in alphabetical order, artificial lights, reflectors, selfluminous surfaces, and translucent shades. It should be noted that reflectors must be maintained in a inertial orientation which may be difficult in low orbits, and large reflectors may have an air drag in low orbits. Translucent shades have some of these difficulties, but they do simulate the terrestrial phenomenon of a bright sky.

6.6 Local Television Capability

At least during the early years of EVA it is essential that the astronaut be visually monitored at all times. One cannot take the chance of an accident occurring without being able to judge immediately what has happened and thus initiate the correct rescue procedures. Since the astronaut is in motion, it is imperative to monitor the astronaut's motion. Other telemetry channels may, for instance, indicate a broken faceplate; this information is of little use unless the visual history of the accident is available for use in preventing recurrence of such an accident. The unforeseen must be seen.

If this philosophy is followed, the astronaut must be able to position monitoring cameras whenever he is out of view of the parent vehicle. This is true whether he is inside another craft or out in space.

Another consideration is the monitoring of the extravehicular tasks. It is easy to conceive of a task, especially one involving repair, where the expertise of another person, a scientist or the equipment designer, could aid materially in the success of the task. For this to be completely exploited, visual information or monitoring of the tasks is required. Both the television camera and adequate lighting must be available to the astronaut.

Cameras like the one being developed by the Westinghouse Company (Ref.75) for the lunar surface missions (LEM) may be adequate for this task.

7.0 EXTRAVEHICULAR SUBSYSTEMS

An EVA system resembles nothing more than a small manned spacecraft with a limited duty cycle. For orbital space it is somewhat simplified in that it need not have the subsystems a spacecraft usually requires for reentry. However, extreme reliability over very long periods is required for EVA systems since they are intended to last through as many refueling and duty cycles as possible.

The subsystems examined are listed below more or less in order of their importance to the EVA system.

7.1 Propulsion
7.2 Life support
7.3 Power
7.4 Communication
7.5 Guidance and stabilization
7.6 Remote operations
7.7 Rescue

7.1 Propulsion (Ref. 52, 53, 57)

Previously in Section 4 we have discussed the types of operations an astronaut will be called upon to perform in orbital space. The degree to which these operations will be performed will, of course, depend upon the type of propulsion system used. Probably more than any other single subsystem it determines the final weight and volume characteristics of the EVA vehicle.

Barring some unforeseen development in propellant technology, the material presented here represents current thinking regarding the future direction of propulsion systems.

For the above reasons, a thorough evaluation of space propulsion concepts has been made. This effort has been facilitated by many excellent contributions to propulsion technology, notably by Kephart and Walker in Reference 57. Much of the material that is included here has been drawn from their comparison of propulsion systems for astronaut maneuvering units.

The following discussion will attempt to define the propulsion requirements and to specify the system that is most suitable for EVA application.

Interface Requirements:

Generally, the interface between the propulsion system and an EVA vehicle can be characterized by four parameters; weight, volume, power loads, and propellant servicing requirements. Weight and volume are interdependent and will be discussed accordingly. The power load on the work pack's power supply is considered negligible in terms of total power available. Propellant servicing requirements will seriously affect the overall weight assigned the propulsion unit. The ability of the propulsion unit to use the same propellants as the spacecraft will, of course, imply a savings of weight and volume. But whether or not the propulsion unit uses the same propellants as the spacecraft is not as important as such other considerations as the gross weight of the servicing system and the complexity of servicing procedures.

There are two major areas of concern with respect to the interface between the propulsion unit and the astronaut; (1) exhaust plume damage to the spacesuit and (2) the possible exposure of the spacecraft life support system to toxic and/or corrosive fumes. Exhaust plume heating of the spacesuit material could easily endanger the astronaut's life if uncontrolled, and it is therefore very much an area of concern. The possibility of contaminating the spacecraft air supply with toxic and/or corrosive fumes or vapors must also be given attention. Hazardous contamination is a potential problem in the case of virtually all liquid propellants, having as its two major sources, direct leakage of propellants into the spacecraft or from in-use contamination of the spacesuit and subsequent boil-off into the spacecraft atmosphere when the astronaut re-enters the vehicle. Of course these dangers are largely precluded if the astronaut operates from within a completely enclosed EVA vehicle.

Propellant Requirements

Specific impulse performance is one requirement which plays a major role in determining the weight of the propulsion unit. As a support item for an orbiting spacecraft, an EVA vehicle will perform many extravehicular excursions which will require a re-fueling capability. The weight of propellants carried aboard a spacecraft specifically for use by the propulsion unit is directly a function of the performance efficiency (specific impulse performance) of the propulsion system. Since specific impulse is very much a function of operating mode, it is imperative that a selected propellant have a fully defined performance capability over the entire expected operating range. Because the specific impulse varies considerably as a function of "on-time" (generally decreasing as "on-time" is decreased) it is necessary to predict the mission specific impulse of the propulsion system for each mission.

Pulse repeatability (impulse per impulse bit) is another important parameter in terms of operating efficiency. Performance repeatability at various pulse widths at which the propulsion system operates must be known to assess mission specific impulse. The propellant capacity of the propulsion system should be sized, based on the maximum mission impulse requirement. The effect of the actual duty cycle performed by the system on the weight of propellant carried on-board must also be determined. In addition, the handling characteristics of the propellants should not be such that complex equipment and procedures are necessary. In particular, toxicity, shock sensitivity, and material compatibility must be considered in terms of their effect, singularly and combined, on the system. Shock sensitivity is a hazard which should be completely avoided. Storability is a requirement which cannot be eliminated from consideration in the propulsion design system. Propellants which decompose rapidly or are seriously degraded by long term storage are undesirable. The possibility of a propellant freezing during a mission must also be considered. This is generally not an insurmountable problem in storage aboard the spacecraft since relatively simple electrical heaters can be employed to provide heat to the propellant when necessary. The same solution can be applied to the propulsion unit propellant tanks, through the weight and power increments are larger in this case.

The above characteristics can be used to define what might be called the "ideal" propellant. Such a propellant would feature a high specific impulse, low exhaust temperature, performance repeatability, material compatibility, stability in storage, and would be non-toxic, non-caustic, and non-shock sensitive. In addition, the propellant would be stored in a liquid phase at low pressure, would require a very simple feed system, and have a well-developed technology.

Kephart and Walker (Reference 57) have conducted a comparison of propulsion concepts for astronaut maneuvering units. In Table B are listed the types of propulsion systems and the representative propellants that were studied.

TABLE B (Ref. 57)

SYSTEM	COMPONENTS
Stored gas	Nitrogen
Monopropellant	Hydrogen Peroxide, Hydrazine
Liquid bipropellant	N_2O_4 / 50-50
Gaseous bipropellant	O_2H_2
Solids	Cap Pistol, Solid gas generator

In Tables C and D, the propellant's performance and characteristics are given. The criteria for selecting the optimum propellant system were the overall characteristics of the propellants rather than any particular feature such as performance.

TABLE C (Ref. 57)

PROPELLANT	STORAGE PHASE	COMPATIBILITY	STORABILITY STABILITY	STORABILITY LOSSES	CONTAMINATION PROBLEMS (1)
Nitrogen	gas	excellent	excellent	negligible	n/a
N_2O_4/50-50	liquid	good	excellent	none	toxic
N_2H_4	liquid	very good	excellent	none	toxic
H_2O_2	liquid	poor	fair (2)	decomposition	caustic
O_2H_2	gas	good	excellent	negligible	n/a
	liquid	good	excellent	negligible	n/a
Cap Pistol	solid	very good	excellent	none	

(1) The problem of contaminating the Life support system is implied.

(2) The storability of O_2H_2 has been greatly advanced by the MMU Program, with reference to elastomeric bladders.

TABLE D (Ref. 57)

PROPELLANT	ISP (1)	COMBUSTION TEMPERATURE
Nitrogen	70	ambient (2)
N_2O_4/50-50	340	5200
N_2H_4	243	1800
H_2O_2	180	1350
O_2/H_2	425	5500
Cap Pistol	220	4000+

(1) Vacuum, steady state specific impulse.

(2) Initial storage temperature; does not include effect of high rate "glowdown".

By comparing the propellants class by class and taking into consideration respective system constraints, it is possible to provide a framework for more extensive and more detailed analysis of specific propellants. Rather than burden the reader here with a lengthy discussion and comparison of these propulsion systems, attention is again called to Reference (57) which trates this problem in detail. Of greater importance are the final results that were synthesized from their comparison of propulsion concepts.

Thus, of all the propulsion systems considered, monopropellant systems were deemed the best solution to EVA propulsion problems. With respect to monopropellants the choice is between hydrazine or hydrogen peroxide (ref. 57). The chief advantage of hydorgen peroxide systems lies in their state-of-the art development status. On the other hand, hydrazine monopropellant systems offer improvement in virtually every area of concern and provide unchallengeable flexibility and very few drawbacks. The problem was resolved by choosing hydrazine, decomposing spontaneously in a cayalyst bed of shell 405, for the following reasons:

(1) Hydrazine does not present problems in storage, or material compatability, thus eliminating much of the concern associated with the use of hydrogen peroxide;

(2) Performance characteristics of pulsed hydrazine engines are higher than those using hydrogen peroxide;

(3) Exhaust flame temperature of the hydrazine propellant system can be controlled by blending water with the hydrazine propellant. Therefore, the exhaust plume of hydrazine and water is thermally compatible with present spacesuit materials. On the other hand, the exhaust plume of hydrogen peroxide has been found to be thermally incompatible with present spacecuit materials;

(4) Hydrazine systems have flown space missions (Mariner, Ranger) and, with the exception of the catalyst used, may be considered as representative of the state-of-the art; and

(5) The future possibility of eliminating the nitrogen pressurization system in favor of a hydrazine gas generator which would result in lower system operating pressures, lower weight, and a vast savings in volume.

Toxicity of hydrazine does represent a problem to spacecraft personnel. However, since most propellants are toxic or at least biologically hazardous, the problems associated with the use of hydrazine are not peculiar to the system.

Propellant Weight Requirements

Previously, we have discussed how the mission specific impulse decreases as "on-time" or effective pulse width decreases. This effect is shown in Figure 7.1.1 for a nozzle expansion rate (ϵ) of 50:1, a duty cycle of 1%, and three propellants (Ref. 53). From this graph of vacuum specific impulse vs. pulse width, it is possible to determine the propellant weight requirements. An exact determination of overall propellant weight require-

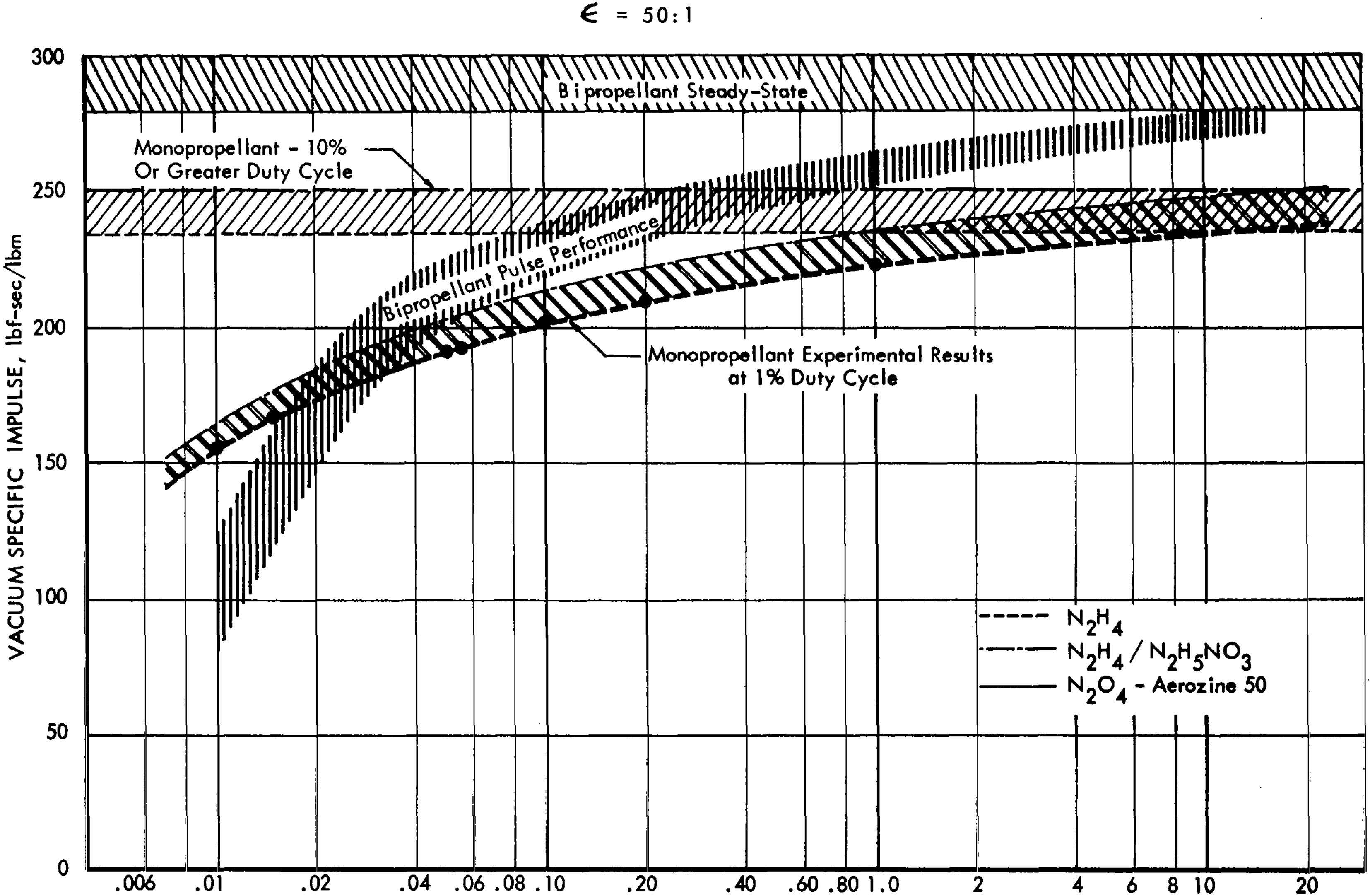


Fig. 7.1.1 VACUUM PULSE PERFORMANCE COMPARISON

ments. An exact determination of overall propellant weight requirements for a given mission would, of course, require a numerical integration over the time varying thrust and pulse width. However, for our purposes, an order of magnitude analysis will suffice.

For small transfer velocities of the order of 2.5-15 ft./1 sec., the pulse width is given to a good approximation by:

(1) $$\Delta t = \frac{MV}{F}$$

where

M - is the total mass of the system

F - is the total thrust level,

V - is the transfer velocity, and

t - is the pulse width.

From Section (8) it has been determined that the total dead weight of the EVA vehicle is of the order of 570 lbs. Thus, for thrust levels of the order of 500 lbs., equation (1) yeilds a pulse width of the order of .1 sec. From Figure 7.1.1 it is seen that for a pulse width of the order of .1 sec., a specific impulse of 200 16f. - sec./1bm. is well within dynamic constraints.

The propellant weight is given by the equation:

(2) $$W_p = W_M \left[\exp\left(\frac{\Delta V}{g I_{SP}} \right) -1 \right]$$

where:

ΔV - is the mission characteristic velocity,

g - is the acceleration of gravity,

I_{SP} - is the specific impulse of the propellant,

W_M - is the dead weight of the man-vehicle combination, and

W_P - is the propellant weight.

Propellant weights and total systems weights as a function of characteristic velocity are summarized in Table E.

TABLE E

ΔV (ft./1 sec.)	W_P (lbs.)	V_p (ft.^{3})[1]	$W_P + W_M$ (lbs.)[2]
1000	97	1.51	667
2000	212	3.36	782
3000	342	5.47	912
5000	676	10.9	1246
10000	2155	34.5	2725

(1) V_P - the volume displaced by the hydrazine propellant

(2) W_M - is assumed to be 570 lbs.

These results show the dependence of the weight of hydrazine propellant on the total characteristic velocity. It should be noted that for low (1000-3000 ft./sec.) characteristic velocities the dead weight is the main contribution to the total weight of the EVA vehicle. For high (5000 & 10,000 ft/sec.) characteristic by each respective propellant weight is included in the table.

7.2 Life Support

The life support subsystem for an EVA system does not present usual problems in providing a breathing atmosphere and thermal cooling to the astronaut. The presence of the EVA Unit will also act as a partial shield against micrometeorites and radiation upon the astronaut.

The most suitable current technique for thermal cooling appears to be through the heat of vaporization of water sublimated into space from a suitable heat exchanger. The function of the heat exchanger is to cool water circulated through heat exchange undergarments on the astronauts. The most suitable current technique for a breathing atmosphere appears to be use of a closed loop recirculatory pure oxygen atmosphere gas system using pressurized oxygen storage and chemical removal of carbon dioxide and other gaseous impurities. These technologies are employed in the "Block 2 PLSS." The "Block 2 PLSS" appears to be compatible with the EV system described in Section 9.

It is expected that continued development programs will produce new back packs able to cope with very high metabolic rates, unusual thermal conditions and to be of high reliability. Suit developments such as the Litton Industries "hard" suit (Ref. 76) will reduce or eliminate the restrictive effects of increased suit pressure and may permit compatibility with a 2-gas cabin atmosphere.

The technologies useable for atmospheric gas supply and temperature control are limited by the requirements for light weight, low power consumption, and high reliability. Fixed weight and power consumption increase drastically when one attempts to incorporate such refinements as regenerable carbon dioxide absorbents in the atmospheric supply system. Provision of a two gas atmosphere will be feasible only if the composition can be held within desirable limits by simple techniques.

At present, atmospheric supply sytems for spacecraft utilize pure oxygen, because simple reliable oxygen partial pressure sensors are unavailable to monitor oxygen concentration in oxygen - nitrogen atmospheres. Present fabric "soft" space suits also do not permit adequate mobility when inflated to pressures of 5-7 1/2 pounds per square inch. These pressures result when one adds inert gas to a 3.5 pound per square inch oxygen atmospheric partial pressure. Greater astronaut comfort would result even if only the gas (oxygen or some mixture) breathed were partically humidified to decrease the extreme dehydration effects of breathing absolutely dry gases as provided by pressurized or cryogenic storage.

The breathing gas in the space helmet, however, is also used for demisting the astronaut's visor. Use of a different inert gas such as helium or neon instead of nitrogen in a two gas atmosphere may facilitate measurement of gaseous composition and thereby permit the design of a simple two gas atmospheric control system applicable to a back pack life support unit.

If operations are on the moon during the lunar day or in space, the astronaut's solar exposure is such as to lead to a net heat influx into his garments, and his thermal comfort control problem is that of heat removal in amount equal to body metabolic heat plus net absorbed radiation. Except for adverse geometrical circumstances as exist in a lunar crater, the radiation geometry of the astronaut is such that external heat input is small compared to body heat metabolism. High levels of metabolic activity are required for walking in pressurized flexible space suits and require heat removal rates of 1200-200 BTU/HR. These should decrease for EVA using the "hard" suit. One to two pounds of water per hour must be sublimated to remove the 1000-2000 BTU/hr metabolic heat.

Radiative means of heat removal are not attractive for this heat removal rate since 7 square feet of radiation area (directed away from the sun or any nearby hot object) would be needed to remove 1000 BTU per hour at a 70° F temperature. If a small radioactive power supply unit could provide 100 watts of cheap power to operate a thermodynamic refrigerator, the required radiation area might be cut to 4 sq. ft. which is still a large area.

The probable improvements in the back pack support are thus likely to be improvements in technology to reduce weight, enhance reliability, and enhance performance of evaporation coolers and closed circuit rebreathing oxygen systems. Since these systems expend their chemical carbon dioxide absorbers and exhaust their stored oxygen and water, essential attributes must be designed for quick servicing and recharging.

