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DESIGN STUDY OF SPECIAL PURPOSE SYSTEMS FOR THE LUNAR SURFACE

Prepared Under Contract NAS8-5307 by

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HAYES INTERNATIONAL CORPORATION
Missile and Space Support Division

For

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

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ABSTRACT

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This report deals with special purpose equipment that will be required to support lunar surface operations with emphasis on the 1969 to 1975 time period. Special purpose equipment as used here pertains to items such as tools; small wagon-like vehicles; portable shelters and shields; emergency devices; etc. Their purpose is to complement the scientific equipment and other systems, specifically LSSM, MFS, MOLAB and LEM shelter.

The pattern of the study was to analyze the missions to determine the support operation and tasks which needed to be performed, then to plot charts of tasks versus equipment. Based on these equipment requirements, conceptual designs were derived. The objective was to provide a limited number of multi-purpose devices which would replace the many items of equipment listed on the charts. These multi-purpose devices and their applications are described in the report. The utilization of existing lunar equipment by rework and conversion is also considered.

The conceptual designs and other items of special support equipment are related to the various lunar mission phases, i.e., LEM, AES, and semipermanent base establishment.

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Propulsion and Vehicle Engineering Laboratory

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PREFACE

This report was prepared by Hayes International Corporation, Apollo Logistics Support Group, Huntsville, Alabama, for the Base Development Group, R-P&VE-AB, George C. Marshall Space Flight Center, under the authorization of Task Order H-34, Contract NAS8-5307.

The NASA Technical Representatives were Mr. J. Rains and Mr. C. Darwin, R-P&VE-AB.

Illustrations for this study were prepared by Mr. K.D. Renfro, and the sketches, and Appendix A were prepared by Mr. Love, NASA, R-P&VE-ABT.

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1.0 INTRODUCTION

This report is issued in response to the NASA sub-task work statement entitled "Design Study of Special Purpose Systems for the Lunar Surface."[1] Generally, the work statement pointed out the desirability of having a variety of small, special purpose devices for mobility, transportation, and other special jobs, such as emergency shelters, to be used as aids in lunar surface base development.

The purpose of the sub-task is to outline the range of potential requirements for special equipment, conceptually outline some general approaches for providing these systems, and to define how the more promising of these devices fits within the AES and subsequent programs with emphasis on the 1969-1975 time period. These items would be of a secondary nature to such systems as LEM Shelter, MOLAB, LSSM, and MFS.

Briefly, the scope of work was:

1. Prepare a skeleton outline of planned and proposed lunar surface systems and mission operations.

2. Outline potential areas where special purpose equipment, of any nature, might be used and show how it would support the mission.

3. Conceptually design certain selected items including weight estimates and integration with mission operations and primary lunar surface systems.

4. Study proposed systems, such as MOLAB, LSSM, MFS, and Lunar Shelters to identify accessories which might at some point be added to accomplish a desired function.

5. Coordinate with other MSFC and Hayes organizational elements for inputs concerning equipment requirements, design, and mission analysis.

Many ideas were generated during the course of the study. Time did not permit a detailed analysis of all the items or even the complete design consideration of those devices which had obvious merits. One of the greatest difficulties was to restrain the effort to the bounds of the study and not encroach on other areas such as design of equipment for scientific experiments and larger systems already under study.

Consequently, the devices presented herein depict equipment for performing the more mundane, but nevertheless important, functions required for lunar surface base development.

Another great difficulty, which is not peculiar to this study, was predicting the nature of the lunar surface. This, of course, would have a great effect on the type of equipment required as well as on the detailed designs of obviously necessary equipment. An attempt was made to present a choice of items from which a selection could be made once the surface conditions are determined; for example, an auger or shaped charge for hole drilling.

In addition, other items are proposed which would be useful regardless of the surface condition. Design modifications would be made to optimize their performance, if required, for specific lunar surface conditions. For instance, the load-bearing capacity of the surface would determine the wheel configuration for vehicles.

Reliability, weight, cost, and the other usual factors were considered in the design derivations as well as the interfacing with the transport modules and their associated payloads.

