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ORBITAL EXTRAVEHICULAR MOCKUP DESIGN

by P. IRIBE

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Statements made herein with regard to plans, conclusions and recommendations for EVA operations and equipment are those of the writer and do not necessarily reflect NASA policy or opinions.

THE JOHNS HOPKINS UNIVERSITY ▪ APPLIED PHYSICS LABORATORY
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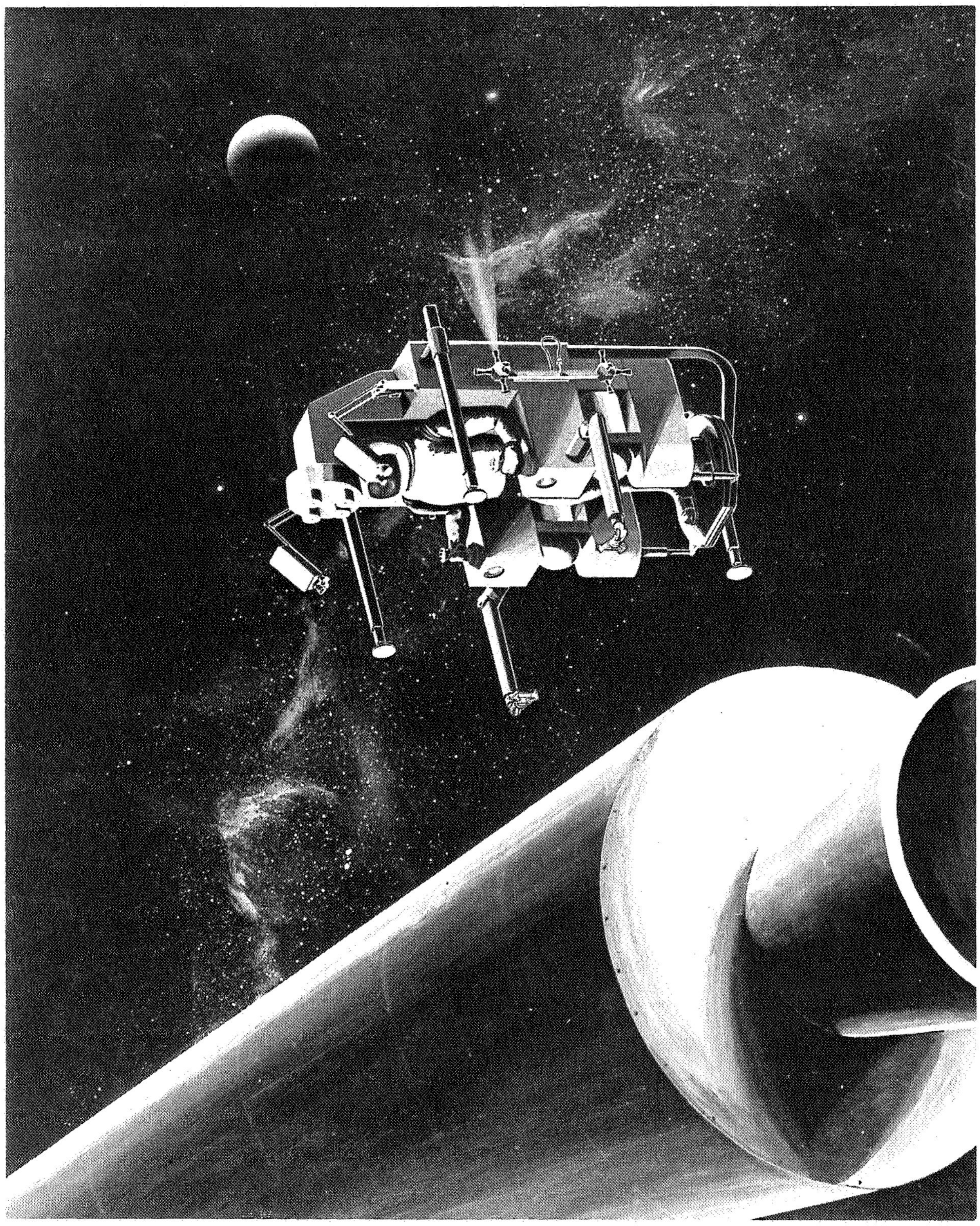

ORBITAL EXTRAVEHICULAR WORK PLATFORM AT WORK

ABSTRACT

Extravehicular activities (EVA) in space such as inspecting orbiting spacecraft, servicing orbiting equipment (e.g., an orbiting telescope), performing assembly tasks in space, and making space rescues will require an extravehicular work platform. The proposed one-man extravehicular work platform is an example of extreme man-machine integration. A study of the requirements for extravehicular protection and operation for such activities led to the immediate construction of a full-scale mockup of the required type of platform in order that it might serve as a focus for discussion, give a first look at the engineering feasibility of the platform, arbitrarily reduce the number and variety of contending designs, and be useful in future studies. The principal design features of this full-scale mockup are described. Of the contending designs, the one chosen for the mockup was a modularized "backpack" equipped with a propulsion capability, a backup for a portable life support system (PLSS), a communication subsystem for voice and telemetry, a TV monitoring subsystem, a rechargeable electrical power source, and pack-mounted illumination and mechanical manipulators. The basic design can be augmented by special modules to meet the requirements of particular missions.