7.3 Electric Power

The present concept of EV systems assumes a limited use time of 4 to 8 hours, after which the system must be refueled and occupied by another astronaut. Since the electric power demands are varied depending on the particular phase of EVA and since many of the tools (discussed in section 6.4) carry their own power supplies; the most satisfactory and versatile solution to the power supply problem lies in the use of rechargeable battery packs. Power demands for communication, illumination, life support, propulsion, and tools can then be easily met. Certain battery sections can be isolated from the general supply to ensure availability of emergency power for communication, life support, propulsion, and navigation-stabilization for the most extended mission contemplated.

The characteristics of the nickel-cadmium batteries now well-developed for use in space power supplies are given below.

Operating Temp.	85°F. to 35°F.
Storage Temp.	110°F. to -40°F.
Chargeability	C/2 rate for 2/3 capacity (C=capacity) C/12 for remainder
Useage	Normal: Approx. 1 A.H. per pound steady state until 1 volt per cell is reached
	High: 5 x C for short periods (a few minutes)

Should large amounts of power be required for special operations such as electric welding, a turbine generator driven by the propulsion fuel may provide a sufficient power supply for future systems. Fuel cells capable of very long life also represent a very usable power source.

7.4 Communications

This is a subsystem area where not much development is required and where virtually any requirement can be met in a small volume, low weight package. The following list of requirements is an example of a satisfactory subsystem for the EVA contemplated.

Voice Communication

(1) Astronaut to mother craft - two way for a maximum distance of two miles.

(2) Astronaut to astronaut - two way for distances of 200 to 300 ft.

(3) Astronaut to earth - emergency mode of 10 to 15 minute duration at orbits of up to 300 nautical miles.

Telemetry

Astronaut to mother craft - one way. The telemetry will consist of body functions (7 are currently monitored) and an equal number of external sensor functions (temperature, strain, etc.).

Television

Astronaut to mother craft - one way. A slow scan camera with sufficient resolution to monitor technical work. Only one camera would be used at a time for a group of EV astronauts.

Figure 7.4.1 is a block diagram of the system terminals and signals paths. At this point one has a choice of 3 routes.

(1) Start from scratch and suggest a system to do the job.

(2) Suggest a system that is compatible with existing manned space flight communication networks.

(3) Suggest a system that is a blend of (1) and (2) above.

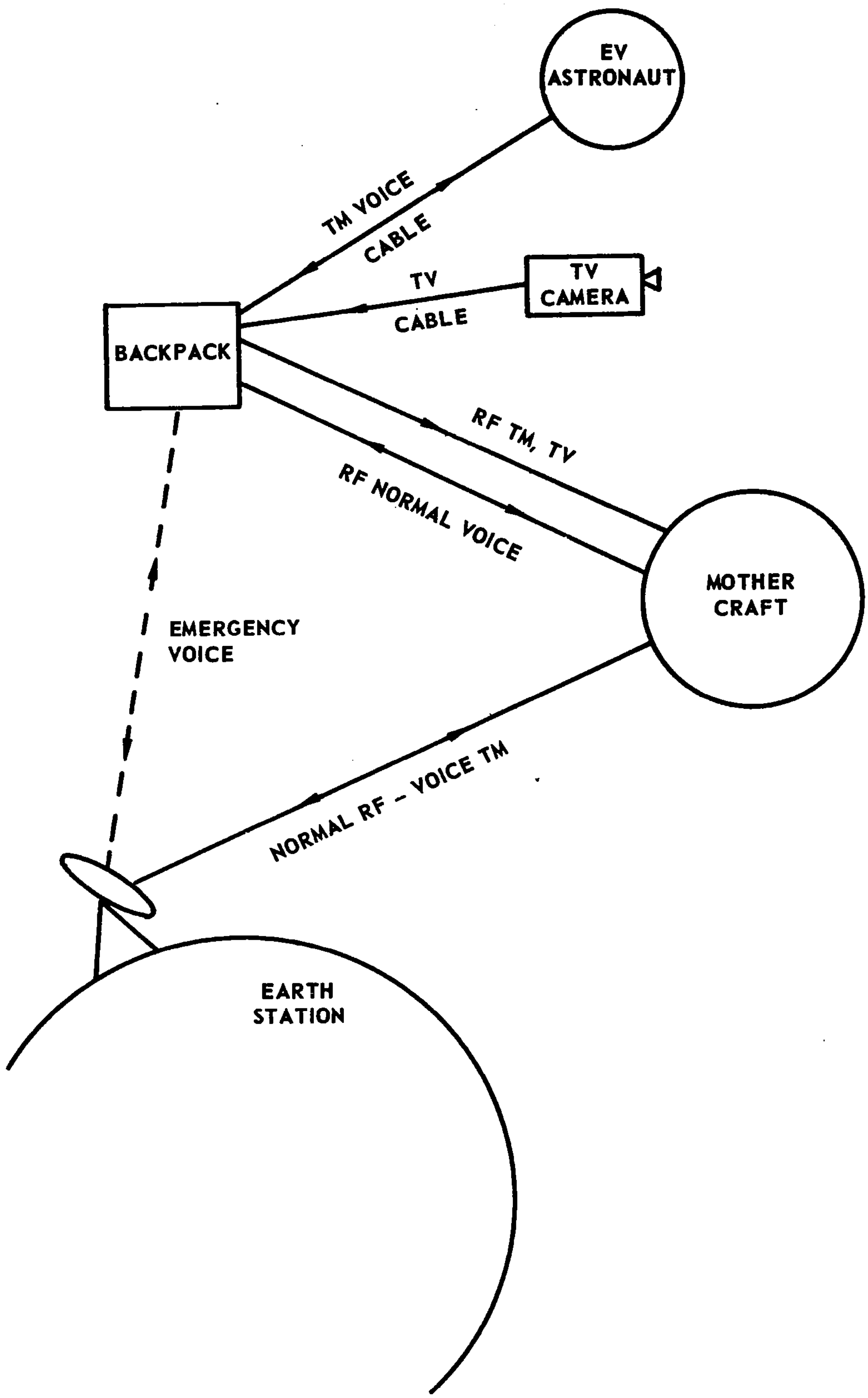

EV
ASTRONAUT
TM VOICE
CABLE
TV
CAMERA
TV
CABLE
BACKPACK
RF TM, TV
RF NORMAL VOICE
MOTHER
CRAFT
EMERGENCY
VOICE
NORMAL RF - VOICE TM
EARTH
STATION

Fig. 7.4.1

Route (2) has the greatest future potential, and one should overlook the confidence factor associated with proposing known techniques.

There are two manned space flight communications systems known to us that are either in existence or on the verge of becoming operational, these are the Gemini VHF-UHF system or the Apollo Unified S-Band System (USB). Again after short consideration we have chosen the USB because:

(1) It is for the United States the manned space flight communication system of the near future.

(2) The astronaut back pack antenna would be simpler at S-Band.

(3) For the worst case (emergency voice to earth) it offers a slight advantage in signal level performance.

(4) The use of an FM communications system compatible with FM modes of the USB appears to be simpler in terms of EVA equipment as compared to equipment compatible with the Gemini System.

Let us now justify items (2), (3), and (4) above.

Antenna

The EVA antenna should be omni-directional and circularly polarized to avoid attitude problems and minimize polarization loss with respect to the receiving antennas which are circularly polarized. At S-Band such an antenna could be 2 orthogonal arrays of 4 helices each spaced at 90 degree intervals about a cylindrical ground plane. The overall antenna would fit in a 12 inch diameter sphere. Performance requirements would be a minimum gain of -3 db with respect to a circularly polarized isotropic source including feed loss.

At UHF an array of whip antennas appears best, although crossed dipoles could give circular polarization if space permits. The factor G_t in the UHF signal calculation assumes a minimum gain of -3 db, and 3 db polarization loss for a total of -6 db.

Signal Calculation

Tabulated in Table 1 are power requirements for the Gemini and Apollo systems. The worst case, consisting of emergency voice to earth, is considered for a maximum range of 1465 n. mi. This is the slant range for a 300 n. mi. orbit.

It can be seen from the table that because of superior sensitivity and receiving antenna gain the USB enjoys an advantage in normalized power (dbm/cycle). However, the greater pre-detection bandwidth of the USB decreases this advantage in terms of transmitted power but offers an important advantage in terms of equipment simplicity. A Gemini type transmitter will require frequency stabilization while an S-Band oscillator capable of $\pm \frac{1}{2}$ mc stability would suffice. This is the performance of the USB spacecraft oscillator and should thus be compatible with the frequency tracking loops in the USB data demodulator.

For either case, however, it should be practical to generate the required power with a miniature solid state source.

TABLE 1

Power Requirements

GEMINI	APOLLO
G_R = + 18 db (circular polarization)	G_R = 44 db (circular polarization)
L = -151.2 db	L = -169.0 db
G_T = -6 db (Polarization loss of 3 db included)	G_T = -3 db (circular polarization)
NF = 4.5 db	NF = 2 db
P_{Rmin} = -169.5 dbm/cycle	P_{Rmin} = -172 dbm/cycle
SNR = + 10 db	SNR = + 10 db
S_{min} = -159.5 dbm/cycle	S_{min} = -162 dbm/cycle
P_T = -20.3 dbm/cycle	P_T = -34.0 dbm/cycle
at 70 KC BW	at 1 mc BW
P_T = (48.45 -20.3) dbm	P_T = (60.0 -34.0) dbm
= + 28.15 dbm	= + 26 dbm
= .652 watts	= .398 watts

where,

G_r = receiving antenna gain

L = free space propagation loss

G_T = transmitting antenna gain

NF = noise figure of receiver

P_{Rmin} = minimum detectable signal (signal-noise) on a per cycle basis

SNR = signal to noise ratio

S_{min} = minimum signal for the specified SNR on a per cycle of noise limiting bandwidth basis

P_T = required transmitter power on a per cycle basis

Normal EVA Communications

There are two basic requirements for the EV astronaut; the television and telemetry channels require individual, parallel, one-way links from each EV astronaut to the mother craft. The voice link may take the form of a two way "party line" common to the mothercraft and all the astronauts, or it may be of the form of discrete two way links between each EV astronaut and the mother craft where the mother craft would act as a central exchange with conference loop facilities. Both modes of operation offer advantages and disadvantages and both are simple to implement in the USB system.

The central exchange concept requires a greater spectrum and the requirement that the EV astronaut's antenna see the mother craft antenna at all times. It would be more useful when several different operations are conducted from the one mother craft at the same time.

The party line concept offers decreased spectrum bandwidth and the possibility that communications could be carried out between astronauts without each being necessarily visible from the mother craft.

Figure 7.4.2 illustrates the central exchange philosophy and Figure 7.4.3 the party line concept. A possible example of the spectrum

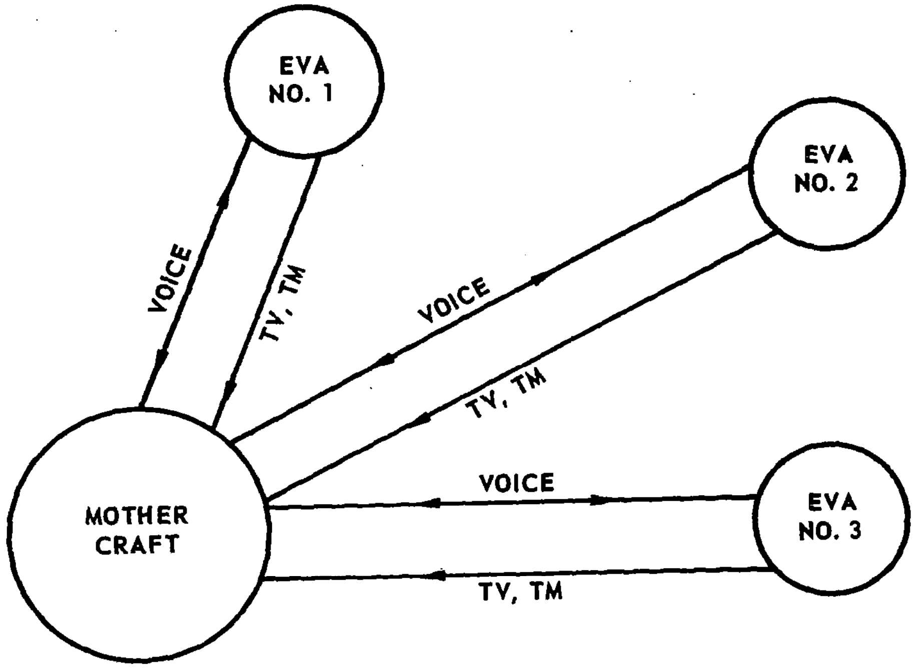


Fig. 7.4.2 LOCAL EXCHANGE

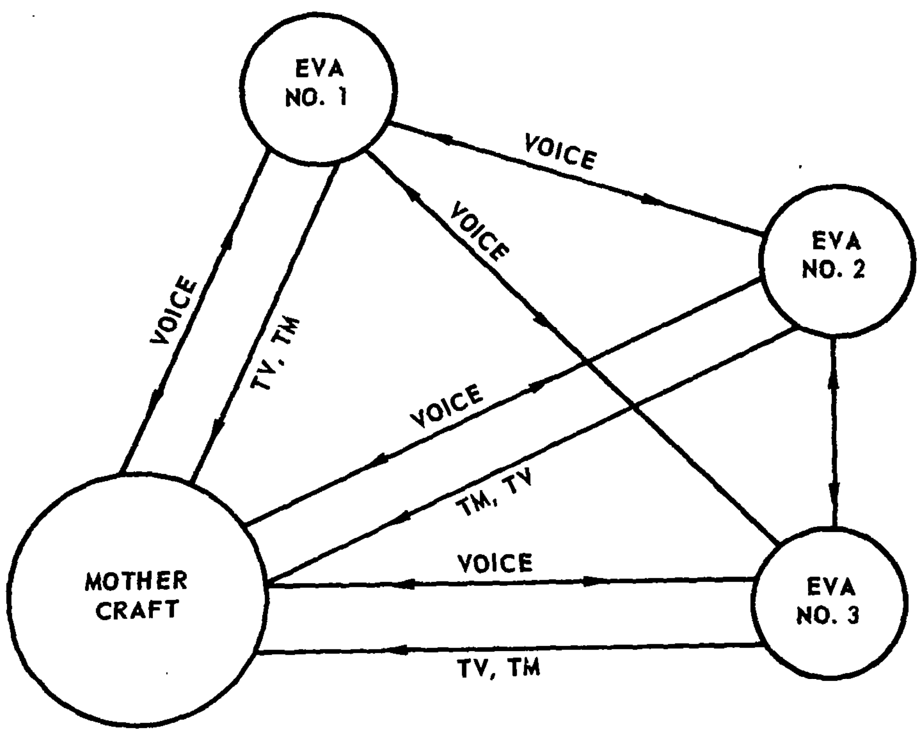


Fig. 7.4.3 PARTY LINE

requirements for three astronauts is shown below using the central exchange (widest bandwidth philosophy):

Frequency = 2292.5 mc (This frequency lies within the USB but is not presently assigned to a spacecraft. It is 5 mc from the closest spacecraft frequency assignment. This is a typical USB frequency separation)

Function	Modulation Technique	Subcarrier Frequency	Subcarrier Deviation	Channel
TV (all EVA)	FM on Carrier	None		500 KC
Voice (EVA#1)	FM/FM	1.25 mc	7.55 KC ± .8 KC	.3 to 3 KC
Telemetry (EVA#1)	PCM/PM/FM	1.024 mc	± 90°	1.6 KBPS
Voice (EVA#2)	FM/FM	1.50 mc	7.5 KC ± .8 KC	.3 to 3 KC
Telemetry (EVA#2)	PCM/PM/FM	1.374 mc	± 90°	1.6 KBPS
Voice (EVA#3)	FM/FM	1.75 mc	7.5 KC ± .8 KC	.3 to 3 KC
Telemetry (EVA#3)	PCM/PM/FM	1.524 mc	± 90°	1.6 KBPS

Note that the biomedical and sensor telemetry data is transmitted in a serial bit stream requiring commutation and decommutation processes. The spectral slots are illustrated in Figure 7.4.4.

The spectral assignments for the party line philosophy is illustrated in Figure 7.4.5. A tabulation of the possible frequency assignments and modulation techniques follows:

Function	Modulation Technique	Subcarrier Frequency	Subcarrier Deviation	Channel
TV (All EVA)	FM on Carrier	None	-	500 KC
Voice (all EVA)	FM/FM	1.25 mc	7.55 ± .8 KC	.3 to 3 KC
Telemetry (EVA#1)	PCM/PM/FM	1.024	± 90°	1.6 KBPS
Telemetry (EVA#2)	PCM/PM/FM	1.5315	± 90°	1.6 KBPS
Telemetry (EVA#3)	PCM/PM/FM	1.5555	± 90°	1.6 KBPS

Conclusions and Recommendations

The EV astronaut communications problem is well within the current "state-of-the-art" requiring only nominal amounts of weight and power. The recommended possible solution appears to be easily compatible

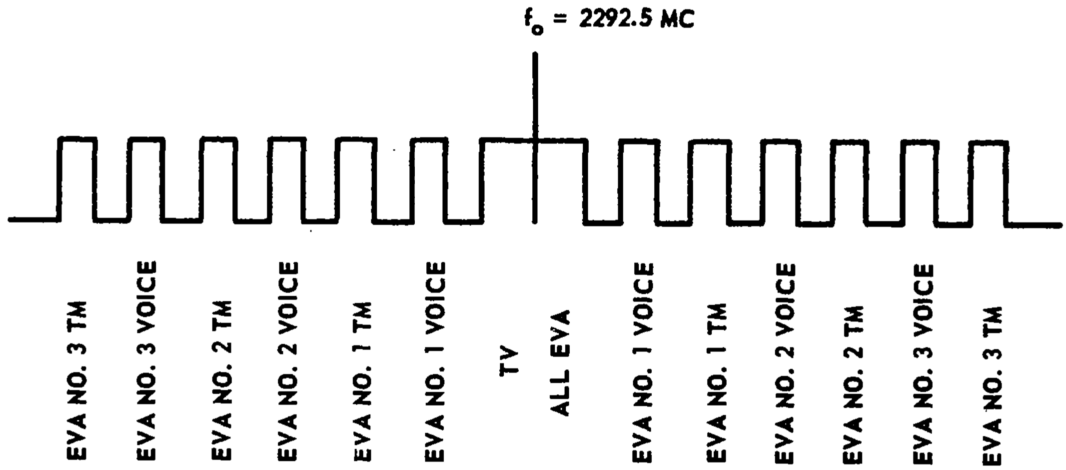


Fig. 7.4.4 CENTRAL EXCHANGE POSSIBLE SPECTRUM

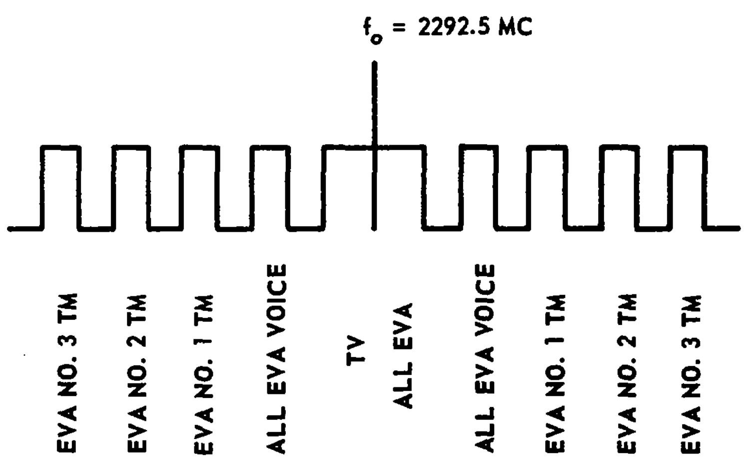


Fig. 7.4.5 PARTY LINE POSSIBLE SPECTRUM

with the current NASA Unified S-Band MSFN equipments. The prime consideration for selecting the S-Band equipment is the relatively small size required for a nearly isotropic antenna for each EV astronaut back pack. Assuming a relatively low overall power efficiency, only 15 to 20 watts of source power would be required to provide the necessary rf power (.398 watts) for all the EV communications including voice links, telemetry (both biomedical and external sensor functions), and TV coverage. The .398 watts of rf power is required for the emergency voice link to earth for a slant range of approximately 1500 nautical miles (a nominal 300 nautical mile circular orbit). Less power could be used for the local communications in space. The weight of the back pack communications equipment is estimated to be in the order of 10 to 15 pounds. The TV camera weight (a current design by Westinghouse) is 7 pounds.