One significant design philosophy resulted from the study, and stems primarily from the high cost of transporting payloads to the moon. That is, every piece of equipment or material should be designed or selected to perform as many functions as possible after reaching its destination. In other words, there should be little, if any, abandoned equipment. The latter part of this philosophy pertains more to the later stages of lunar base development, since earlier missions will likely be made at widely separated locations of various geological points of interest and equipment landed in previous missions would not be available.

These thoughts are probably not new, but seem worthy of emphasis. The experience of this study has shown that, with a little extra thought and some design variations, a piece of equipment can be made to perform several different tasks or facilitate ease of modifications at a later date to perform some other or additional functions.

2.0 MISSION OUTLINE

2.1 GENERAL

The two primary concerns on all manned missions to the moon will be survival and the successful completion of assigned tasks. The equipment required to insure survival will remain fairly constant for each individual man. The equipment required to carry out the mission operations will vary considerably throughout the various phases of lunar exploration and utilization. In general, the equipment will become larger, more complex, and more numerous. That is, the same or similar special utility equipment used in early missions will also be needed for subsequent mission, plus additional items.

The planned and proposed lunar missions are shown in Figure 1 and are briefly outlined in the following paragraphs. These missions are postulated to establish the types of special equipment that would be used to support varying degrees of lunar surface exploration and the time periods for which they would be required.

2.2 LUNAR EXCURSION MODULE (LEM)

The initial landing(s) on the lunar surface will be very significant, although short in duration. The primary purpose, once on the lunar surface, will be to determine the suitability for further exploration and establish more definitive design criteria for equipment on future missions. Since the mission will be of very limited duration, the tasks and, therefore, the items of special equipment needed,will be few. Because of the short time, however, it is imperative that the few items enhance the man's efficiency as much as possible.

The operations performed during a LEM mission could go something like this:

2.2.1 SITE ESTABLISHMENT

After landing and verifying the suitability of the lunar enviornment for outside exploration, the following tasks exemplify those that could be performed:

Unload equipment

Clean dust and debris from spacecraft and surrounding landing areas

Measure impression of landing feet and settling rate

Measure effects of rocket blast on lunar surface

Deploy marker panels and other signaling devices to assist CM in spotting

Level the ascent stage

2.2.2 SCIENTIFIC TASKS

The following scientific support tasks might be performed:

Carry instruments and containers to desired areas

Drill holes to obtain sub-surface readings and samples

Emplace instruments, telemetering modules, antenna, and mark location

Collect samples, seal containers

Observe and photograph lunar features and celestial bodies

Conduct experiments --- gravity, seismic, etc.

2.2.3 EXPLORATION

The investigation of various lunar features could involve:

Trailmaking and marking

Climbing or descending steep slopes

Spanning fissures

Mapping

Finding future landing areas

Transporting instruments and samples

2.2.4 EMERGENCIES

Emergencies which could arise are:

Pressure leaks --- suit or spaceship

Injury or collapse during exploration

Radio failure

Survival pack malfunction

Micrometeorite storm

2.2.5 CONSTRUCTION

Construction would be very minor and limited to such things as:

Burying or covering equipment

Erecting antennas, beacons

Clearing and marking future landing site

Dust retaining walls

Shade tents

The foregoing tasks are charted versus the equipment required to perform them in Figure 2. This chart was then used as the basis for establishing special equipment requirements and deriving equipment designs which could perform multiple functions.

2.3 APOLLO EXTENSION SYSTEMS (AES)

According to a NASA report, "Extended Lunar Exploration"[3], the concepts for AES can vary considerably. Briefly, the concepts presented are:

2.3.1 STEM

The Stay-Time Extension Module would consist of adding more equipment to the LEM to increase the stay time from one to several days and the mobility radius from one to several miles.

2.3.2 AES

The Apollo Extension System utilizes two launch vehicles: a LEM Taxi to transport two men to the lunar surface from orbit and return them, and a LEM Truck descent stage to land the shelter and/or vehicles and equipment, unmanned.

According to the latest thinking, the basic version of the LEM Truck payload consists of a two man LEM Shelter and one or two small, open, powered vehicles called Local Scientific Survey Modules (LSSM) which would provide 14 days stay-time and a mobility of 16 kilometers for each of several sorties lasting from three to six hours each.[4]

Another version, which probably will occur in later AES missions, depicts the MOLAB as a LEM Truck payload. The MOLAB provides a mobility of several hundred miles with a 14 day stay-time for two men. A manned flying system (MFS) may be included with either version.