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
SILVER SPRING, MARYLAND

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

A full-size mockup of an orbital extravehicular work platform has been constructed as a sequel to the APL/JHU report "Study of Extravehicular Protection and Operations" (TG-841, also published as NASA CR 773). The principal objective of the work platform is to allow the feasibility of some of the concepts discussed in that report to be investigated. The main ideas for consideration are:

1. The exposed astronaut.
2. Capability of working from the platform.
3. Modular, mission-oriented concept.
4. Use of a manipulator and attachment arms.
5. Use of radar for long range rendezvous situations such as rescue.

The photographic frontispiece illustrates the design that was chosen to incorporate these concepts. This report discusses the uses or advantages of the various features of the design and the reasons for choosing these features as they are.

II. THE EVA CONCEPT

In order to introduce the EVA (Extravehicular Activity) concept, it was thought best, for the present report, to relate it to a proposed program that requires extra vehicular activity. The program selected is the one discussed in the February 1967 report of the President's Science Advisory Committee (PSAC), "The Space Program in the Post-Apollo Period," which points out the benefits to be derived from large orbiting telescopes. In this connection the EVA concept is introduced as follows:

> "...Engineering operations. This category of operations consists of three types of actions: (1) putting a telescope into operation in orbit (which may range from the one extreme of standing by and physically contacting the telescope only in the case of failure to initiate operations from the ground, to the other extreme of actually assembling elements of the telescope in space), (2) maintaining the telescope at top effectiveness (including repair of failed parts as well as the correction of unexpected deterioration of thermal, mechanical, and electronic adjustments for which no automated readjustments were included in the original design), and (3) updating of subsystems to avoid early obsolescence in a rapidly evolving scientific and technological period (for example, by replacing outdated radiation sensors, electronic imaging devices and spectrographs).
>
> "Only for the third type of engineering action does it appear definite at this time that man in orbit is required, and only then whenever such updating action is warranted in connection with a primary telescope of very large capital cost. For engineering actions of the first two types the same statement cannot be made with any similar certainty at this time. Spacecraft like Mariner and Surveyor may be estimated to have an overall reliability of the order of 50 percent at present. Some of the major instruments on OSO's have failed, and the first and (until now) only OAO has failed. Nevertheless, for the level of complexity of these instruments it seems plausible that the necessary degree of reliability for completely unmanned operations will be achieved without excessive increase in cost.
>
> "However, for the next generation of telescopes, which will be both more complex and more demanding in the perfection of their adjustments, completely unmanned operations will likely require reliability engineering fully as high as is presently practiced in manned missions, with corresponding increases in the cost of the telescopes. Under these circumstances, manned engineering operation of these next generation telescopes may well approach economic competitiveness, assuming that man's ability at zero-G

is not seriously degraded, at least in short duration flights. If this estimate proves correct, then the new telescopes will become critical training-and-test tools for the further development of our ability in accomplishing difficult manned engineering operations in space.

"Three more comments are offered, all based on very limited engineering considerations and practically no relevant actual experience: (1) It is hard to envisage that any single engineering operation on one telescope (whichever of the three types of actions mentioned above may be involved) could require a period greatly exceeding 2 weeks. (2) Any one telescope should require manned engineering attention normally, at most, twice a year; a higher rate would indicate an uneconomically short mean life of the critical parts in the telescope. (A consequence of these two estimates is that any given space telescope is occupied by scientific operation from the ground for 90 percent of the time without any connection with men in space.) (3) The astro-engineer selected for the task of carrying out the engineering operations in space for a specific telescope will have to train himself for this task by participating in the assembling and testing of the telescope on the ground, involving probably a total time (not necessarily all at once) of the order of one year for the larger telescopes and of half this length for the simplest ones."

The PSAC report sets forth clearly the point at which EVA becomes economically useful. However, some conclusions are at variance with engineering studies such as that by the Boeing Co. showing servicing of the telescope on a weekly basis and even more frequently if emergencies are taken into account. One of the reasons for the frequent servicing suggested in the Boeing study is to keep film in orbit for as short a time as possible. This is considered necessary because film in orbit is particularly subject to radiation damage, and astronomical film must be kept as clear as possible.

Another, and most important, EVA is that of rescue, a concept that has been very much neglected. Special studies will undoubtedly uncover particular requirements. An EVA work platform equipped with power manipulator arms, extra life support, and a large assortment of space tools may play a valuable role.

III. REASON FOR MOCKUP CONSTRUCTION

Among the several reasons for attempting a mockup of the orbital work platform at this early stage, the principal ones are that the mockup will: (1) be necessary because it is an example of extreme man-machine integration, (2) reduce arbitrarily the number and variety of contending designs, (3) serve as a focus for discussion, (4) give a first look at its engineering feasibility, and (5) be useful in future studies.

A work platform represents a most compact man-machine integration. It must sustain the life of the astronaut, convey him to and from his work, and facilitate his work to the greatest possible degree. No features other than those that will increase the efficiency of the astronaut have been considered in its design.

The design approaches mentioned in Section IV also indicate that a mockup demonstrating the chosen design should be available as soon as possible. That the orbital work platform be presented in an easily understandable form to those concerned with all aspects of future missions requiring EVA is made necessary by the widely different uses visualized for it. Therefore, the reasons for the complex integration required in EVA mission planning will be introduced in discussions of the selected design.