7.5 Attitude Control System: (Ref. 56)

The EVA vehicle should be capable of automatic stabilization and manual translation and attitude maneuvers.

The attitude control system controls attitude for target viewing and for aiming the translational thrusters and can, at times, serve as an inertial reference system. Attitude control can be accomplished by an acceleration command system, angular rate command system, or a rate command system with attitude hold.

Stabilization functions involving very small position tolerances can be accomplished by automatic control circuitry to conserve propellant which would otherwise be wasted through human inefficiency and to free the crew member from unnecessary time consuming labors. This mode of operation, involving very short pulse widths, would be the primary mode for flights which are made to inspect another vehicle.

Tests conducted at Bell Aerosystems (Reference 56) for various EVA type vehicles using an angular acceleration command mode (i.e., commanding thrusters on and off directly through the system logic) showed that adequate attitude control could be maintained as long as the c.g. thruster misalignments were reasonably small and angular accelerations were not large. However, it was found that maneuvering was difficult at times and occasionally led to loss of attitude control with a resulting tumbling of the vehicle when large or fast angular maneuvers were attempted. Recovery in real space will probably be dependent on the severity of the tumble. Because of this, the need for some form of attitude stabilization is indicated especially if missions require the vehicle to maneuver to other than the immediate vicinity of the parent vehicle. This could be obtained by use of inertia exchange devices, such as control moment gyros or from a system of reaction jets. The ultimate design will be a function of weight, time, angular momentum, and mission tasks.

The incorporation of an attitude hold feature into the attitude stabilization loop has been found to be an effective means of overcoming attitude drift, thus precluding the need for precise rate control.

Guidance

Simulation test results have also shown that when flying close to a stabilized target which is adequately illuminated, the astronaut will be able to determine his relative position and rate from aspect and range of change of aspect, and he will be able to control his vehicle accordingly. However, as the range of operation increases, it becomes progressively more difficult for the astronaut to reference to vehicle detail. Consequently, the astronaut is forced to rely on other devices for position and rate attitude information and in other references to determine whether the apparent translation of the target is due to a change in relative position or a change in attitude of his own vehicle. These devices and the guidance techniques that are used will depend upon the distance between vehicles and the time required to complete the maneuver.

The design philosophy for future EVA vehicles should emphasize simplicity with as much independence as possible from external sensors and elaborate on-board sensing devices. Proportional navigation (lead collision) techniques are applicable for most of the missions of EVA class vehicles. The proportional guidance approach depends upon the astronaut to accomplish the following tasks:

(1) Acquire the target object either visually or by means of sensors such as radar.

(2) Control his vehicle in attitude and apply thrust of specified durations which will be dependent upon range to effect a closing speed with the target.

(3) Position the target with respect to an inertial reference (such as the stabilized attitude of his vehicle axes) and command specified thrusts to keep the bearing angle from changing. As a result, the line of slight direction to the target stays inertially constant, and a straight line collision course is maintained.

(4) Monitor the progress as the maneuvering unit approaches the target, and apply corrective thrust along the line of sight, thereby controlling closing velocity as a function of range. Retro thrust epochs may be either determined by stadimetric ranging by timing (as a function of range and velocity from radar or other range measurement sensors, or determined from gross visual observations when other equipment is not available.

Bell's test results indicate that lead collision guidance techniques would enable a vehicle with a stabilized attitude control system to maneuver safely and efficiently for mission distances of several thousand feet. For greater distances, more sophisticated, nonvisual methods are required such as radar sensing, laser or IR tracking, or use of optical pointing and tracking equipment. In Table 7.5.1 alternate guidance systems for EVA are compared (56). So far, the studies conducted at Bell have shown that a large number of the EVA missions can be completed with visual cues and manual control alone.

7.6 Remote Operations

The concept of having an astronaut control a family of remote automatic helpers is very attractive because his efficiency is definitely increased. Thus, in fuel transfer cases, hoses could be transported and connected, welds could be automatically made, sections to be assembled could be moved to correct positions under remote control.

TABLE 7.5.1

COMPARISON OF ALTERNATE GUIDANCE SYSTEMS FOR EVA (Ref. 56)

Manual Guidance Techniques	Description of Techniques	Class or Type of Trajectory	External Supporting Equipment	Onboard Sensors	Displays	Range of Operation
(1) Fly utilizing target stabilized axes	Operator flies from visual cues alone.	Lead collision	Reference vehicle must be stabilized	None	ΔV timer	$R < 100$ ft $\dot{L} < 5$ fps
(2) Reference target object to rate stabilized axes of the maneuvering vehicle	Operator flies from visual cues, using the attitude system to determine relative positions and rate.	Lead collision	None	None	ΔV timer	$R \leq 1000$ ft $\dot{R} \leq 15$ fps
(3) Reference target object to position stabilized axes of the maneuvering vehicle	Operator flies visually relying on the attitude system to determine relative position and rate.	Lead collision	None	x, y, z accelerometers	ΔV timer $\dot{x}, \dot{y}, \dot{z}$	$R < 10,000$ ft $\dot{R} \leq 30$ fps
(4) Reference to the line of sight connecting two vehicles stabilized in orbit	Operator maintains position of the vehicle along the line of sight and flies from one vehicle to the other.	Lead collision	None	x, y, z accelerometers	ΔV timer $\dot{x}, \dot{y}, \dot{z}$	$R > 10,000$ ft
(5) Reference to the line of sight established by the parent craft	Operator receives information from a second person in the parent craft and uses this information to monitor the program of the maneuver. Proper aiming and coasting can compensate for tidal accelerations.	Lead collision or orbital mechanics	Progress monitored by person in parent craft and positional data and rates relayed.	x, y, z accelerometers optional	ΔV timer Range Range rate Cross range Cross range rate	$R < 100,000$ ft
Automatic and Semi-Manual Guidance Techniques						
(1) Reference target object to position stabilized axes of the maneuvering vehicle	Radar or equivalent equipment used to determine relative position and rate information. Automatic or manual attitude control used to point at target object R and cross rate can be controlled by automatic or manual thrust commands.	Lead collision	None or nominal	Range and range rate sensing, automatic thrustor control optional	$R, \dot{R}$ α, β	$R < 10,000$ ft $\dot{R} \leq 50$ fps
(2) Reference to a line of sight established by the parent craft	Similar to (5) above, but may be made automatic in thrustor control. Visual contact with target vehicle necessary for attitude control.	Lead collision or orbital mechanics	Position monitored by second person in parent craft. Data relayed to maneuvering vehicle.	x, y, z accelerometers Automatic thrustor control	ΔV timer	$R > 10,000$ ft
(3) Fly utilizing equipment on board parent craft	Radar on board parent craft can be used to monitor relative position and rates. Computer, implemented with trajectory equations can be used to determine directions in which maneuvering vehicle is to be aimed and thrust to be applied.	Lead collision or orbital mechanics	Radar and computer facilities on board parent craft	No equipment	$R, \dot{R}$ α, β ΔV timer	$R > 50,000$ ft

The major difficulty with this concept is that lacking the versatility of a device having a man on board, the robot operator must be designed to do only a specific task. Thus, an automatic welding device will differ from a positioning device, which in turn will differ from a hose transporting and connecting device. In fact, any robot system which must make mechanical contact and connections with structures in space probably will require a special design keyed to attributes of the particular structure. If no physical connections are required, as in the case of a remote controlled satellite inspector, the design can be made without knowing the detailed satellite.

really ?

Configuration

There are certain characteristics of the concepts presented in Section (9) which make them applicable to remote controlled operations. These are: the requirement for a command return capability in case the astronaut is disabled, the presence of illuminating devices and a TV camera, and the inclusion of manipulators. Thus it is not difficult to extend the manipulator link to the main vehicle from which the EVA system can then be commanded to go about some simple tasks.

An example of the need for such a system is included in the mission of orbital launch facility (OLF) assembly described in Section (4.8). The OLF (Ref. 73, 74) has an isotope power supply whose liquid metal cooled radiator operates at a cherry red heat. The changing of the radiator can be made a simple task which could be carried out by a remote controlled EVA system.

7.7 Rescue

The words "rescue system" represent both a subsystem and a subsystem capability in EVA. At present very little work has been done to determine the requirements of a rescue operation.

Several types of accidents can require a rescue mission as shown in the list below:

(1) Loss of atmosphere due to puncture.

(2) Failure of life support subsystem.

(3) Failure of propulsion-stabilization subsystem.

(4) Active propulsion failure.

(5) Power failure.

(6) Mechanical immobilization or entrapment.

(7) Failure in main vehicle.

(8) Astronaut illness or distress.

Each of these categories of accidents requires different action to effect rescue. Most require the assistance of another EV astronaut. Special rescue devices and tools may be of great value.

Careful attention to these accident possibilities during the design phase can greatly reduce the probability of their occurrence. Redundant systems may be required for such subsystem capabilities as propulsion, power, life support, and communication. The characteristics of the emergency subsystem being determined only by the probable "time to rescue". The "time to rescue" is a very critical factor in the design of any rescue system.

8.0 EXAMPLE OF EVA SYSTEMS

From the general requirements drawn up in Section (4.8), it is possible to arrive at some preliminary design concepts which will embody these requirements.

Although it seems quite clear that some specific space tasks might be better performed with a space tug, it is certainly more apparent that a soft suit with suitable aids would find much wider utility. Comparison of a soft suit with aids to a space tug does not assume that other approaches might not have merit. In the use of an aid module to support a soft suit, one of the main considerations to be made is that the device must present a minimum amount of interference to the work the astronaut has to do. Therefore, the device will resemble an enormous back pack whose size will be determined mainly by the propellant and life support requirement. It will be able to anchor itself by means of the manipulator arms it carries or to position work pieces in front of the astronaut by means of these arms. Ample provision will be made for illuminating the work, including lamps available for the manipulators to direct as required.

Tools will be available suitable to the work required on a mission. A television camera and relay will be available to monitor conditions encountered by the astronaut and enable the crew of the main vehicle to observe his work. Propulsion and guidance systems will permit delicate maneuvers to be executed as might be required in assembling the flimsy structure of a radio telescope. The guidance system will enable the crew of the main vehicle to keep track of his orientation so that his propulsion system can be remotely activated for emergency recall; the same recall condition would disconnect the manipulators anchoring him to his work if these are activated.

The umbilical capability would be provided either by keeping the life support back pack independent of the large working aid, using the aid as a topping off reservoir to provide the life support extension time or, incorporating the life support entirely in the working aid, forcing the astronaut to work at the end of an embilical life support line whenever he works at a distance from the device.

Figure 8.0.1 shows a concept of such an EVA system. The astronaut has an unencumbered work area in front of him. He is restrained in the device by a large belt which can be unlocked to permit him to turn and slide up and down. When he needs to lean against the unit to exert force on his work, the shoe restraints become useful.

The system can be fastened to other structures by means of the lower grips and, if necessary, by one or both of the upper manipulators. The manipulators are near shoulder height so that they can be operated to position work in a natural fashion.

Access to tool storage is from within the semi-enclosure. Controls and displays are also available on either side of the astronaut.

Table 8.1 gives a weight breakdown of the various sybsystems required for an integrated work pack. It is important to remember that

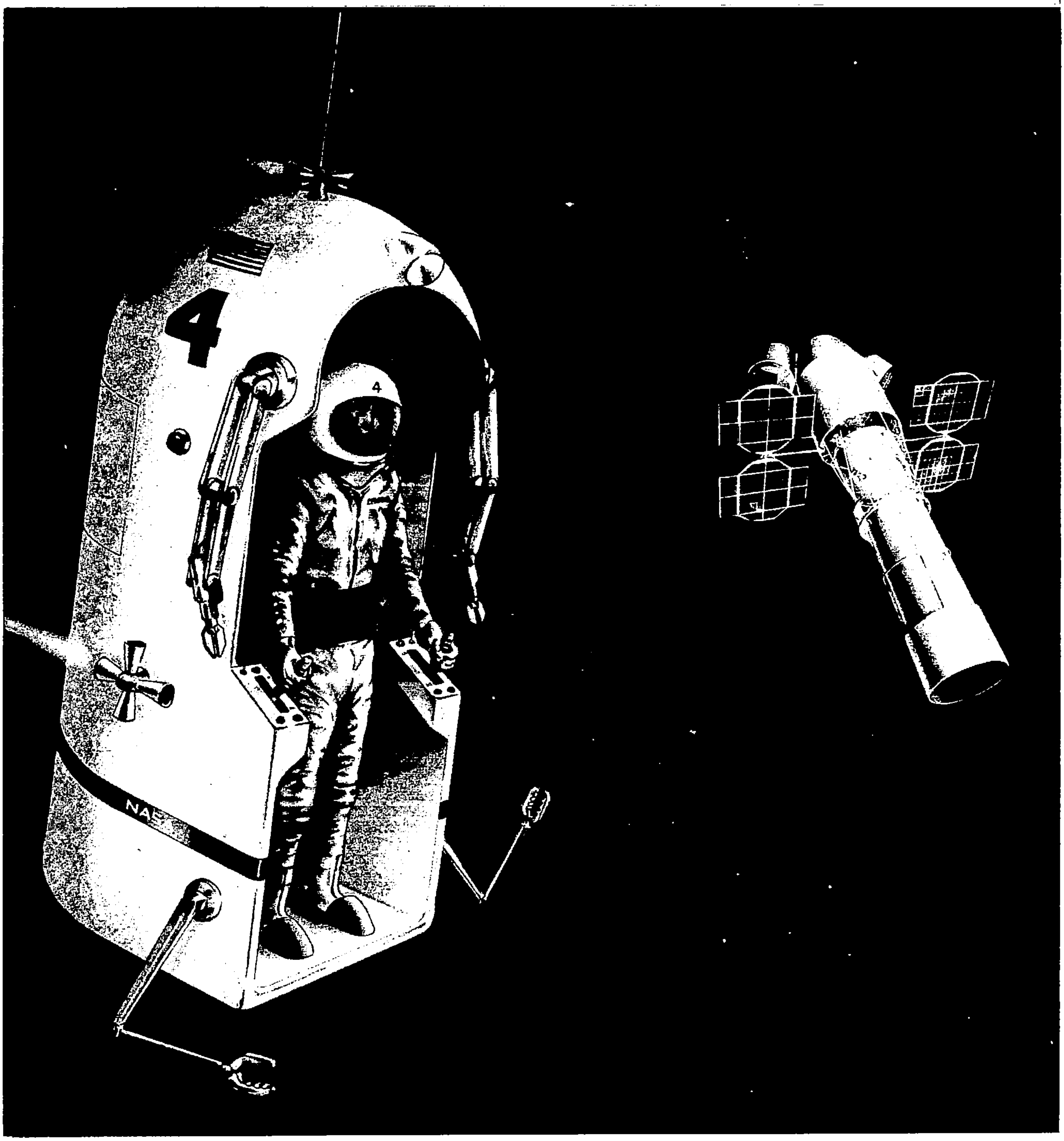


Fig. 8.0.1

these are estimated weights only and do not represent the final design specifications. They are estimates based on the literature and engineering judgment. As can be seen from Table 8.1, the total estimated weight of the work pack is approximately 570 pounds.

TABLE 8.1

	Weights in pounds
Man and Suit	200
P.L.S.S. Backpack	65
Communication	20
L.S. Extension	50
Propulsion Motors	45
Power Supplies (Batteries)	35
Orientation	55
Tools	50
Manipulators	50
	W_m = 570 pounds dead weight

Modular Concept

Since the various missions discussed in Section (4) differ markedly in their extravehicular requirements the concept of an extravehicular system assembled from modules of different characteristics is particularly attractive. As an example, the extravehicular system described above can be modularized in the following manner (seé figure 8.2)

The structure is assembled from modules resembling flattened half doughnuts as shown below:

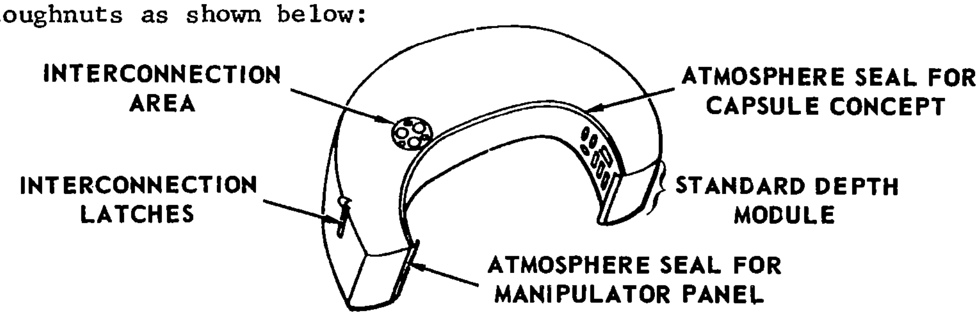


Fig. 8.2 EV SYSTEM MODULE

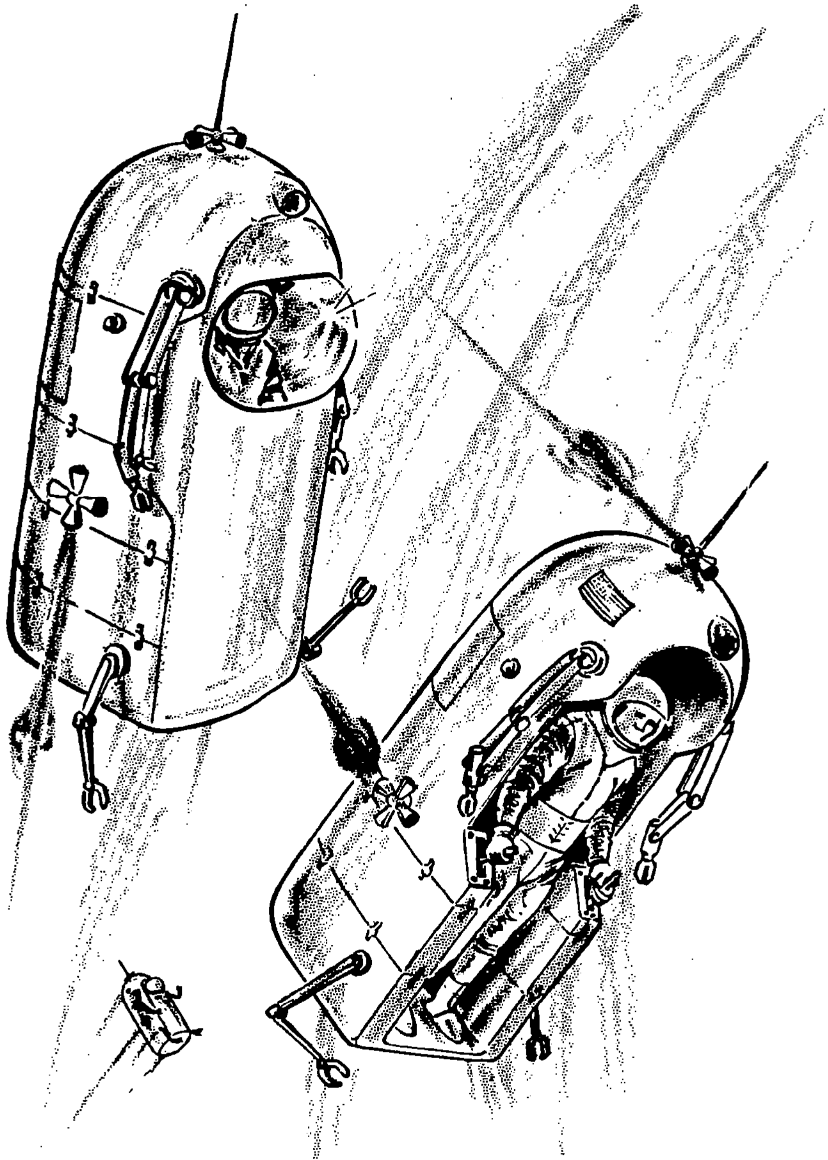


Fig. 8.0.2

These modules may comprise the following special designs:

(1) Propulsion fuel

(2) Life support

(3) Power generator for tools

(4) Communication

(5) Navigation, stabilization, controls (Master Module)

(6) Tool storage, special tool systems

In this manner a mission requiring large fuel expenditures while moving massive structures may be made up of two or more such modules at the expense of a tool power generator module and a tool storage module. A satellite inspection mission may require two or more communication modules to transmit the output of various sensors.