The operations to be performed would be similar to those for LEM except on an expanded scale. The two descent stages might require the clearing of two sites and a link between them. As a minimum, the same special equipment and materials as used for the LEM missions would be needed with an increased quantity of certain items such as marker poles, explosives, etc.

Subsequent AES missions would require larger special items. Such things as conversion of LSSM by the addition of inflatable, self-contained cabin systems are considered. Generally, the special purpose equipment would fall between those items required for the LEM and semi-permanent base establishment. The chart in Figure 3 depicts the equipment required for the various tasks and, as with the chart for LEM, was used to establish requirements and conceptual designs.

2.4 SEMI-PERMANENT BASE

One of the important tasks of the earlier missions will be the selection of a site for a semi-permanent and, eventually, a permanent base complex on the moon. Data on the suitability of lunar materials for structures and other uses also should be available from the earlier exploration and would be utilized as extensively as possible in the base facilities and systems. It is likely, however, that nearly all of the material will still be transported to the moon in an almost final form, as was done on earlier missions.

The Lunar Exploration System for Apollo (LESA) proposes landings, with the unmanned logistic spacecraft being a direct flight capable of delivering 11,370 kilograms (25,000 pounds) to the lunar surface. The payload would be a large shelter-laboratory and a MOLAB type vehicle. This system would allow a 90-day stay-time with extensive mobile exploration.

The semi-permanent base could consist of multiple LESA-type shelters with different laboratory-type equipment or central support type systems in each, such as an astronomical observatory in one, a nuclear power generator in another, etc. The following is a partial listing of the various types of facilities and systems which could be found in such a base complex.

2.4.1 FACILITIES

1. Basic living shelters
2. Astronomical observatory

3. Earth TV monitor station

4. Experimentation laboratory analysis and testing of lunar materials and earth materials in lunar enviroment

5. Repair and fabrication shop

6. Medical facility

7. Physical conditioning facility - Exercise equipment, bathing equipment, sun lamps, centrifuge

8. Storage areas

9. Solarium - Hydro-ponic and soil growing of food. Uses waste for fertilizer, CO_2 and O_2 exchange for ESC.

2.4.2 SYSTEMS

1. Power generation and conversion - Solar cells, thermo-electric, thermionic, thermo-mechanical, nuclear, power distribution, battery charging.

2. Environmental control

   (a) Temperature - Heat-pumps, radiators, solar reflectors

   (b) Humidity

   (c) Atmosphere

   (d) Pressure

3. Lighting - Natural: reflectors, diffusers; Artificial: flourescent, incadescent

4. Waste reclamation and disposal

5. Communications - Radio, TV, telephone (sound power)

6. Cryogenics conditioning and handling

7. Pumping - Airlocks, pressurization

8. Automatic landing/launching system - Radar, beacons, doppler, computers

Some of the special equipment requirements that can be envisioned for integrating, linking, and supporting the separate semi-permanent base facilities and operations are listed below:

Road construction

Power and utility distribution lines and poles

Flood lights

Emplacement of heat-pump coils

Interconnecting conveyor pipes

Setting-up an automatic landing/launching system

Shuttle bus between shelters for transporting personnel without leaving pressurized environment

Hoisting and transporting large items

Maintenance and repair of various equipment

Excavation/mining type operations

Processing and utilization of lunar materials

This is a partial listing to cover only those facilities and systems which are likely to occur or be initiated during the early part of a lunar semi-permanent base establishment since the greater portion of this operation lies beyond the time period covered by this study. Figure 4 shows the equipment postulated to support the early phases of semi-permanent base development.

2.5 PERMANENT BASE

Since this phase of lunar development falls well beyond the time period covered by this study, a detailed analysis of special purpose equipment was not carried out. Some general thoughts on the subject are:

1. The type of equipment needed will depend primarily on:
   (a.) The environment, topography, and materials on the moon
   (b.) The type and method of construction to be used
   (c.) The extent to which the base(s) will be developed.