Many of the concepts included in the selected work platform are not space proved. The mockup provides a first look at the difficulties presented by including these untried concepts in a spacecraft.

The mockup itself can obviously be useful in determining such factors as placement of instruments, controls, and illumination. It can be physically used and modified for perfecting the final design.

IV. CONTENDING DESIGNS

Two principal approaches suggested themselves during the design study. One resembles a skeletal telephone booth, to the structural members of which the various subsystems needed for a particular mission could be fastened. Several advantages can be claimed for this design, the main one being its extreme simplicity of construction.

The second approach consists of a basic "backpack" which furnishes the propulsion, communication, navigation, and stabilization that are always needed. To this backpack, modules can be attached successively so as to eventually provide a floor for the astronaut's feet if required. Such a platform can be assembled with modules to satisfy any particular mission requirement, and for this reason it was chosen for the mockup (Fig. 1).

There is a third design approach which, although it was not considered, it should be mentioned in any review of the problem. It consists of having the work platform designed and built by the contractor responsible for the mission in which the platform is expected to be used. Thus, when a contract is let to orbit a telescope that has an aperture larger than 100 inches, the contract would also require the design of a tailored-to-fit maintenance unit. (Such a concept should be the subject of a tradeoff study and may depend on what other missions are in orbit, and on the value of the telescope and its expected life in orbit.)

V. DESIGN CONSIDERATIONS OF BACKPACK

In the design that was selected, the backpack forms the basic minimum element that will sustain the astronaut. As such if must provide

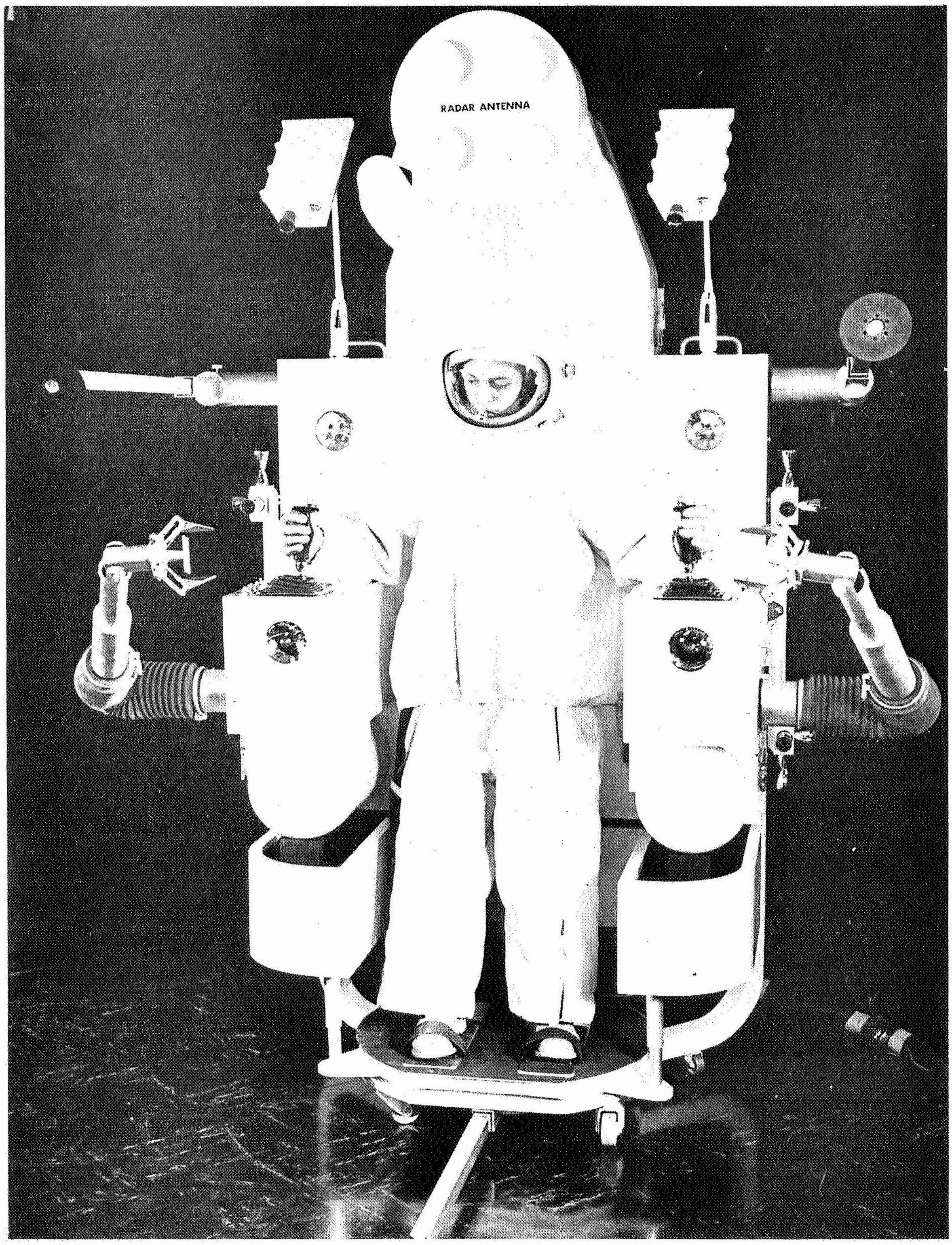

Fig. 1 ORBITAL EXTRAVEHICULAR WORK PLATFORM WITH MODULES ASSEMBLED

adequately the capabilities of: (1) propulsion, (2) life support, (3) communications, (4) TV monitoring, (5) electrical power, (6) illumination, and (7) manipulators. These capabilities have been provided in the mockup design as discussed in the following paragraphs.