The modular concept can be extended to the interior of the module. Thus a communication module may be made to accommodate either a number of standard telemetry systems or one or two television channels, or recording equipment. Some of the modules may require their own control panels. Others, such as the propulsion modules, can be monitored from switched displays on modules that are always carried such as the navigation, stabilization, and control module.

It is possible to extend the modular concept even further. The base plate of this extravehicular system can be designed with an airlock, and a special seal can be incorporated on each side of the modules as shown in Figure (8.2). Then an entire front assembly incorporating manipulators, illumination equipment, etc., can be incorporated thus changing a semi-enclosed work platform to a total encapsulation extravehicular system.

Considering the cost of placing extravehicular systems in orbit, the large amount of engineering work required to develop such a versatile system may well be worth while.

9.0 RECOMMENDED DEVELOPMENT PROGRAMS

This report has examined the present state of extravehicular system design together with some of the missions such systems will be called on to implement. It is evident, even now before in space experience is accumulated, that many development programs must be implemented so as to take full advantage of all possible in space experiments.

Many of these suggested programs will extend into the period during which the vehicles will be required to operate in space. Thus the criticality of the entire EVA development program is further emphasized, for it may be a pacing item in the space exploration program.

In this section some R & D programs are suggested and briefly outlined. Careful planning may show that some of the subtasks merit a major effort in themselves and that, in other cases, two or more of the programs can be executed as a single one of larger scope and longer duration.

The table below gives the order in which these programs appear.

EV Methodology Study
Astronaut EV Debriefing
Eye Protection and Illumination Study
Visual Feedback and Work Monitoring
Space Suit Development
Nonanthropomorphic EV System Development
Develop Promising EVA System Configurations
Develop Manipulator System for Space Usage #1
Manipulator Development Program #2
State of Art Study in Prosthetics Control
Exoskeleton Evaluation Study
Remote Operations for EVA Study
Study of the Space Rescue Problem
Development of Space Rescue Technique
Space Rescue Hardware Development
Special Tool Development for Rescue Operations
EVA System Maintenance and Repair Study
EVA Modular Concept Study
Transportation of EVA Systems Study
Determination of Martian Environment
Prevention of Atmosphere Contamination
Astronaut Bording and Evacuation Techniques Development

EV Methodology Study

Objectives:

To develop comprehensive methods for reporting and categorizing all aspects of EV operations. This will permit rapid classification and evaluation of new requirements which will develop as orbital and lunar missions are further studied and approach the point of execution.

Utility:

At the present time, EVA requirements are developed with difficulty from engineering studies having other primary objectives. In mission studies, EVA requirements are usually slighted and are discussed in varying ways with varying emphasis.

Approach:

Initiate a study which would develop instructions on methods of reporting on EVA aspects of space missions. The following progression is suggested for the study:

1. Determine and list all the categories of EVA which future missions may require.
2. Decide on a simple but adequate format for EVA time line analysis.
3. Develop a comprehensive method of reporting environment compatibility specifications, e.g. thermal, radiation, acceleration, etc.
4. Develop a uniform method for reporting the interface requirements of the EVA.
5. Determine methods of reporting possible mission emergencies requiring EVA.
6. Construct summary chart to enable the principal aspects of EVA to be shown for any mission.

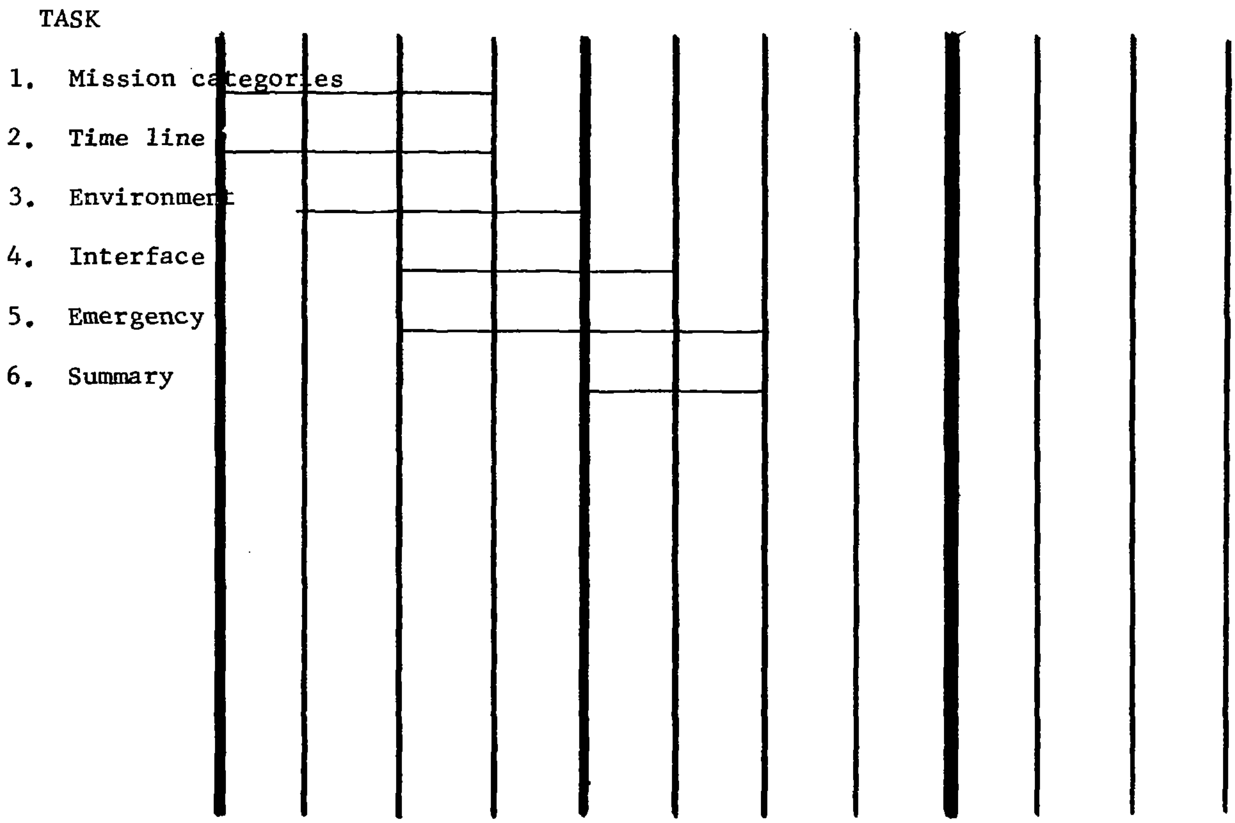
TITLE: EV Methodology Study

TASK BREAKDOWN:

1. Determine mission requirement categories.
2. Determine time line analysis methods and presentation.
3. Environmental compatibility specifications.
4. Interface requirements specifications.
5. Methods of emergency operations evaluation.
6. Development of summary reporting methods.

SCHEDULE

SIX MONTH PROGRAM



Astronaut EV Debriefing

Objective:

To develop debriefing procedures and forms which will insure the most complete debriefing of astronauts who have participated in EVA.

Utility:

The astronauts will participate increasingly in EV tests. It is important that a standard debriefing method be developed to obtain the fullest possible return from each mission and to have the data well correlated with the EVA methodology.

Approach:

The methodology developed in the EV methodology study is to be interpreted in the form of an astronaut questionaire. A method of summary reporting will also be developed.

TITLE: Astronaut EV Debriefing

TASK BREAKDOWN:

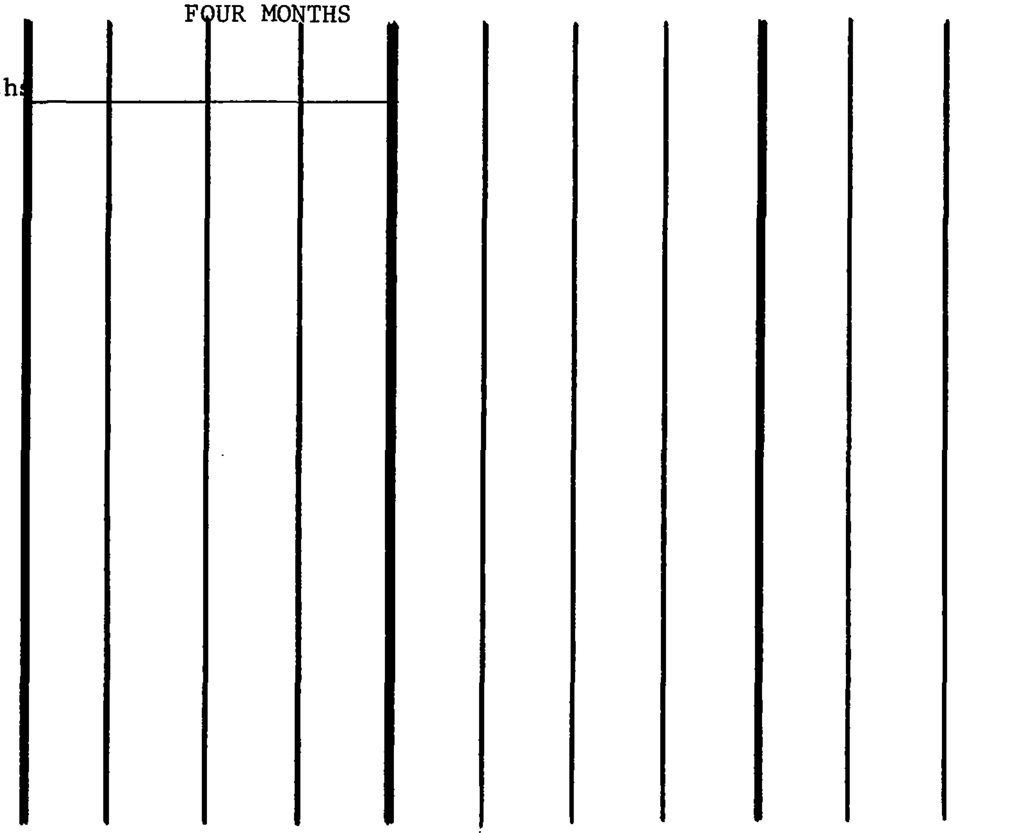
1. Develop debriefing forms similar to methodology study results.

SCHEDULE

TASK

FOUR MONTHS

1. Four months



Eye Protection and Illumination Study

Objective:

To determine the protection requirements which will prevent astronaut eye injury, and to determine the illumination aids required by the astronaut to work in space.

Utility:

The peculiarities of the space environment make the astronaut particularly susceptible to eye damage when the sun is in the field of view. The same is true of work illumination which may often be insufficient for the work to be performed by the EV astronaut.

Approach:

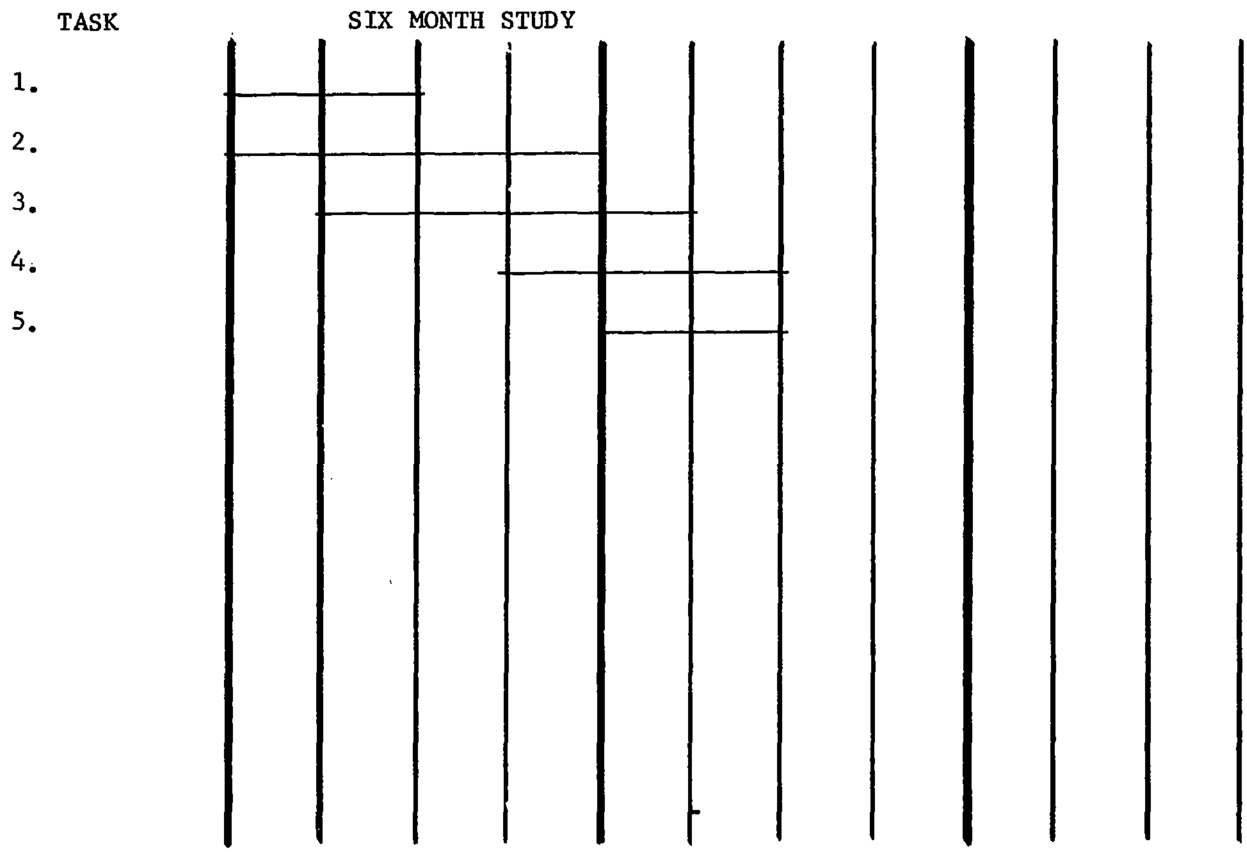
1. Determine by study the time varying illumination conditions in orbit and on the lunar surface.
2. For a variety of missons, determine from the above the work area illumination and eye damage potentials.
3. Evaluate the feasibility of various solutions.
4. Evaluate the reliability of eye protection techniques.
5. Recommend simulation and test programs.

TITLE: Eye Protection and Illumination Study

TASK BREAKDOWN:

1. Determine time varying illumination conditions in orbit and on lunar surface.
2. Determine work area illumination and potential eye damage under conditions in (1).
3. Evaluate feasibility of various solutions.
4. Evaluate reliability of eye protection techniques.
5. Recommend simulation and test program.

SCHEDULE



Visual Feedback and Work Monitoring

Objective:

To produce a television and illumination system which will give monitors the best possible view and information on the EV work being performed by an astronaut.

Utility:

The monitoring of EV work is useful for several reasons: to provide a work history in case something goes wrong, to permit experts monitoring the work to provide guidance, and to permit improved work methods and the development of work aids.

Approach:

The method of approach to this task is illustrated by the subtasks given below:

1. Determine from the literature and simulation the qualities which such a monitoring system should have.
2. Determine from mission analysis and simulation the operating conditions of such a system.
3. Perform engineering design study of the proposed system.
4. Construct a prototype.
5. Tests of prototype in thermal-vacuum chambers and in actual space EVA tests.

TITLE: Visual Feedback and Work Monitroing

TASK BREAKDOWN:

1. Determine requirement of a visual feedback and/or T.V. Monitoring system.
2. Determine conditions of operations.
3. Engineering study.
4. Prototype development.
5. Prototype tests.

SCHEDULE

ONE AND ONE HALF YEAR PROGRAM

TASK

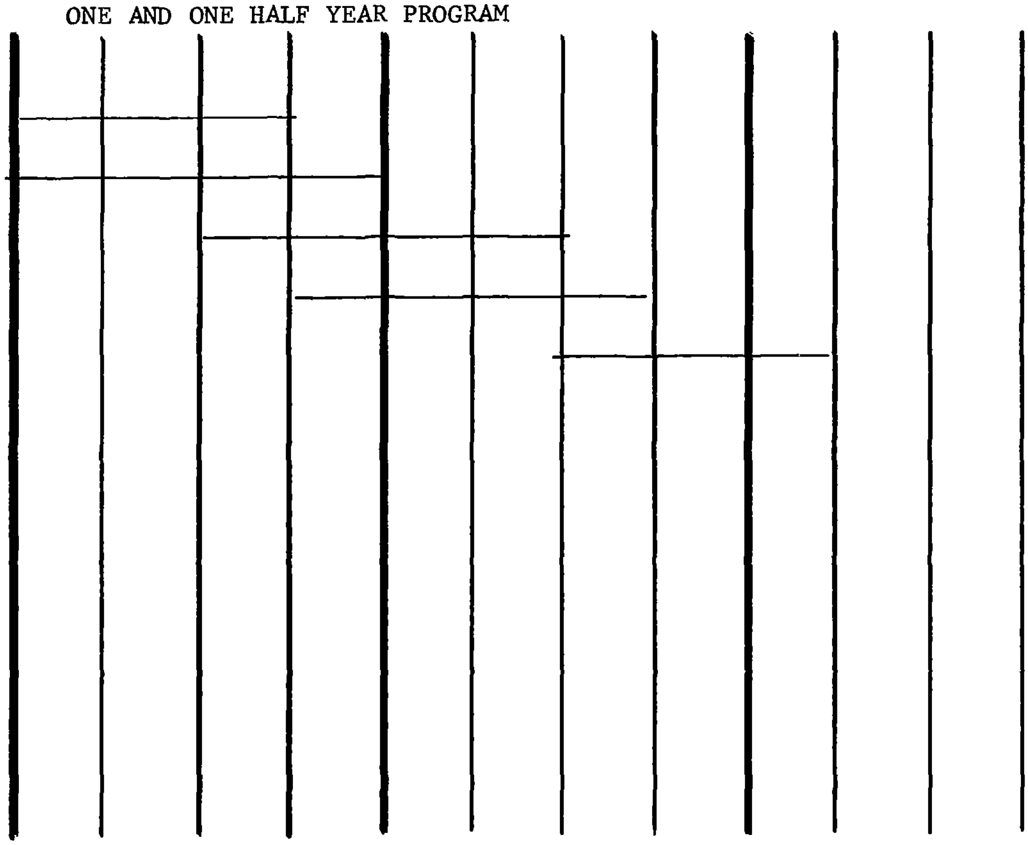
1.

2.

3.

4.

5.



Space Suit Development

Objective:

To continue the improvement of soft space suits so as to overcome problems of discomfort, mobility, and dexterity. New designs should also provide for a far greater survival potential in case of space suit damage.

Utility:

Present soft suits have a definite discomfort time limit and impose mobility and dexterity restrictions on the astronaut. EVA missions could be performed far more efficiently if these limitations could be further minimized. Present suits are virtually nonrepairable so that astronaut survival chances in case of suit damage are very small.

Approach:

The suggested steps in this development program are:

1. Careful and exhaustive study of the materials, requirements and the development of ideal suit materials.
2. An evaluation with tests to determine the best design.
3. Development of any mechanical devices such as seals, flexible points, valves, etc.
4. Construction and testing of the chosen design.
5. In-space testing.