2. The facilities and systems likely to be established would be similar to those listed for the semi-permanent base.

3. The method of sheltering these systems, facilities, and personnel would be different. Lunar materials would be used for optimum meteoroid, radiation and thermal protection. One of the most obvious ways of using the natural materials is by tunneling beneath the surface or into the side of a mountain. The latter appears more attractive since mountains would likely be composed of more solid material and would be clear of surface dust.

Needless to say, a much better insight to the problem will be attained as data from the preceding missions becomes available.

2.6 SUMMARY

As a result of the above, the items of special equipment were separated into categories of tools, vehicles, instruments, materials, and miscellaneous. They are further grouped as small, medium, and large and are presented in Tables I, II, and III respectively.

Selections were made from these lists of the items for which new concepts were desired. These concepts are presented in the following section.

TABLE I

SMALL EQUIPMENT

(for LEM, AES, LESA)

Tools	Vehicles	Instruments	Materials	Miscellaneous
Broom	Scooter	Transit	Reflective and/or Colored Cloth	Umbrella-Shield
Shovel	Tricycle	Scale (Weighing)	Tubes	Germicides
Pick/Hammer	Wheelbarrow	Volume Measurer	Stakes	Medicines
Pry Bar	Wagon	Calipers	Rope	Special Clothing
Hacksaw	Sled	Fractures/Hardness Test	Wire (Electrical)	Stilts
Hand Drill/Bits		Microscope	Sheet Metal	Snow Shoes or Skis
Chisels		Geiger Counter	Fasteners	Mountain Climbing Gear
Soldering Gun		Multimeter	Chemicals	Explosives
Tongs-Pliers		Camera	Turnbuckles	
Hooks		Chronometers	Couplings	
		Thermometers	Adhesives	
		Tape Measure		

TABLE II

MEDIUM EQUIPMENT

(for AES, LESA)

Tools	Vehicles	Instruments	Material	Miscellaneous
Welding Equipment	Motor Scooter	Metal Detector	Glass, Mirrors	Solar Furnace
Jacks-Mech/Pneum.	Rockets	Sound Power Telephones	Sealers	Food
Drilling Rig	Tug	Pressure Gages	Beams	Water
Jack Hammer	Fork Lift	ECS Monitors	Flooring	Flood Lights
Stone Cutter	Trailer	TV Monitors	Generators	
Ladder			Pumps	
			Tubing, Pipe	
			Wiring	
			Fuel	
			Fittings, Valves	
			Filters	

TABLE III

LARGE EQUIPMENT

(LESA, Permanent Base)

Tools	Vehicles	Instruments	Materials	Miscellaneous
Machine Tools	Dozer/Grader	Spectrometer	Air Locks	Heat Pumps, Fans
Mining Tools	Truck	Radar	Domes-Transparent	ECS Equipment
Processing Equip.	Diggers	Automatic Controls	Batteries	Centrifuge
		Computers	Battery Charger	Lighting System
			Elevator	ILS/T.O. System
				Hydroponics
				TV - Closed Circuit
				Recreational Equip.
				Recovery of Combustion Products from Rockets

3.0 CONCEPTS

As stated previously, the lists of equipment presented thus far were not meant to infer that each of these items should be used to support lunar operations. Rather, they formed the basis for deriving a few items of multi-purpose equipment which would perform the required functions. This was not always possible. Those items which already exist and are directly applicable to lunar operations are included in the final list of proposed equipment. Such items might undergo detail design changes to better suit them to lunar operations, but the basic concepts are directly applicable and, therefore, are not presented as new concepts here. Some examples are shaped charges, transit, flashlight, etc.

Numerous conceptual designs and ideas were generated, but only those items that seemed particularly unique and practical are presented. The proposed application of the special purpose equipment to the different mission phases is shown in Figure 5. Some of these items are referred to by the nicknames assigned for identification purposes in this report. The items are described in the following sections.

In addition to the assistance and suggestions provided by the NASA Base Development Section in the periodic review meeting, the sketches attached as Appendix A at the end of this report also were furnished by them. The appendix is a pictorial summary typifying various small lunar vehicle configurations and other ideas culminating from previous efforts and recent ideas applicable to this study.