A. Propulsion

The astronaut requires enough propulsion to navigate between the mother ship and his work several times during an eight-hour work period without his having to pause to refuel. A backpack weighing 800 pounds and carrying a 200-pound astronaut is provided with 50 pounds of hydrazine for a velocity change (ΔV) of about 300 ft/sec.

B. Life Support

The life support concept requires that the astronaut be capable of leaving the work platform. Consequently, he wears the Portable Life Support System (PLSS), for which a recess is provided in the backpack. At the time of this writing, the PLSS provides life support for a duration of four hours. In order to extend this period to eight hours, the backpack carries additional oxygen and lithium hydroxide. (The exact method of topping-off the PLSS or switching the circulation of the astronaut's atmosphere has not been investigated, but it is not expected to present any great problem.)

C. Communications and TV Monitoring

The communications subsystems provide for main and spare voice channels, astronaut-monitoring telemetry channels, and two video pickups. The video pickups are capable of remote control by the monitoring astronauts or scientists on the mother ship. The pickups are intended primarily to monitor the astronaut when he is out of visual contact. Two pickups are provided, so that any work the astronaut may perform in front of the work platform can be monitored. The work platform, without additional modules, has a work capability probably limited to inspection missions.

D. Electrical Power

Ample electrical power is provided by means of batteries that are recharged at the end of each mission. If a quick turn around is required, a fresh power pack may be inserted when the used one is removed for recharging. The turn-around time should not exceed that required for replenishment of life support expendables and for refilling the hydrazine tank, or tanks, and the associated nitrogen pressurizing system.

E. Illumination

Under certain conditions, depending on orbital characteristics and the orientation of the work site, the working astronaut will not be illuminated by the sun. For these conditions, artificial illumination must be provided. This is accomplished in part by lights located on the surfaces of the backpack, and, in addition, the TV cameras are provided with their own lights.

F. Manipulators

The best location for the manipulators, although they are not needed on all missions, is on the backpack. In this position, they can serve as temporary anchors for the backpack, and can hold cargo to be transported or can support work in front of the astronaut. The anchoring arms can be extended some six feet to provide ample working room in front of the astronaut. Their extension capability also permits the astronaut to attach the backpack to a surface, after which he can exit from and return to the work platform with ease at the end of a tether or umbilical.

VI. SELECTION AND DESIGN OF MISSION-ORIENTED MODULES

A guiding concept throughout the study has been that of a basic unit (Fig. 2), the backpack, equipped with the necessities discussed in Section V, augmented by modular designed units the contents and purpose of which are determined by the particular space mission.

Although it is certainly not possible to determine all future orbital missions at this time, a selection can be made of a representative number of module types. One such selection is: (1) long-range rendezvous, (2) additional propulsion, (3) tools and repair hardware, (4) communications, (5) rescue, (6) heavy electric utility, and (7) cargo (film, instrument packages).

A. Design and Placement of the Long Range Rendezvous Module

Typically, the mother ship would be only a few hundred, or a thousand, feet distant from the satellite where the work has to be performed. Hence for the majority of missions, the target (larger than a Gemini capsule) will be well within visual range and the simplest type of rendezvous will suffice. However, owing to differences in their ballistic coefficient and because of the fuel conservation requirement, station-keeping may be reduced to one or two efforts a year, and the two satellites may then drift apart. In such cases, the distance can increase to a point where visual rendezvous becomes uncertain and hence hazardous.

Some method of long range detection and tracking in relative azimuth and elevation must be provided. The interferometer-type radar (shown