TITLE: Space Suit Development

TASK BREAKDOWN:

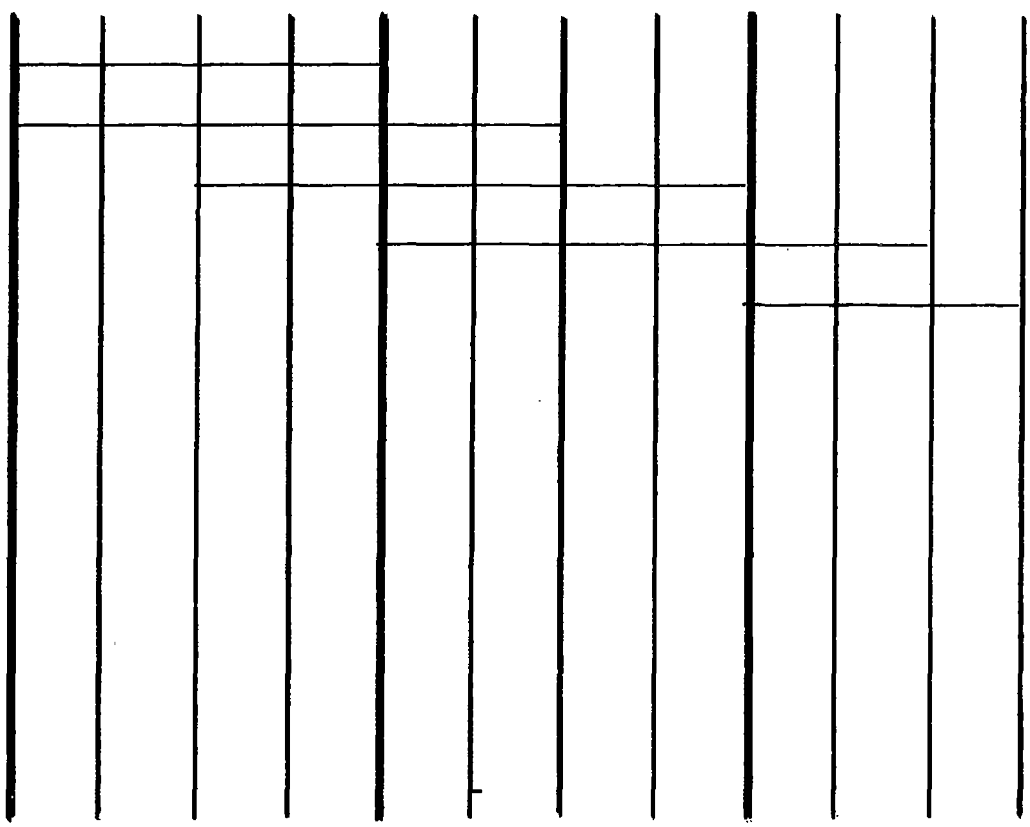
1. Materials development.
2. Design evaluation.
3. Mechanical development.
4. Construction and testing.
5. In space testing.

SCHEDULE

TASK

CONTINUING PROGRAM - THREE YEAR CYCLE

1. 1 year
2. 1½ year
3. 1½ year
4. 1½ year
5. 1 year



Non-Anthropomorphic EV System Development

Objective:

To development an astronaut enclosure providing greater comfort than a soft space suit while providing, in the same enclosure, the mobility and dexterity required in orbital and lunar EVA.

Utility:

Present soft space suits do not permit the astronaut to feed or relieve himself and further impose a wearing discomfort time. Improvement in these factors would aid in all facets of EVA.

Approach:

The method of approach is outlined in the following tasks:

1. A determination of what are the requirements which would permit the astronaut an EVA work time of six to eight hours.
2. An evaluation of the various designs which would achieve the requirements developed in 1.
3. An in-depth engineering study of selected designs to determine adequally in the space environment engineering feasibility.
4. Prototype construction.
5. Testing in vacuum and thermal chambers.
6. Testing in space.

TITLE: Non-Anthropomorphic EV System Development

TASK BREAKDOWN:

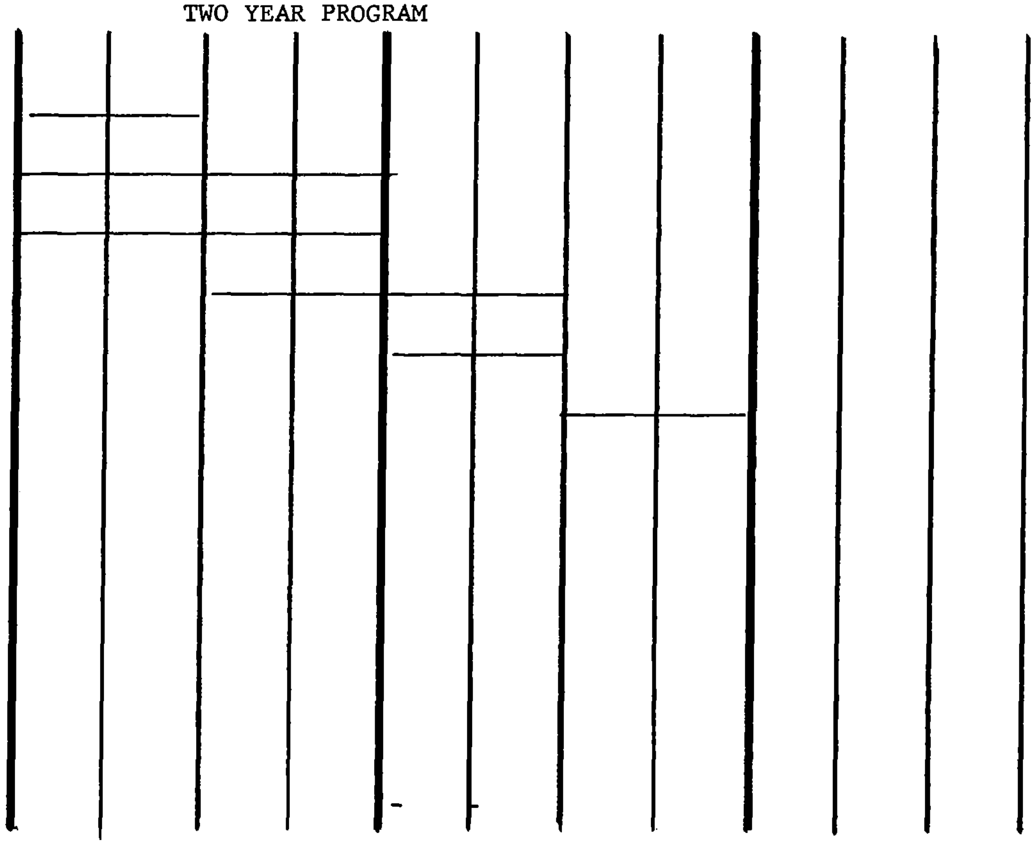
1. Requirements study.
2. Design evaluation.
3. Engineering study.
4. Hardware construction.
5. Simulation testing.
6. Space tests.

SCHEDULE

TWO YEAR PROGRAM

TASK

1. 6 months
2. 1 year
3. 1 year
4. 1 year
5. 6 months
6. 6 months



Develop Promising EVA System Configurations

Objective:

To search for EVA vehicle system concepts which will be more efficient in meeting the totality of EVA requirements, in particular the rescue requirements which are often neglected.

Utility:

It is not evident that present EVA system concepts represent the best possible designs. Any improvement in this field is worth striving for as it represents greater capability in orbit or on the moon for the same launch cost.

Approach:

The sequence of topics suggested for consideration in developing novel designs is given below:

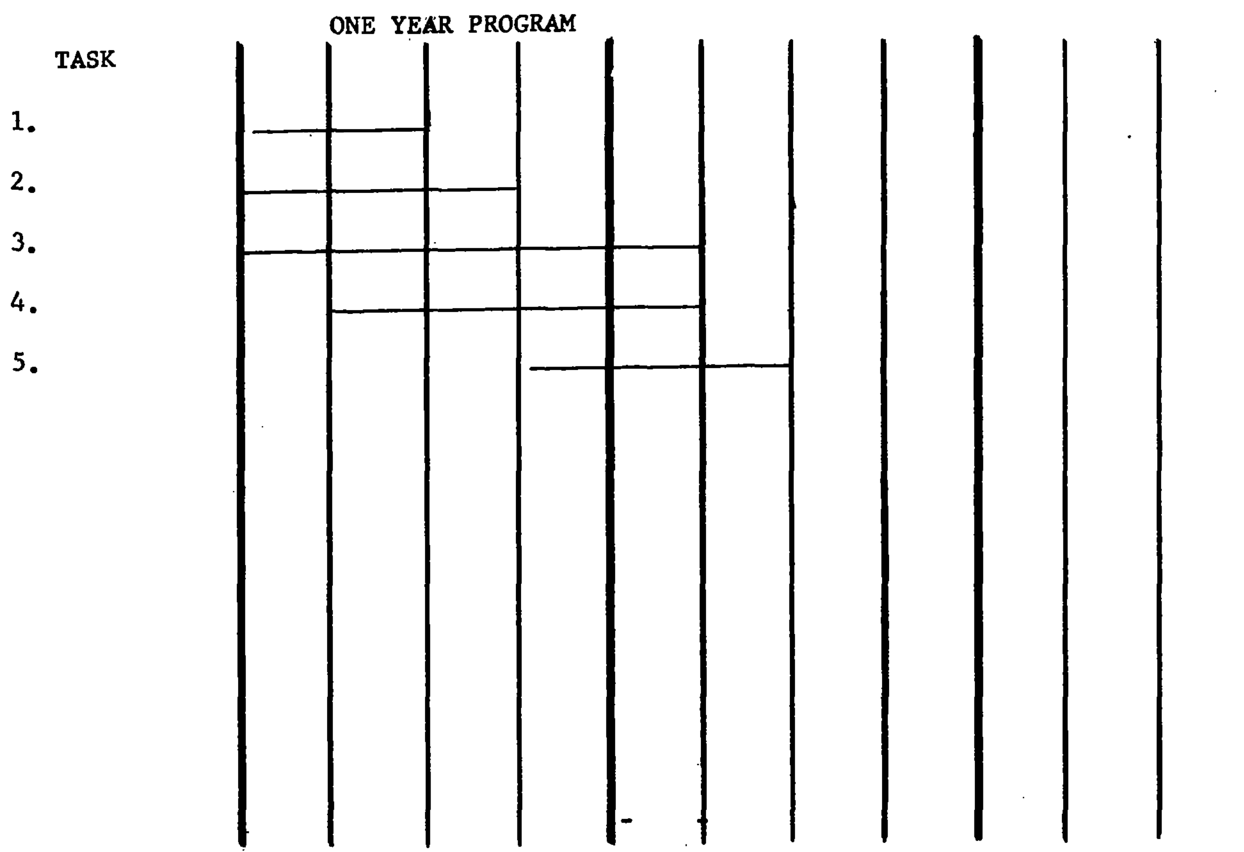
1. For each particular design determine the requirements for which the system functions optimally.
2. Determine the feasibility of transferring these functions to other concepts of different design.
3. Perform studies seeking unique solutions in specific problem areas such as:
   a. Minimum airlock losses
   b. Large advances in manipulator performance
   c. Astronaut comfort
   d. Ease of rescue
   e. Astronaut safety in case of suit damage
4. A design study can then be made whose objective is to combine the favorable aspects brought out in 2 and 3.
5. Construction of mock-up to aid in evaluation of the suggested design or designs.

TITLE: Develop Promising EVA System Configuration

TASK BREAKDOWN:

1. Determine requirements particular to specific systems.
2. Determine feasibility of coverting between systems.
3. Study requirements in:
   (a) Minimum airlock losses
   (b) Breakthrough in manipulators
   (c) Astronaut comfort
   (d) Ease of rescue
4. Design study.
5. Mock-up construction.

SCHEDULE



Develop Manipulator Systems for Space Usage #1

Objectives:

To specify and develop a manipulator system for fastening a work platform to another space vehicle, positioning work in front of the astronaut, and simple assembly operations.

Utility:

Present manipulator systems are severely restricted in the complexity of tasks they can perform. Yet, manipulators can serve the astronaut as useful work aid supplements in performing his orbital tasks.

Approach:

In the first phase, emphasis should be placed on simplifying manipulator handling rather than manned handling in meeting fastening, positioning, and assembly needs. This approach would apply present manipulator technology to specific tasks by modifying the item to be worked on. It is suggested that a near-future manipulator development program adhere to the following format:

1. Determine manipulator requirements for various space systems.

2. Determine optimum power selection for space manipulator. Existing manipulator systems employ hydraulic, electro-mechanical, and pneumatic forms of actuation. Hydraulic actuation represents state-of-the-art equipment, since the sealing problem has been essentially solved. Electro-mechanical actuation suffers from the problem of electrical arcing in a vacuum.

3. Define manipulator and space component commonality requirements. Specifications of a manipulator system should include dexterity, feedback, sensitivity, force reflection, and speed criteria. Of the two main types of manipulator systems - position control and rate control - position control shows the most promise for fastening the positioning operations because of its greater speed and dexterity. However, rate control manipulators offer greater fidelity.

4. Consider emergency operation.

5. Recommend development program and award a sub-contract to an experienced firm.

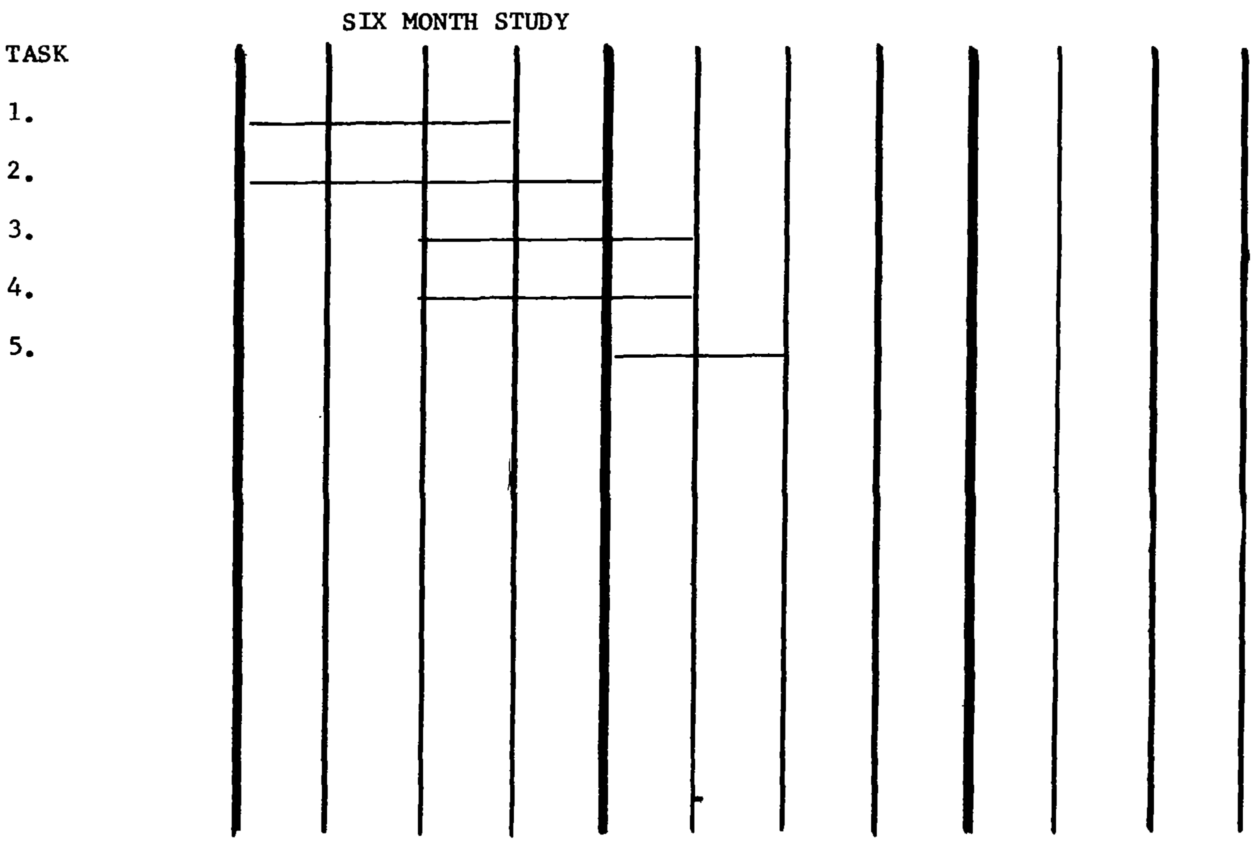
6. Monitor and coordinate manipulator system with work pack concept and existing Apollo system.
7. Construct prototypes and test in simulation chambers.
8. Modifty and space test.

TITLE: Develop Manipulator Systems for Space Usage #1

TASK BREAKDOWN:

1. Determine requirements for various space systems.
2. Determine optimum power selection for space manipulator.
   (a) Hydraulic
   (b) Electric
   (c) Pneumatic
3. Consider emergency operation.
4. Determine program to develop speed and dexterity in manipulator.
5. Recommend development program.

SCHEDULE



Manipulator Development Program #2

Objective:

To specify and develop manipulator systems capable of performing more demanding tasks required in future missions. Consideration would be given to more complex fastening and clasping, positioning, and assembly operations.

Utility:

In future proposed missions there are maintenance, repair, and assembly tasks that require a sophistication in performance not obtainable by present manipulator technology. One such task would require replacing coolant coils on a nuclear reactor located in an orbital launch facility.

Approach:

The following progression is suggested for specifying and developing an advanced manipulator system:

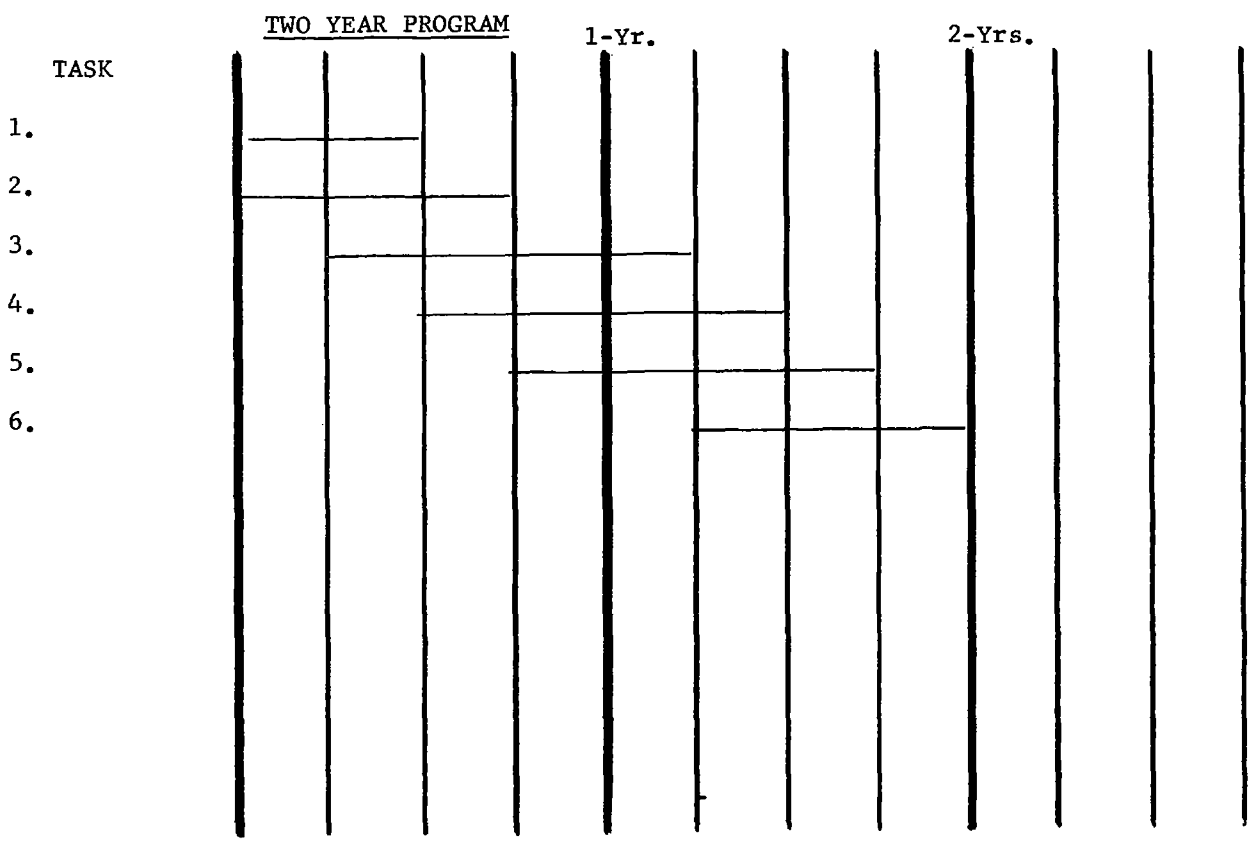
1. Determine future mission tasks requiring the employment of manipulator systems.
2. Compare mission requirements with current state-of-the-art of all types of manipulators and their development programs.
3. Specify advanced manipulator requirements from the above considerations and those enumerated in phase 1 of the manipulator study.
4. Apply feedback control design techniques using newest sensor combinations.
5. Conduct computer simulation studies testing concepts evolved in 4.
6. Construct prototype employing features determined from 1-5.
7. Test in simulation chambers.
8. Modify and space test.