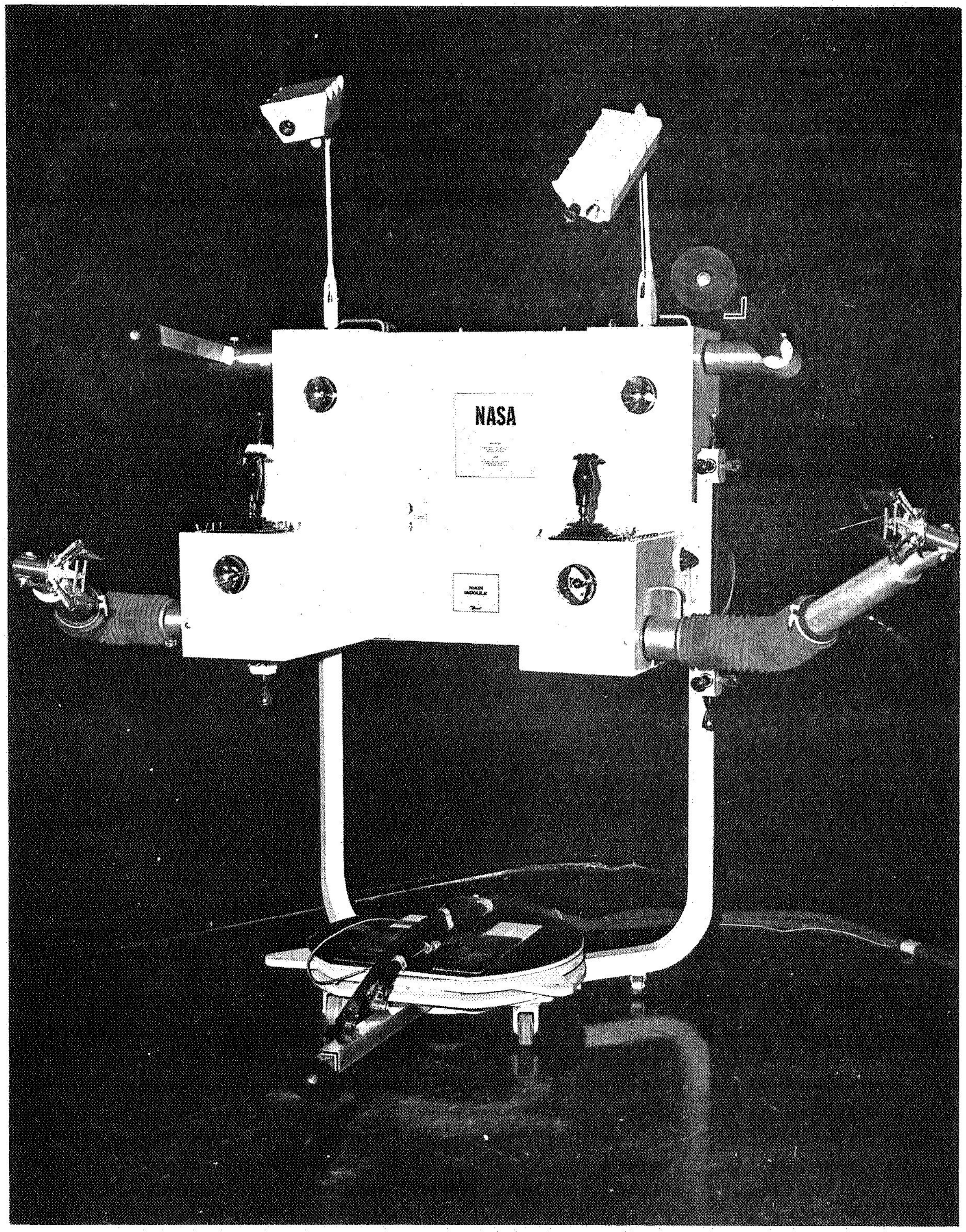

Fig. 2 BASIC BACKPACK UNIT (LEGS FOR MODEL SUPPORT ONLY)

in lower center of Fig. 3) used in the Gemini missions has been chosen for this job. The four antennas and their ground plane are placed over the head of the astronaut as far forward as possible so as not to interfere with the antenna patterns. One antenna is a transmitting antenna while the other three provide azimuth and elevation bearings. The antennas (metal spirals on plastic discs) are enclosed in protective cups for pressurization or protection. Two of the receiving antennas are rotated so as to provide the direction information. Range and range-rate information are also provided by this radar.

An instrument package for the pilot is pivotable so he can view it directly above him. It contains the radar range-rate information as well as the so-called Q-ball which gives him the target bearings relative to his normal stabilization mode.

In the normally stabilized mode, the work platform is oriented vertically and facing the orbital track. It is anticipated that an on-board computer would use this information in conjunction with the target-bearing and range information to determine the required propulsion direction and velocity change. (Such a computer is only 2-1/2 inches thick and occupies only a square foot of surface.) The propulsion direction and the velocity change would be implemented automatically on command from the astronaut. The astronaut would then resume autonomous propulsion control for a final docking or inspection maneuver.

The radar rendezvous range with a transponder on the target, is 250 miles. Such a transponder weighs some 14 pounds. The work platform would carry both the radar and a transponder in order to have a redundant homing capability on the mother satellite, which would also have comparable equipments.

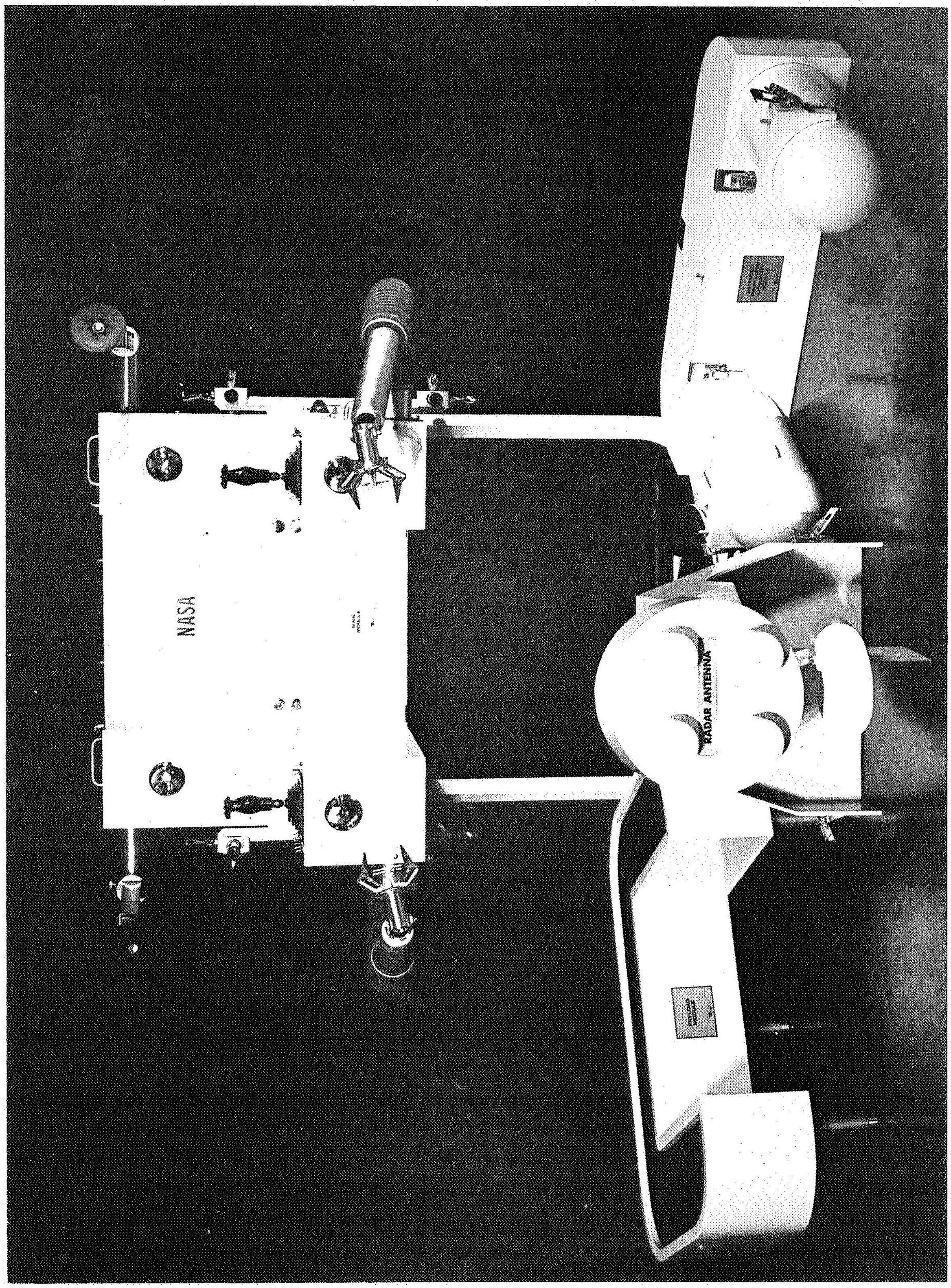

Fig. 3 BASIC BACKPACK WITH THREE SNAP-ON MOUNTINGS

Handles near the radar-module fasteners are used to react the force applied in operating the fasteners that secure the module to the backpack.

B. Extra Propulsion Capability Module

There may be tasks, such as space station assembly, that require the work platform to propel and position large and sometimes massive hardware in orbit. For example, such is the case if a station is assembled from Saturn V second stages. Under these conditions one or two extra fuel modules can be attached beneath the main backpack (shown in right of Fig. 3). Each of these modules contains two tanks, each with 60 pounds of hydrazine, and nitrogen pressurizing for 3000 psi of regulated hydrazine-delivery pressure. The tanks have integral bladder expulsion mechanisms for zero-G conditions.

When two fuel modules are used, the work-platform has a ΔV in excess of 1000 feet per second. For a mission requiring greater propulsive capability, it is possible to attach a total of three modules to the backpack, or the astronaut must return to the main vehicle for refueling.

The thruster assemblies on the two sides of the work platform are servo-connected to the stabilization system so that their position is adjusted with respect to the center of gravity of the platform. (If this were not so and the center of gravity were offset with respect to the center of translational thrust, one set of thrusters would have to pulse more frequently than another in order not to propel along a curved path. Fuel would not be wasted, however, unless a thruster had to be pulsed contrary to the heading in order to counteract the torquing force.)

C. The Tool and Repair Hardware Module

In the early 1960's, the concept of special tools required for work in space was developed. Some companies have had contracts to develop such a class of tools. The main characteristic of the tools developed for this purpose is minimal reaction force, so as to enable the astronaut to work without having large forces that must be reacted upon his work ground plane through a restraint system.

The particular type of tools transported in the module (shown in left of Fig. 3) depends upon the kind of mission, and they may be of special design for particular situations. Such tools are exemplified on earth by the many special ones required to work on particular automobile engines. Typically, special tools would be ones designed to extract and insert electrical subassemblies, since actual repair involving component disconnection and replacement would be rare because of the astronaut's poor dexterity.

At the present time, the National Observatory at Tucson is remotely operating a 50-inch reflecting telescope at Kitt Peak in Arizona, yet the telescope requires regular maintenance at the site because it was designed with more or less standard components. Therefore the changing of instruments at various optical foci, and the regular inspection and lubrication schedules are constant chores. To adapt such an instrument to remote usage in space will require extensive earth experience, and it is to be borne in mind that anyone servicing the Kitt Peak remote telescope must record this experience as the equivalent of an EVA mission.