TITLE: Manipulator Development Program #2

TASK BREAKDOWN:

1. Determine current state-of-the-art for all types of manipulators and their development programs.
2. Apply feedback control design techniques using newest sensor combination.
3. Computer simulation studies testing concepts evolved in 2.
4. Construct prototypes.
5. Test in simulation chambers.
6. Modify and space test.

SCHEDULE



State of the Art Study in Prosthetics Control

Objective:

To determine the present state-of-the-art in prosthetics control so as to judge the effort and time necessary to develop myoelectric or other control schemes suitable for in-space usage.

Utility:

The efficiency of man in EVA can be greatly enhanced if other control methods besides his hands and his voice are made available. The field of research which has investigated this subject is that of prosthetics control.

Approach:

The procedure recommended makes use of medical consultants and procedures in the following steps:

1. Literature survey - many agencies of the government are operating in this field, and their work needs to be correlated.
2. Evaluation of the work and its direction with the aid of medical consultants.
3. Discussion of possible progress with the assistance of medical consultants.
4. Recommendations for future action.

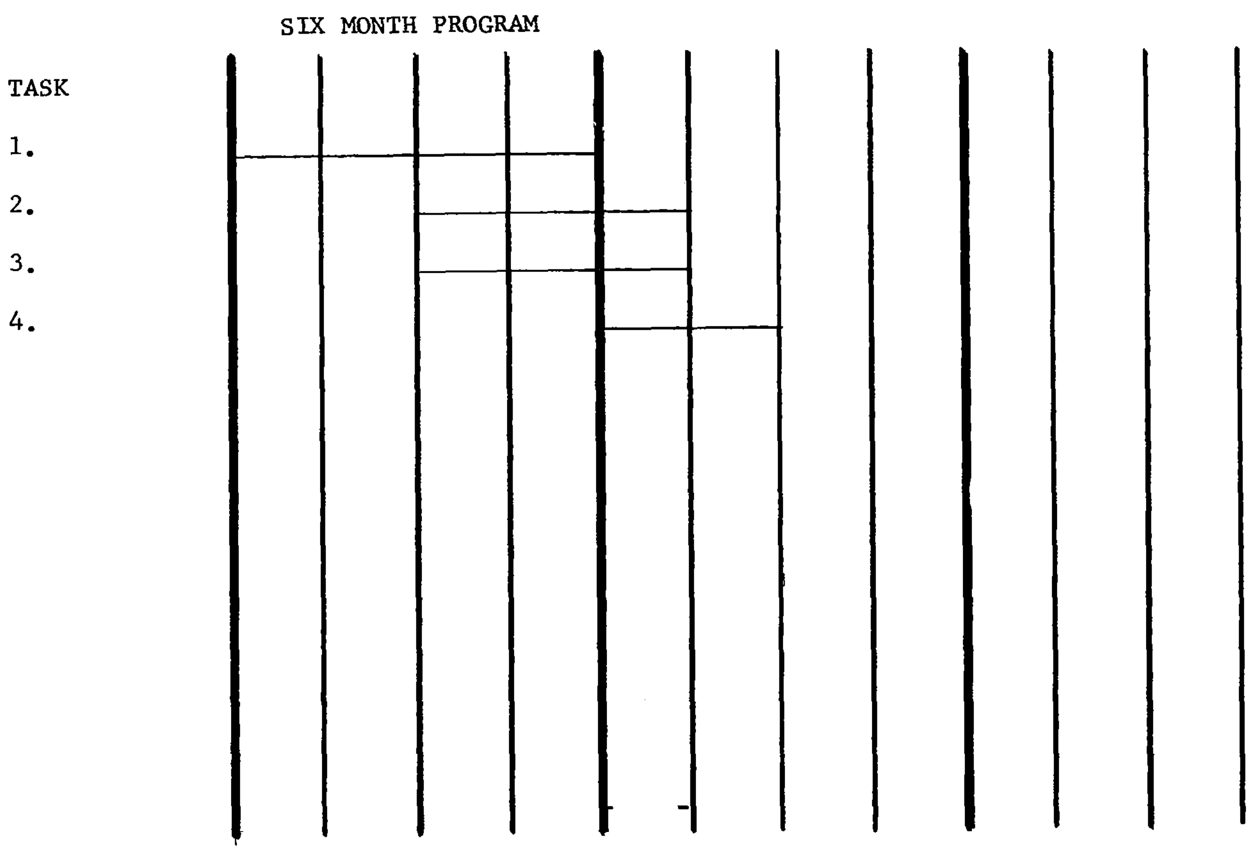
TITLE: State of the Art Study in Prosthetics Control

TASK BREAKDOWN:

1. Literature survey.
2. Evaluation.
3. Discussion of possible progress.
4. Recommendations.

Remarks - Will require use of medical consultants.

SCHEDULE



Exoskeleton Evaluation Study

Objective:

To determine the usefulness of the man-amplifying or man-following exoskeleton concept.

Utility:

The concept of the exoskeleton appears to have utility in space applications either to exert forces beyond man's capability or to remote control an unmanned anthropomorphic exoskeleton on the lunar surface.

Approach:

The principal work has been done at Cornell University but is only in the mock-up stage at present. The suggested program would comprise the following steps:

1. Construct part of the exoskeleton for test
2. Perform simulation tests to determine:
    a. Dynamic range
    b. Encumbrance
    c. Danger to wearer
    d. Accuracy
    e. Reliability
3. From these results the next steps can be decided, and future recommendations can be made.

TITLE: Exoskeleton Evaluation Study

TASK BREAKDOWN:

1. Construct part of exoskeleton for test.
2. Simulation testing.
   (a) Dynamic range
   (b) Encumbrance
   (c) Danger
   (d) Accuracy
   (e) Reliability
3. Future recommendations.

SCHEDULE

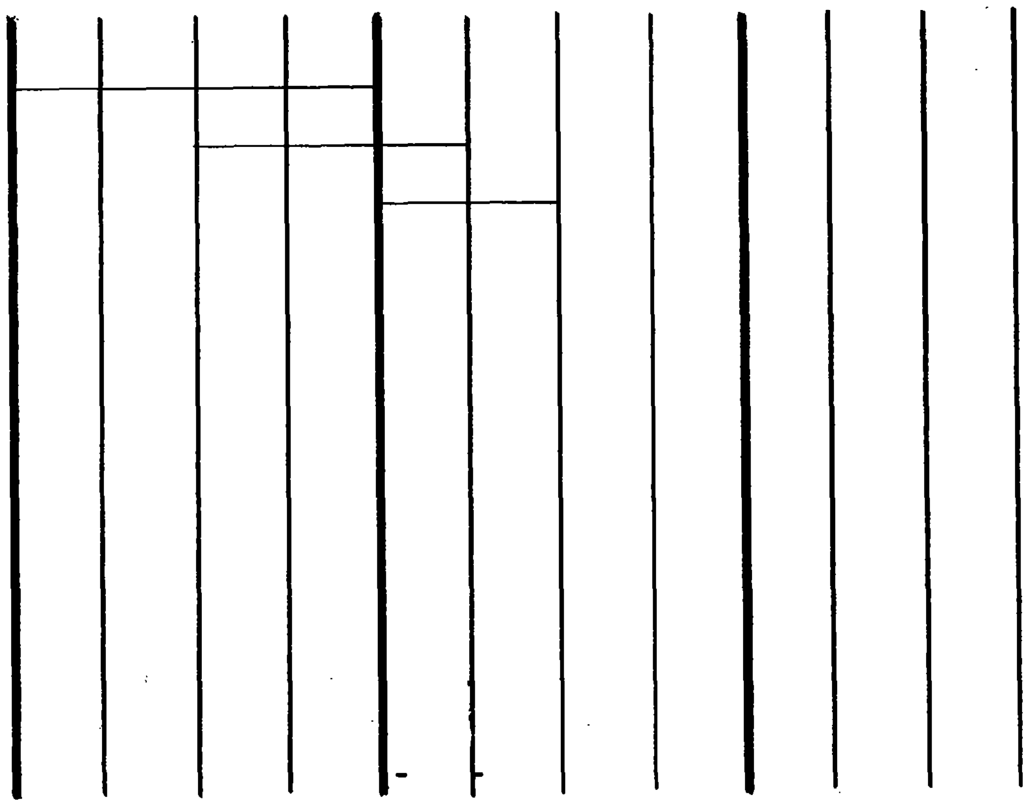
ONE YEAR STUDY

TASK

1.

2.

3.



Remote Operations for EVA Study

Objective:

To determine the tradeoffs between active manned EVA and remotely controlled EVA, and to see if an optimum combination of the two may be of value.

Utility:

Some features of proposed EVA systems are designed to be remotely controlled in case of astronaut incapacity, or controlled at a distance by the astronaut as in the case of changing extremely hot radiators on isotope generators. An increase in these capabilities is of great value in EVA.

Approach:

The following sequence of tasks is suggested:

1. Analyze currently contemplated EVA missions for possible remote operations.
2. Determine requirements for remote control vehicles to perform tasks determined in 1.
3. Undertake an engineering study of the mechanization of these requirements.
4. Feasibility study of the remote control system.
5. Construction of prototype.
6. Simulation testing of prototype.
7. In space testing

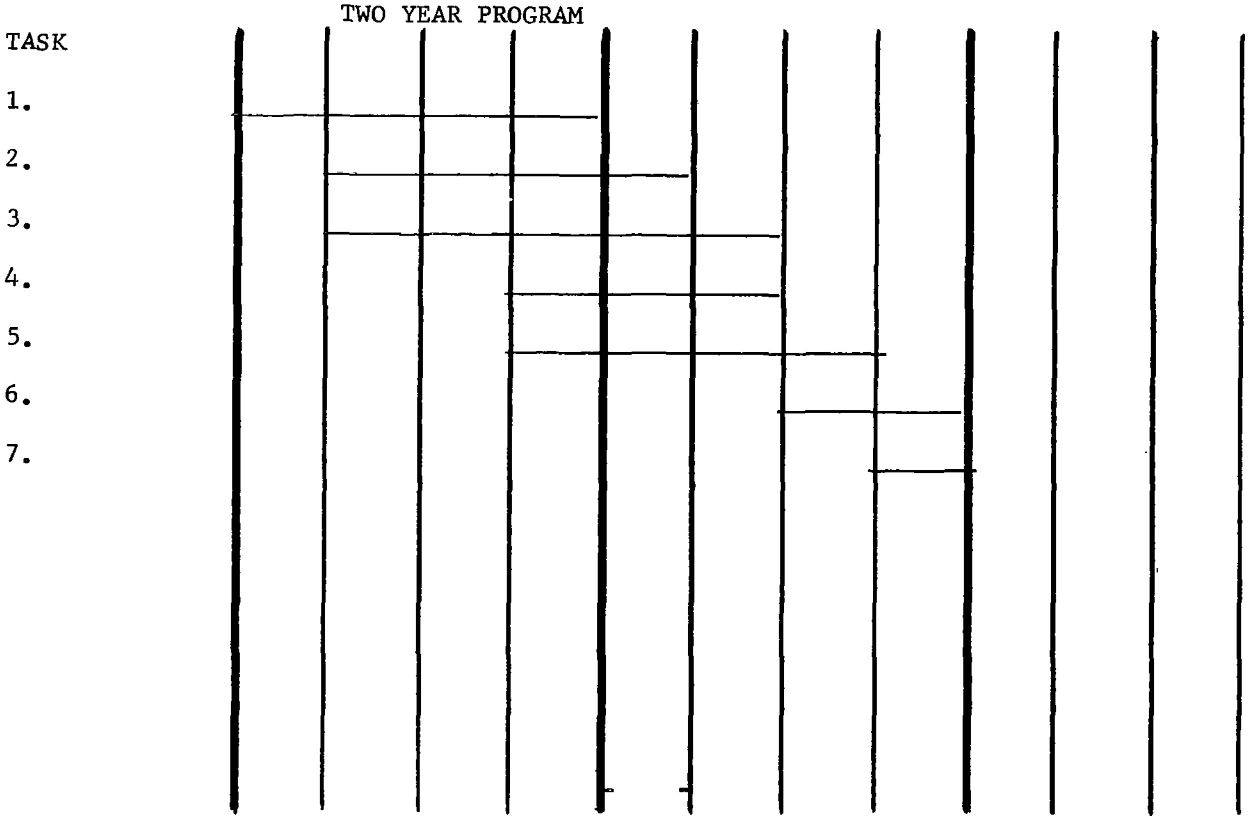
TITLE: Remote Operations for EVA Study

TASK BREAKDOWN:

1. Evaluate EVA's for remote operations.
2. Determine requirements for remote control vehicles.
3. Engineering study.
4. Feasibility evaluation of critical components.
5. Prototype construction.
6. Prototype test (simulation).
7. In space prototype experiments.

SCHEDULE

TWO YEAR PROGRAM



Study of the Space Rescue Problem

Objective:

To outline a solidly based approach to the problem of rescue in the space environment.

Utility:

The problems of rescue in space must be based on any analysis of future plans and contingencies. At the same time, the problem is so complex that a separate study is proposed to develop the most productive approach to the subject.

Approach:

The following order of subtasks is suggested:

1. A study of the probability of various types of failures leading to a rescue situation.
2. A study to determine the type of remedial action required by various failures.
3. A determination of the critical times, actions and components involved in coping with the rescue situations.
4. From the above, it should be possible to establish the EVA requirements for rescue.
5. The hardware requirements should also be capable of development.
6. From these analyses and requirements, a well founded program to implement rescue operations can then be recommended.

TITLE: Study of the Space Rescue Problem

TASK BREAKDOWN:

1. Categories of failure probability study.
2. Study of remedial action requirements.
3. Determination of critical times, actions, and components.
4. EVA requirements for rescue capability.
5. Hardware requirments for rescue capability.
6. Suggested development program.

SCHEDULE

ONE YEAR STUDY

TASK

1.

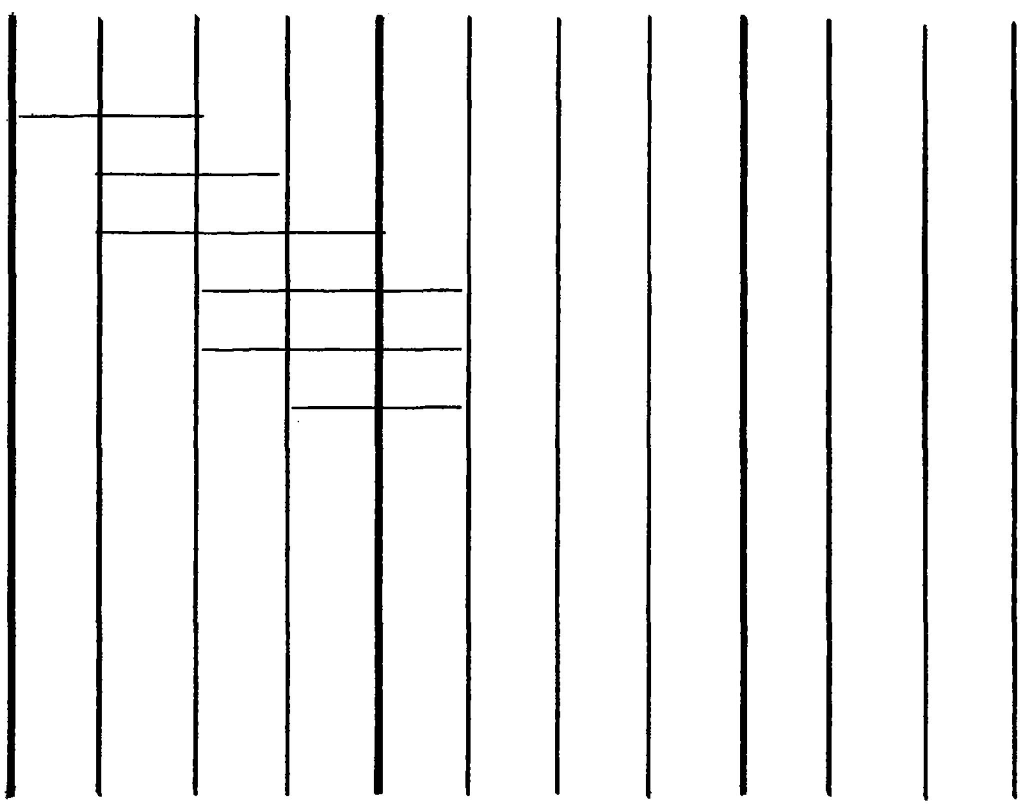
2.

3.

4.

5.

6.



Development of Space Rescue Techniques

Objectives:

To develop the necessary rescue techniques so that there will be a high confidence level associated with the techniques developed to rescue an astronaut.

Utility:

It is certain that a great deal of simulation experimentation will be required to perfect the necessary rescue techniques. They must be useable by a suited or encapsulated astronaut in orbital space or on the lunar surface.

Approach:

The following succession of tasks is suggested for this program:

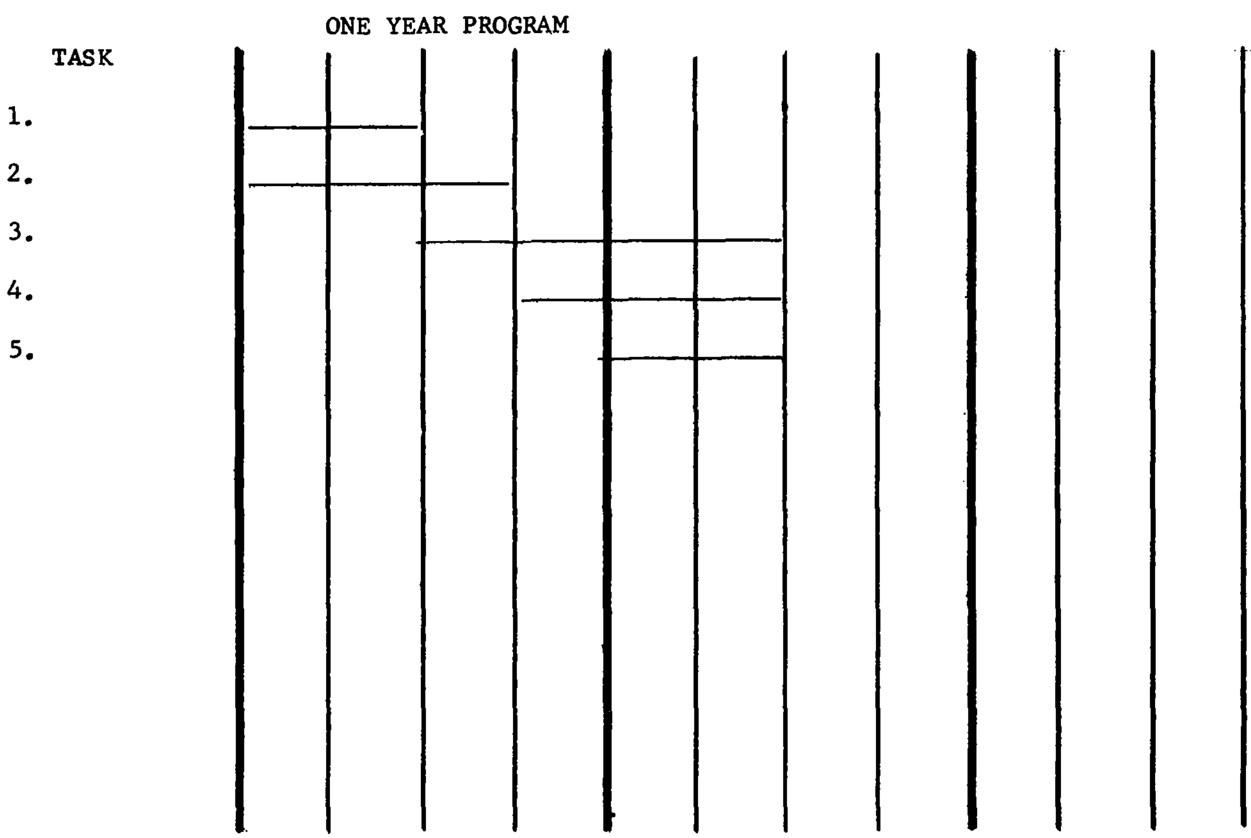
1. From the space rescue study, determine the extent of the simulation program.
2. Design equipment necessary for the most complete zero G simulation
    a. Suspension techniques
    b. Air bearing techniques
    c. Submersion techniques
3. Carry out the simulation program.
4. Determine new requirements in rescue techniques.
5. Recommend hardware and space experiment program.

TITLE: Development of Space Rescue Techniques

TASK BREAKDOWN:

1. From space rescue study determine simulation program.
2. Design special equipment for simulation.
   (a) Suspension technique
   (b) Air bearing technique
   (c) Submersion technique
3. Execute simulation program.
4. Determine new requirements in rescue technique.
5. Recommend hardware and space experiment program.

SCHEDULE



Space Rescue Hardware Development

Objective:

To develop specialized devices which will enable space rescue operations to be conducted rapidly and reliably. These devices are derived from previous rescue studies requirements, and many include systems to encapsulate an astronaut, and various quick repair devices.

Approach:

Various rescue methods and their hardware requirements will be studied and trade-off analyses made to minimize rescue time and maximize reliability.

The chosen devices will be constructed and modified from a prototype study.

Simulation tests will be conducted in space chambers and zero G simulators.

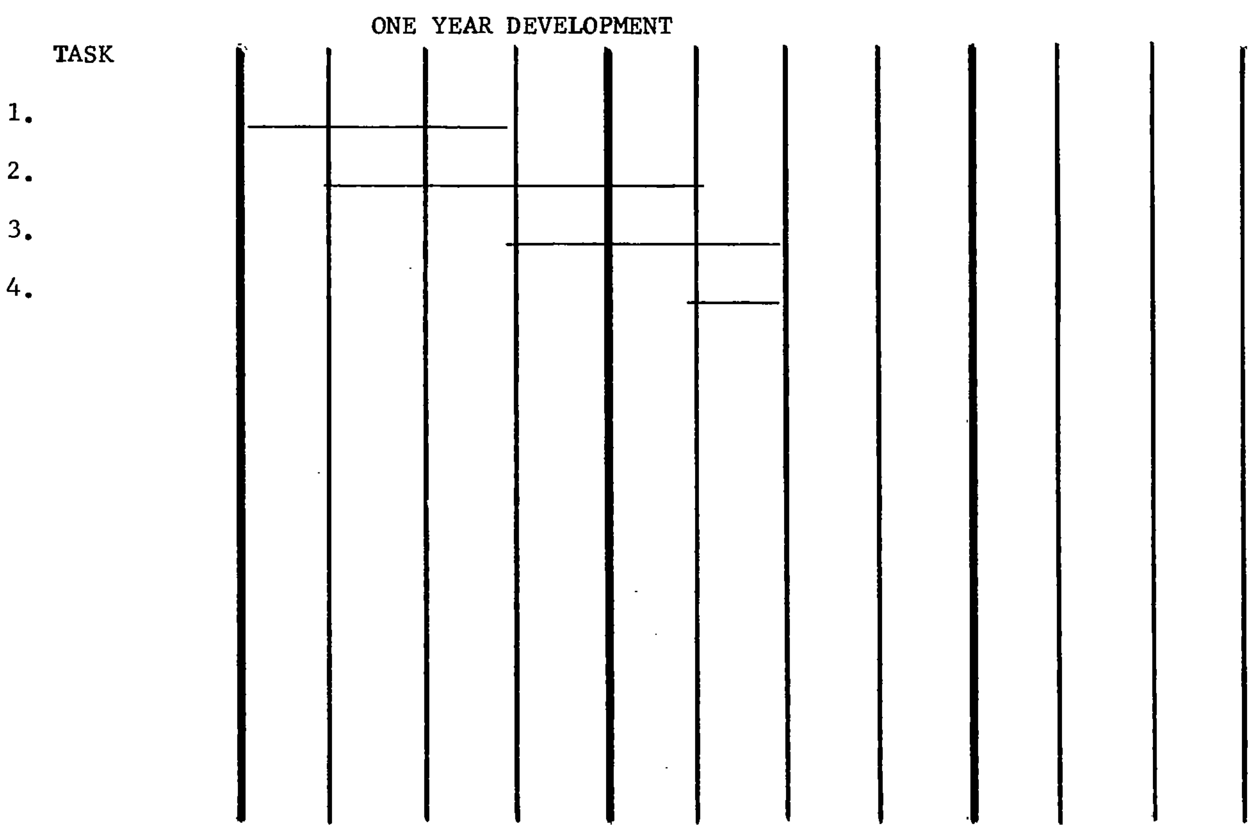
Finally extension tests will be conducted in actual space EVA.

TITLE: Space Rescue Hardware Development
(Coordinate with rescue techniques development)

TASK BREAKDOWN:

1. Design study including trade-off problems.
2. Prototype construction.
3. Simulation tests.
4. In space experiments.

SCHEDULE



Special Tool Development for Rescue Operations

Objective:

To equip an emergency EV rescue astronaut with tools equivalent in purpose to those carried by the rescue squad trucks currently operating in U. S. cities. The purpose of these tools being to decrease to the utmost the time required for rescue.

Approach:

From the space rescue techniques study, the type of action required will be used to determine some of the tool requirements. A literature survey must be conducted. A design and engineering study will be carried out to produce the most efficient tool design for the rescue requirements.

Prototype tools will be constructed. Earth simulation testing will be followed by in-space tests as required.

TITLE: Special Tool Development for Rescue Operations

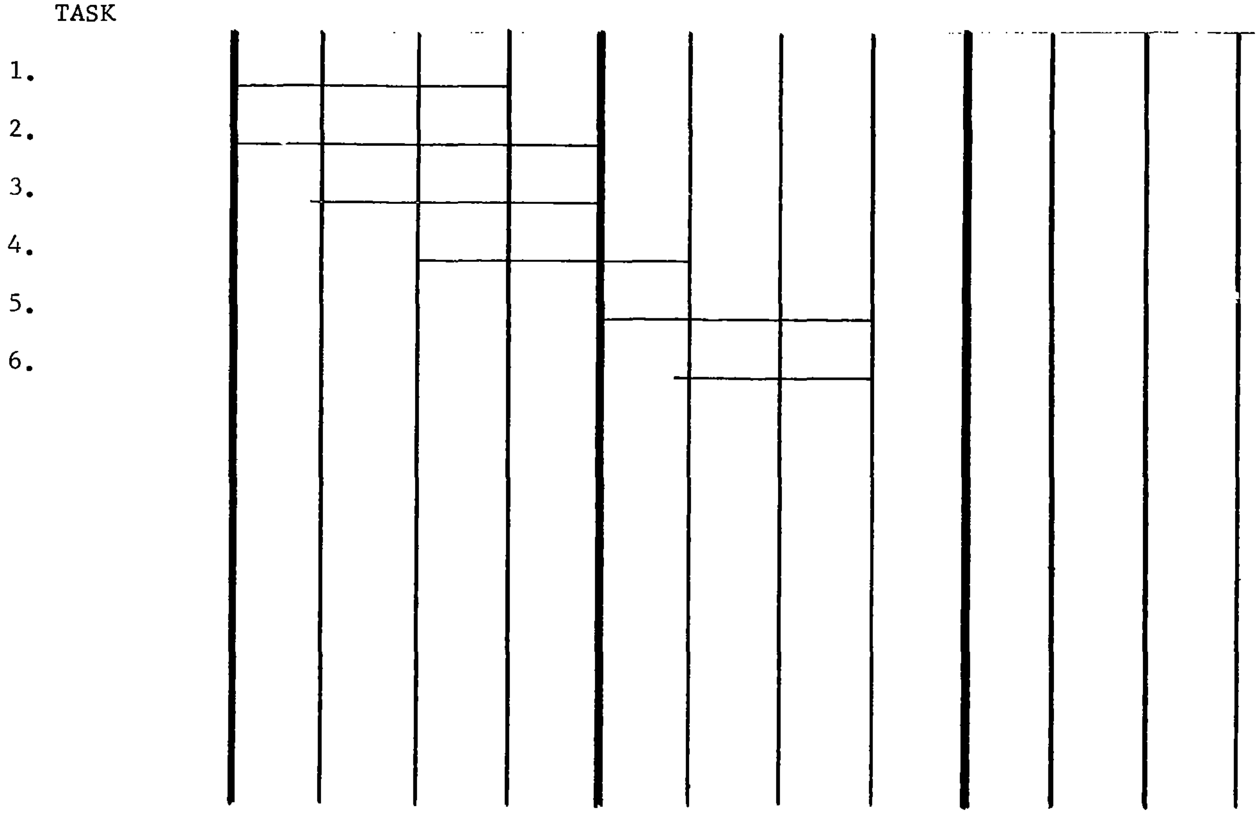
TASK BREAKDOWN:

1. Literature search - Results of rescue study
2. Develop tool requirements (general and specialized)
3. Design and Engineering study
4. Tool assembly
5. Simulation testing
6. In space experiments

SCHEDULE

ONE YEAR STUDY

TASK



EVA System Maintenance and Repair Study

Objective:

The EVA system may see a great deal of use on certain missions and will certainly require maintenance and repair. The study would determine optimum methods and interface considerations necessary to carry out maintenance and repair efficiently.

Approach:

A failure analysis and preventive maintenance study must be conducted on EV subsystems. The critical subsystems or components must be studied from the point of view of providing for accessibility or modular replacement. Extensive simulation tests and actual flights are then required before EVA system design freeze.

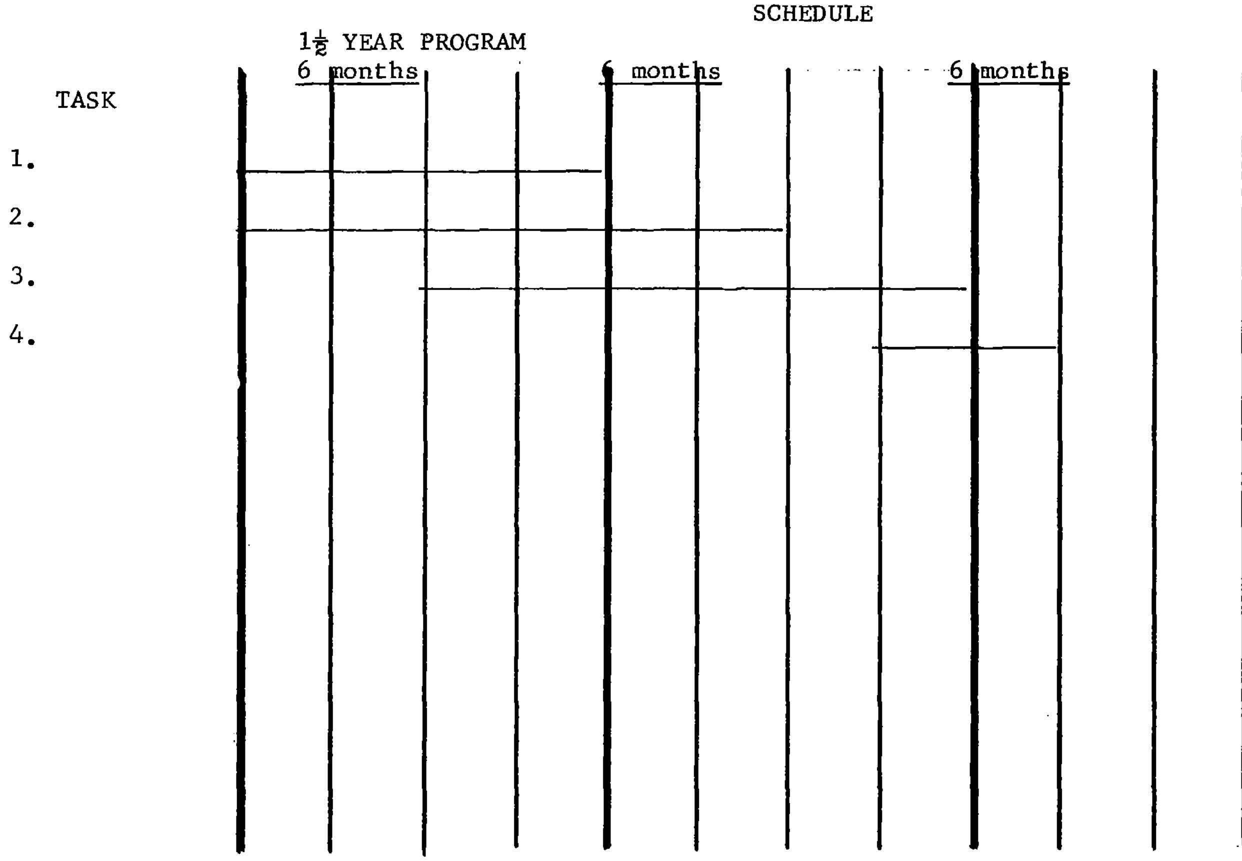
Engineering design recommendations are then determined and written up.

TITLE: EVA System Maintenance and Repair Study

TASK BREAKDOWN:

1. Failure and preventive maintenance study on EV subsystems.
2. Design study for accessibility and modular replacement.
3. Extensive simulation trials and flight results.
4. Engineering design recommendations.

SCHEDULE



EVA Modular Concept Study

Objective:

To design and develop a logical extension of the present AMU backpack configuration that would allow the introduction and removal of different subsystems resulting in optimum EV systems for each major mission.

Utility:

Present EV system proposals suffer from a lack of versatility in task performance. Because future missions will vary in length, task, and complexity, it is desirable to be able to modify EV hardware to meet changing requirements.

Approach:

The following program is suggested for the design and development of an EVA modular concept:

1. Definition of mission life support and hardware requirements.
2. Specification and design of subsystem characteristics.
3. Design study modularizing various mission oriented EV system proposals.
4. Effectiveness evaluation.
5. Mock-up and simulation.
6. Recommendation for system hardware.

TITLE: EVA Modular Concept Study

TASK BREAKDOWN:

1. Design study modularizing various EV system proposals.
2. Effectiveness evaluation.
3. Mock-up and simulation.
4. Recommendation for system hardware.

SCHEDULE

$1\frac{1}{2}$ YEAR PROGRAM

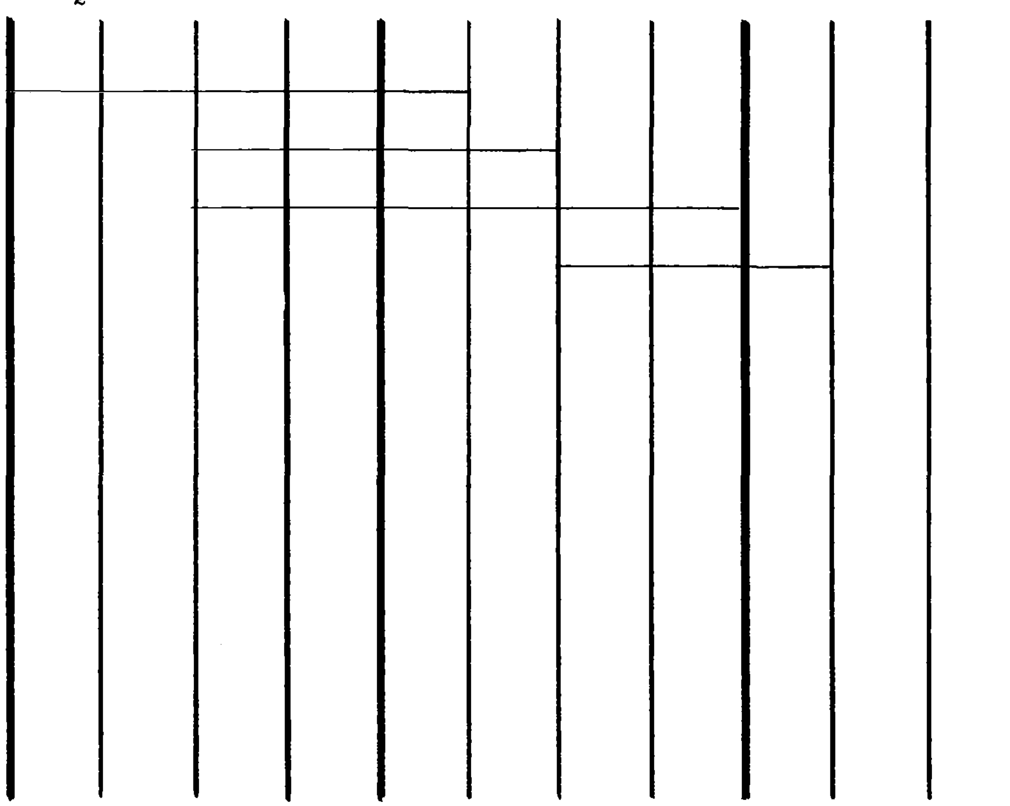
TASK

1.

2.

3.

4.



Transportation of EVA Systems Study

Objective:

To examine the problems of transporting into orbit optimum design EVA systems. To determine the constraints placed on EVA system design and the possibilities of transporting oversized systems by blistering on boosters or by other methods.

Approach:

Review current plans and alloted space.

Examine other transportation possibilities including the worth of individual launch.

Determine the maximum volume and weight available in these various methods. Condense these restrictions into specifications. Determine the restrictions these specifications place on contemplated EVA systems.

Recommend solutions.

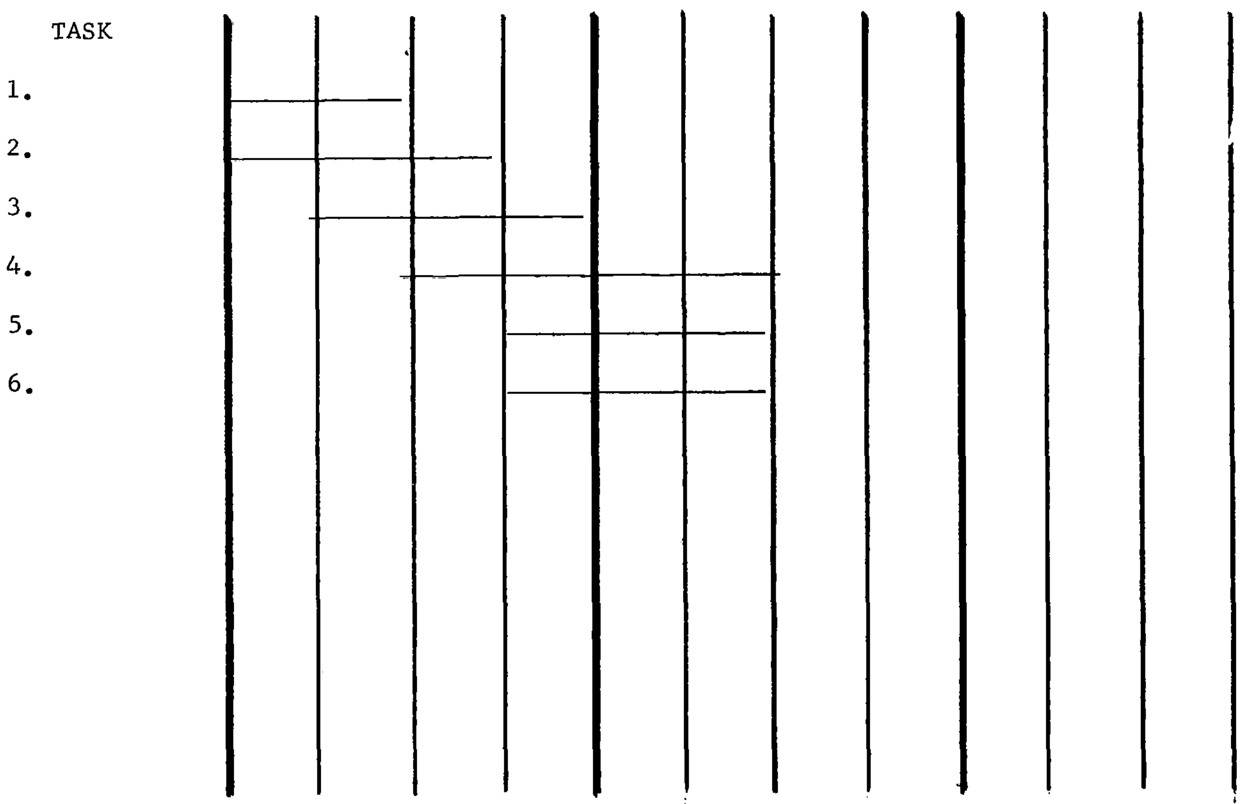
TITLE: Transportation of EVA Systems Study

TASK BREAKDOWN:

1. Review of current concepts.
2. Review of other concepts such as outside blistering.
3. Determine restriction for all worthwhile concepts.
4. Write general specifications for EVA Systems based on (3).
5. Evaluate importance of (3) on EVA Systems.
6. Recommend optimum solutions.