In the mockup, the tool module is rotatable to make it easily accessible in front of the astronaut. The interior of the module would contain the tools and materials required on a mission, together with means for securing them in zero G while the astronaut alternately uses them during his work.

D. Design Considerations of Communications Module

The main backpack is well equipped with communication channels in voice, telemetry, and video. There may be missions which require additional channels, in which case, a communications module would be added to the backpack. Missions requiring the additional channels might include inspection of a satellite, a work assignment for which an unusual amount of television monitoring is necessary, or a work assignment where telemetry and sensors must be attached and left in place together with a transmitter. (The last of these may be especially true if the cause of some repeated failure must be determined.)

E. Rescue Module Design Factors

Although not constructed for the current mockup, a rescue module should be studied and designed. The type of modular construction and the 250-mile rendezvous range of the work platform concept suggests for it great possible utility as a rescue vehicle.

A rescue module, if it can be quickly connected to and disconnected from the platform, would contain such items as a PLSS unit and a pressurizable bag in which a disabled astronaut could be enclosed so that he can breathe with his helmet open. In addition, special rescue tools that have functions similar to those carried by an earth-surface rescue squad may be necessary.

F. Heavy Electric Utility Module

A module of this type has not been included in the mockup. Such a module was outlined as having a turbo generator power supply using hydrazine from the backpack propulsion supply or, more probably, from a propulsion fuel module such as that discussed in Section V.

Electrical welding is feasible in space and some future assembly tasks may require it. The same feasibility may be assumed for riveting by means of hydraulic pressure or cold welding by means of hydraulic pressure. In all of these cases between 5 and 10 kW of power is required, depending upon the size of the sections to be joined. (Typical of such work would be construction of very large radio telescope assemblies.)

G. Cargo Module (Film and Instrument Packages)

A module can be constructed that will provide for cargo transportations of various types. Thus for an astronomical telescope, film storage that will allow transport of the film with virtual certainty of no radiation damage must be provided.

Other cargo would include whole instrument packages that must be operated outside of a pressurized cabin. Since an important task of the work platform will be that of installing these packages, they would be fitted in a cargo module.

VII. USES OF THE WORK PLATFORM

It is intended that the orbital work platform be as versatile as possible. The astronaut is, in his space suit, free to work away from the platform. The distance he can go is limited by the length of the umbilical power cord. He is always tethered, but he can move the origin of the tether. If he needs power beyond the length of the power umbilical, he must move the space platform.

The manipulators are used by the astronaut as a first anchor; i.e., as he approaches a work site, he uses one of the manipulators to grab some protuberance or edge. He can then delicately position the work platform and attach it by means of anchoring arms (Fig. 4). The manipulators are then free to be used to hold subassemblies in front of the astronaut so that he can work on them under optimum conditions. External metal-coolant radiators, which may be operating at a cherry red heat (some 1500°F), can be unplugged by means of the manipulators while a spare unit is inserted. It is conceivable that some work may require remote controlled operations from the mother ship from which it will be monitored by the TV cameras.

For operations inside vehicles, such as inside a telescope tube, the astronaut would carry a power and communications umbilical. The power umbilical would provide him with necessary lighting. Whether or not he would bring one of the detachable TV cameras would depend upon the job. Of the two television cameras provided, one normally monitors the astronaut while the other observes the work he is performing, however, both can be operated or positioned by the observers on the mother ship. Thus, in delicate repair or maintenance situations, an expert can use them to see the exact spot he requires.

Illumination for casual operations in the shadow of a satellite is provided by the lights on the platform backpack and on the television cameras. Sophisticated illumination devices to provide illumination for complex internal worksites are carried in the tool module. These illumination devices would include fingertip lights as well as diffuse sources of various shapes. When the platform is performing its varied operations, the navigation lights with which it is equipped make possible the observation of its orientation to observers aboard the mother ship, even against backgrounds (such as the earth) that do not allow it to be clearly visible.