SCHEDULE

SIX MONTH STUDY



Determination of Martian Environment

Objective:

To compile and evaluate all available information on the Martian environment and surface characteristics for the purpose of manned exploration.

Utility:

Existing programs have determined to a limited degree the composition of the Martian environment. Future programs will further refine knowledge of the composition of the Martian atmosphere and soil. What remains to be done is to synthesize the information available from these programs for use during manned activity.

Approach:

The following program is suggested as a means of fully exploiting available physical information on the Martian environment for manned exploration:

1. Determine the meteoritic environment with emphasis on contributions from the asteroid belt and atmosphere penetration.
2. Further refined estimates of the atmosphere composition and meterological environment.
3. Study methods of utilizing or combating environmental characteristics for manned exploration.
4. Devise experiments for determining critical factors that relate to manned missions.

Remarks:

Use should be made of the probes set for the 1967-70 time period.

TITLE: Determination of Martian Environment

TASK BREAKDOWN:

1. Meteoritic environment with emphasis on contributions from Asteroid belt and atmosphere penetration.
2. Atmosphere composition.
3. Meteorological environment.
4. Methods of utilizing or combating environmental characteristics.
5. Critical factors remaining to be determined for Manned Missions.

Remarks - Uses data from probes, period 1967-70

SCHEDULE

6 MONTH STUDY

TASK

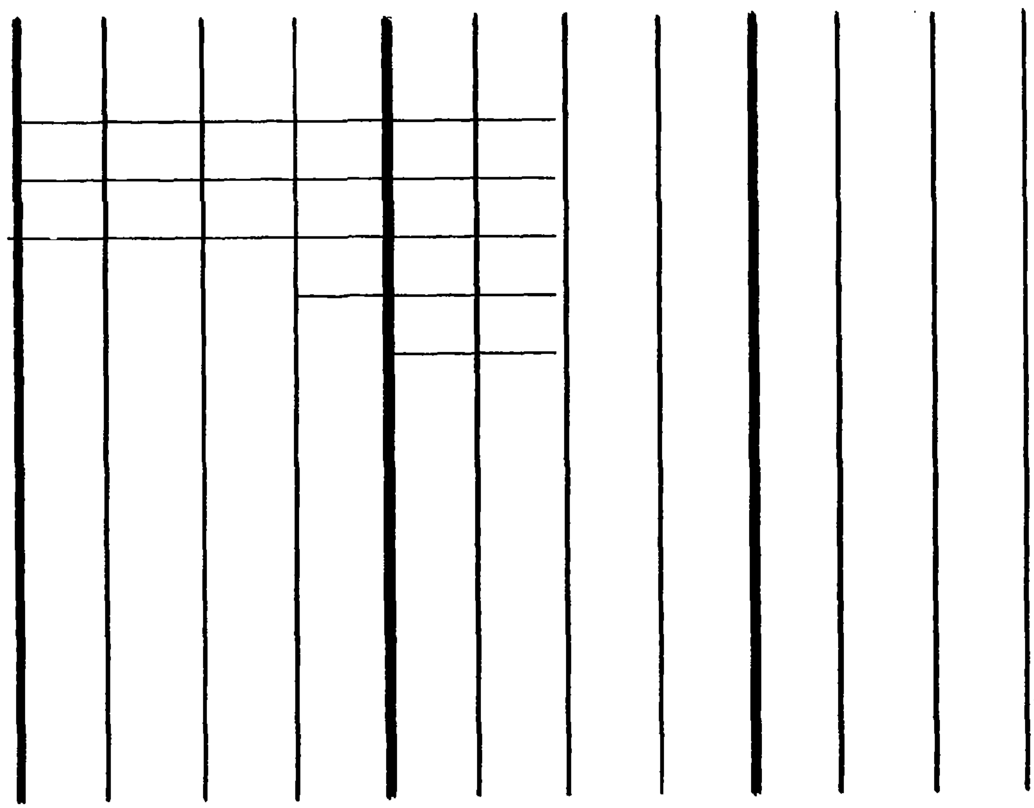
1.

2.

3.

4.

5.



Prevention of Atmosphere Contamination

Objective:

To prevent contamination of the spacecraft atmosphere from boil-off of propellant and exhaust wastes accumulated on an EV astronaut's spacesuit.

Utility:

One of the tasks that an EV astronaut must perform in future space missions is full transfer. In the performance of this task there is the danger of fuel impregnation of the astronaut's spacesuit and subsequent boil-off inside the spacecraft.

Evaporation of exhaust plume wastes accumulated on an EV astronaut's spacesuit is another source of cabin atmosphere contamination.

Approach:

Because a special decontamination airlock would be both cumbersome and heavy, it is suggested that other decontamination measures be developed. These measures should be largely preventive. To this end the following program is directed:

1. Determine toxicity of all spacecraft store and exhaust plume wastes.
2. Study existing full transfer methods to prevent contamination.
3. Design fuel storage systems and transfer methods which preclude contamination hazards.
4. Develop procedures for isolating the astronaut from exhaust plumes.
5. Simulate fuel storage systems and transfer techniques to determine optimal astronaut isolation procedures.
6. Develop specifications for non-hazardous fuel storage, transfer procedures, and requirements for the isolation of the astronaut from exhaust plumes.

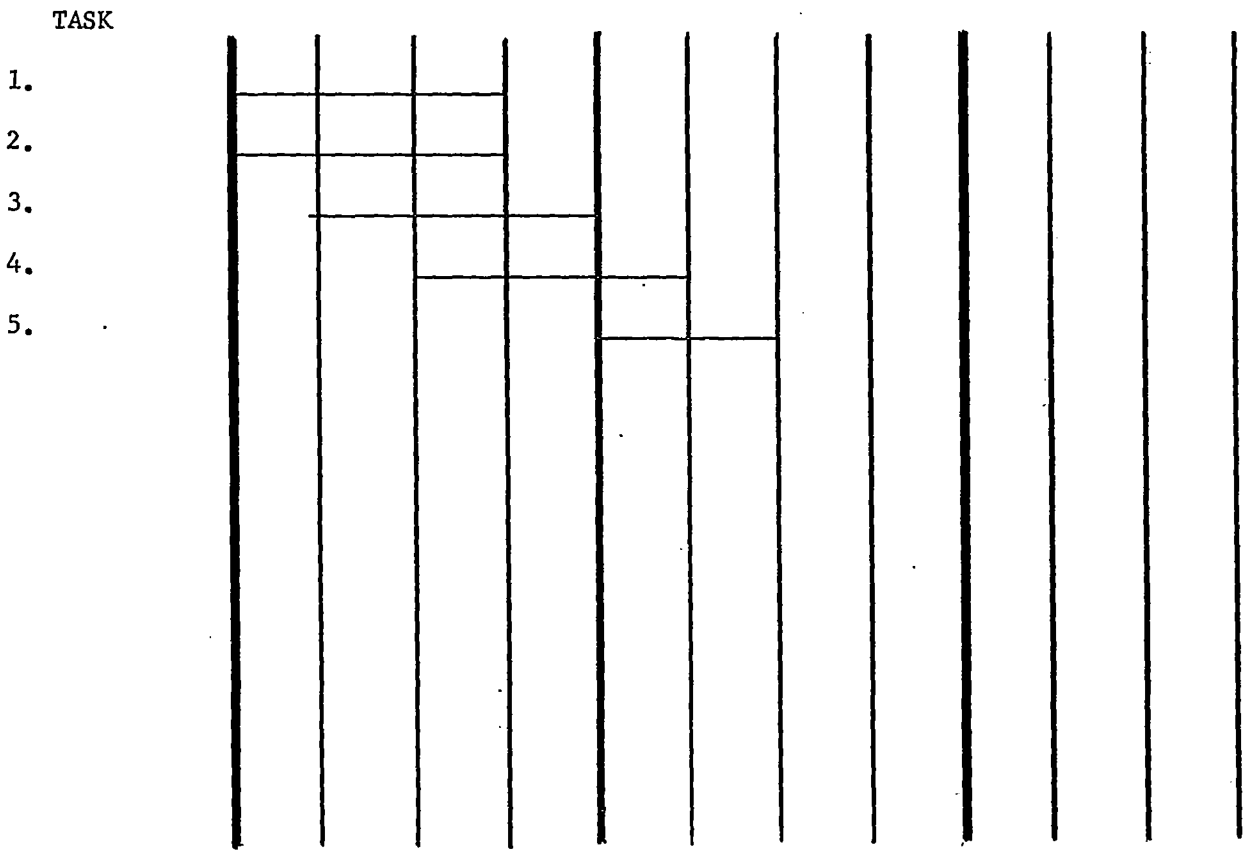
TITLE: Prevention of Atmosphere Contamination

TASK BREAKDOWN:

1. Determine toxicity of all spacecraft stores.
2. Study existing fuel transfer methods to prevent contamination.
3. Design study of secure fuel and stores transfer systems.
4. Simulation of fuel and storesstransfer system.
5. Develop specifications for non-hazardous fuel and stores transfer.

SCHEDULE

ONE YEAR PROGRAM



Astronaut Boarding and Evacuation Techniques Development

Objective:

To determine from all available techniques the best ones for particular requirements such as minimum time, minimum atmosphere loss, pass through of large objects, etc.

Approach:

Study available techniques and determine advantages and disadvantages associated with each one.

Simulation studies for minimum time and minimum atmosphere loss systems, atmosphere loss boarding and evacuation techniques.

TITLE: Astronaut Boarding and Evacuation (B-E) Techniques Development

TASK BREAKDOWN:

1. Study of available techniques of determine individual advantages.
2. Simulation studies for min. time, min. atmosphere loss systems.
3. Specifications for highspeed B-E technique.

SCHEDULE

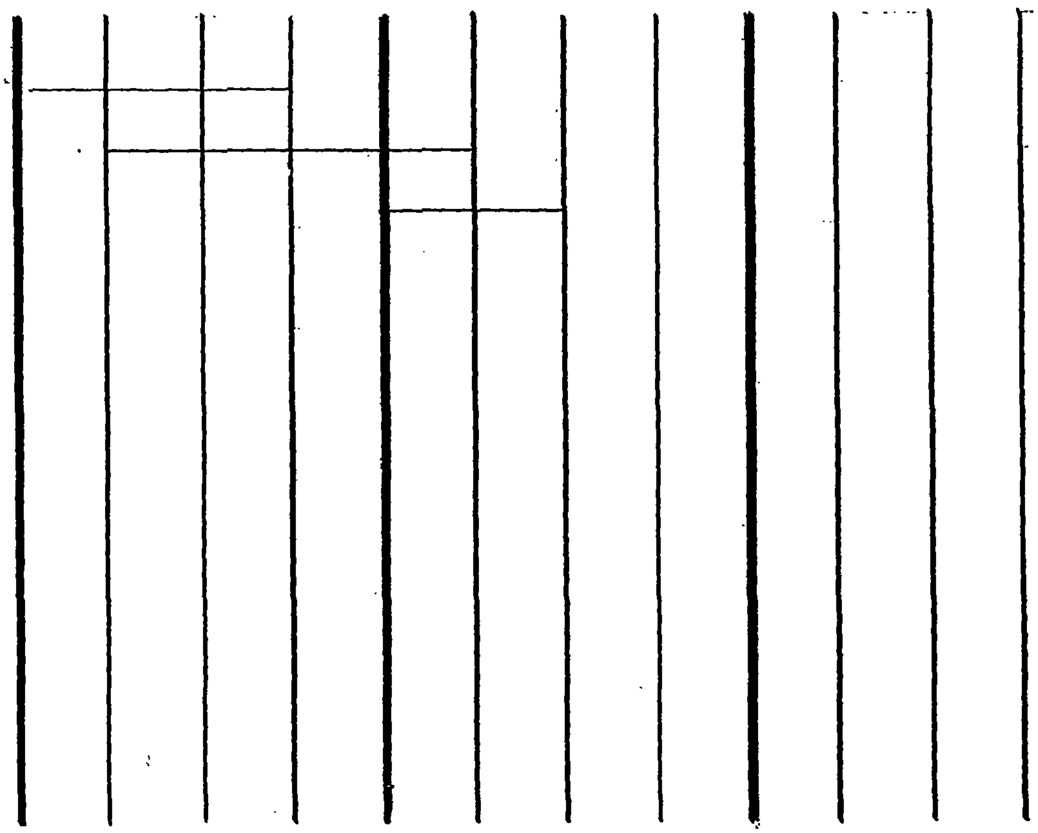
ONE YEAR PROGRAM

TASK

1.

2.

3.



B I B L I O G R A P H Y

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(Very perceptive discussion with good bibliography - nearly 200 titles)

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(Investigation which shows that under zero gravity mass increment must be twice as large as weight increment required for discrimination under 1 G)

3. "Effect of Gloves on Control Operation Time"; Bradley, James V.; AML; November 1956, Wright Air Development Center; Wright-Patterson Air Force Base, Ohio; WADC Technical Report 56-532.
(Early investigation showing dependence on glove design, fit, etc.)

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(Discusses the errors in weight estimation and the effects of the previously lifted weight)

5. "Study of the Thermal Processes for Man-In-Space"; Contract NASW-1015; February 12, 1965; Airesearch Manufacturing Division; Los Angeles, California.
(This is an excellent report on heat transfer mechanisms involved in cooling the human body in space and lunar environments.)

6. "Scientific Exploration of the Moon Using a Roving Vehicle"; Tiffany, O. Lyle et. al.; Symposium on Post Apollo Space Exploration; AAS; May 4-6, 1965.

7. "Rate Controlled Manipulators"; Melton, Donald F.; Presented at Seminar on Remotely Operated Special Equipment; Space Nuclear Propulsion Office; AEC: Washington, D. C. May 15, 1964.
(This paper is a well-written summarization of rate control manipulators by the president of a leading manipulator firm)

8. "The Space Suit"; Rovit, Bernard; Space/Aeronautics; June 1965. (This article emphasizes the problem of resolving mobility and comfort needs over those imposed by environment stresses.)

9. "Joy Stick vs. Multiple Levers for Remote Manipulator Control"; Crawford, Billy M.; BSL/AMD; Wright-Patterson Air Force Base, Ohio.
(Superior perfromance of the joy stick is demonstrated.)

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(An incomplete study of viewing conditions upon performance of a simple remote handling task.)

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(Interim report emphasizing man-machine relationship.)

12. "Performance Capabilities of Man on Earth and In Space: A Study of Continuity"; Christensen, Julian M.; Wright-Patterson Air Force Base; Symposium on Post Apollo Space Exploration; AAS, May 4-6, 1965.
(An excellent qualitative discussion supporting the thesis of man's utility in space.)

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(This paper summarizes results of analytical and simulation studies on the utility of low-powered thrusters and tethers for EVA.)

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(Good discussion of the installation of remote handling tools and the architectural problems which arise in optimizing their use.)

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16. "Methods and Techniques for Sea Floor Tasks"; Ocean Science and Ocean Engineering, 1965.
(This article on the use of manipulators for underwater tasks is important as a parallel to future developments that must be incorporated for space operations.)

17. "Highlights of Foreign Bioastronautics"; 28 December 1964; Aerospace Medical Division; AMD-TR-64-20.

18. "Remote Handling of Mass"; Crawford, Billy M.; Kama, William N.; BSL/AMD Aeronautical Systems Division; Wright-Patterson Air Force Base, Ohio; December 1961; ASD Technical Report 61-627.
(This paper is a study of man's ability to make differential and absolute judgements of remotely handled masses under simulated weightlessness conditions.)

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(Comparison of two early suits (1960); somewhat limited in scope.)

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21. "Survey of Remote Handling in Space"; Technical Documentary Report No. AMRL-TDR-62-100; September, 1960; Wright-Patterson Air Force Base, Ohio.
(This report contains a number of conceptual schemes for using manipulators in space.)

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(This paper compares possible lunar exploration systems in terms of mission capability, efficiency, development problems and costs.)

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(These lectures tend to center around physiological consideration presented by the space environment.)

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(This is a cursory examination of orbital launch techniques using Apollo/Saturn equipment.)

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29. Report Investigating the Feasibility of Space Station Crew Rescue by the Non-Reentry Rescue Module Concept; ASD-TDR-63-778.

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(This paper is a cursory review of lunar surface scientific mission studies utilizing modified Apollo hardware.)

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(This report is a continuation of a previous seminar at Jackass Flats, Nevada on the state-of-the-art of manipulator systems and manipulator requirements for space applications.)

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(This paper emphasizes the advantages of terrestrial observations from space made possible by recent advances in remote sensing techniques.)

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(This is a one-sided report which discusses the feasibility of an exoskeleton by examining mobility restrictions and subject performance in a non-powered model.)

35. "Study of An Atitude Control System for the Astronaut Maneuvering Unit"; Drissel, W. E. et. al.; NASA Cr-198, March 1965.
(This paper describes the mission and system requirements of an attitude control system for the AMU.)

36. "Earth-Orbital Mission Definition Document" (Preliminary Version) NASA Contract NASW-1215; July 30, 1965.
(This report presents the results of an initial assessment of Apollo Extension System earth-orbital missions.)

37. "An Analysis of Hostile-Environment Methodologies"; Clark, Dr. John W.; Battelle Memorial Institute, Columbus, Ohio (Presented at Seminar on Project Rose; May 26-27, 1964.)
(This paper presents a guideline for developing a unified approach to the problems of accomplishing manual operations in areas inaccessible to man.)

38. "Venus and Mars Nominal Natural Environment for Advanced Manned Planetary Mission Programs"; Evans, Dallas E. et. al.; Manned Spacecraft Center, Houston, Texas; NASA SP-3016; 1965.

39. "Extended Lunar Exploration"; Henderson, William C.; Symposium on Post Apollo Space Exploration; AAS; May 4-6, 1965.
(This paper presents a general modular approach to the establishment of a surface lunar base.)

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41. "A Mobile Lunar Laboratory System"; Carr, John H. and Romano, Samuel; Symposium on Post Apollo Space Exploration; May 4-6, 1965. (This paper is almost exclusively devoted to specification of a mobile lunar vehicle to meet extended lunar exploration requirements.)

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(This article describes some of the space tools, fasteners, and work procedures that are being considered for EV maintenance, repair, and assembly operations.)

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(This is an excellent report on the necessary preliminary design features for an integrated self-maneuvering unit.)

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(This is a biased report on the advantages of a monopropellant hydrazine propulsion system over other systems that are in use today.)

53. "Designer's Checklist: Hydrazine Monopropellant: Rockets and Gas Generators"; Rocket Research Corporation; Seattle, Washington.
(This report is intended as a practical guide for designing hydrazine propulsion systems.)

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(This report is an excellent preliminary study of a large orbiting telescope; it also illustrates some of the more demanding tasks that will be required of an EV astronaut in servicing an orbiting telescope.)

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