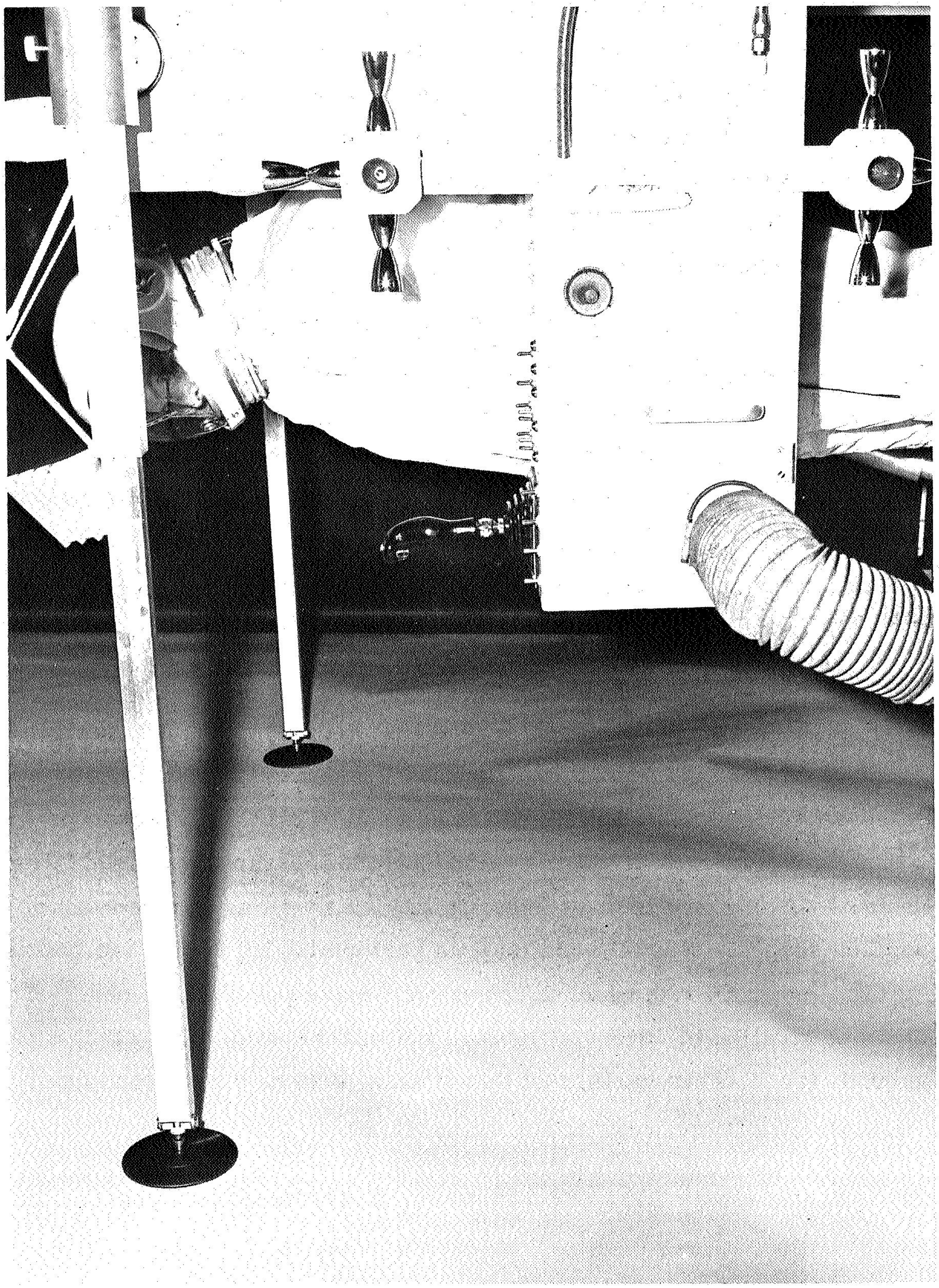

Fig. 4 SIDE VIEW OF WORK PLATFORM, SHOWING ADHESIVE ANCHOR PADS

VIII. RECOMMENDATIONS FOR FUTURE WORK

The mockup should be exploited to the fullest extent in discussions of design. It should be physically useful in deciding upon placement of controls and instruments and in selecting the location of lights for control and work illumination. Future studies should include those parts that the astronaut is expected to reach and adjust, such as the anchoring arms.

The problem of astronaut restraint while working needs a great deal of attention. An articulated framework that would serve as a type of exoskeleton was considered for the mockup but was not constructed. Such an exoskeleton would be electrically firmed on command and would serve to transmit reactions through to the platform, the anchoring arms, and back to the work.

The manipulators require a great deal of development for two reasons: (1) to qualify them for space use, and (2) to improve their dexterity. At the present time, manipulators have little versatility and can perform only specialized assembly or disassembly tasks. The main question at present is, does their use in space warrant the large expenditure that an advance in their dexterity will require?

The problem of anchoring devices requires cooperative design work with spacecraft builders. Also, detailed engineering analysis is needed for the stabilization subsystem. Other recommended development programs (see TG-841, also published as NASA CR 773, for details) are:

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 Boarding and Evacuation Techniques Development

On the more complex side are the requirements for unmanned operations. The exact situations where unmanned operations may be required are not clear, but if remote recall exists, simple unmanned tasks may not be overly difficult to implement while the TV cameras monitor the remotely controlled manipulators.

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13. ABSTRACT

Extravehicular activities (EVA) in space such as inspecting orbiting spacecraft, servicing orbiting equipment (e.g., an orbiting telescope), performing assembly tasks in space, and making space rescues will require an extravehicular work platform. The proposed one-man extravehicular work platform is an example of extreme man-machine integration. A study of the requirements for extravehicular protection and operation for such activities led to the immediate construction of a full-scale mockup of the required type of platform in order that it might serve as a focus for discussion, give a first look at the engineering feasibility of the platform, arbitrarily reduce the number and variety of contending designs, and be useful in future studies. The principal design features of this full-scale mockup are described. Of the contending designs, the one chosen for the mockup was a modularized "backpack" equipped with a propulsion capability, a backup for a portable life support system (PLSS), a communication subsystem for voice and telemetry, a TV monitoring subsystem, a rechargeable electrical power source, and pack-mounted illumination and mechanical manipulators. The basic design can be augmented by special modules to meet the requirements of particular missions.

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