3.1 TOOLS

3.1.1 SMALL TOOLS AND UTILITY BELT

The general type of tools that can be used are shown in Figures 6 and 7: a sample pouch, a tape rule, a battery flashlight, a knife tool hook, a repair kit, a saw, a hammer, and a utility belt. Two portable electric space tools, (PESTs) to be utilized are a battery operated, motor driven drill with drill bits, and a portable electric, battery-operated, multi-purpose space tool.

3.1.2 COMBO

The COMBO (combination tool) is pictured in Figures 8, 9, and 10. The basic tool is a combination pick, shovel,and pry bar. A choice of attachments, as shown, renders it applicable to other functions, most of which are self explanatory. Snap locks provide quick alteration to the various configurations. A rope or cord would be attached to the handle when used as a grappling hook with the pick and shovel extended and the grapple attached at right angles to them. Relatively deep drilling can be performed by adding the extension shaft as the bit progresses into the ground.

The basic device would be fabricated from tool steel and would weigh 7.0 kilograms (15.4 pounds) without attachments. The various attachment weights are listed below:

Handle	0.1 kg	(0.22 lb)
Auger	0.45 kg	(1.00 lb)
Chisel	0.45 kg	(1.0 lb)
Tamper	3.60 kg	(8.0 lb)

Sledge	4.5 kg	(10 lb)
Grapple	0.9 kg	(2.0 lb)
Posthold Digger	0.9 kg	(2.0 lb)
Extensions	1.18 kg/m	(0.8 lb/ft)

3.1.3 FORK LIFT

During the scientific mission and lunar base establishment, many occasions undoubtly will arise when equipment must be moved from one area to another. For this purpose, a lift that will be capable of lifting, hoisting, jacking, and transporting equipment has been designed (see Figure 11). The overall size of this lifting device is 76 x 76 x 183 centimeters (30 x 30 x 72 inches), and it has a weight of 90 kilograms (200 pounds). The design consists of two vertical columns tied together at the top with a header and at the bottom with a gear-drive base. Removeable swing legs are attached to the columns to provide lifting and transporting capabilities. Between the vertical members is a carriage that rides up and down through the use of eight rollers. The carriage is driven up and down with a ball-screw and ball-nut assembly unit. A worm and worm-gear drive is directly fastened to the ball screw and is capable of accepting the axial thrust caused by the exerted load. The gear box is driven by a hand crank through universals and a drive shaft.

The carriage has two useful sides, each with five slots. The four outer slots are used to hold the fork-lift fold-away arms, and locking an arm in the center slot will provide a device to jack up or hoist equipment. A hoist hook can be placed in the center of the fold-away arms so that it could lift hardware that has a sling or nylon rope attached. Two wheels are provided at the bottom of the structure so that the lift may be rolled into position for lifting and also so that the complete unit may be converted into a push or pull cart. For moving from one place to another, items must be loaded onto the two swing legs. These legs can be removed and stowed in a vertical position as shown in Figure 11. The basic super structure is made of aluminum and the drive mechanism ismade of stainless steel. The lift will provide five feet of travel.

The Travois also is readily adaptable to a fork-lift type mechanism through the addition of a crank, a winch, and the Travois ladder. See Figure 22 for a visual description.

3.2 VEHICLES

3.2.1 TRAVOIS

One of the most promising concepts to come out of this study is the Travois. This name was chosen because the initial concept was a simple device to aid in transporting equipment, similar to the travois used by the American Indians. By expanding this basic concept, a versitile, multipurpose vehicle and tool was obtained.

Figures 12 and 13 depict the configuration and design features. The size was dictated primarily by those dimensions required for carrying or covering a space-suited astronaut with back-pack. The basic material is magnesium, with steel applied in those areas where added strength and abrasion resistance is required. The estimated weight, using these materials, is 39.1 kilograms

(86 pounds) or, on the moon, 6.52 kilograms (14.35 pounds). This weight includes 10 D-size, rechargeable batteries.

The primary function of the Travois is to serve as a carrier for the many items of equipment that the astronaut will have to carry in the course of his walking traverses and performance of scientific tasks. In addition, however, the Travois is capable of performing many other functions. Some of the many applications are shown in Figures 14 through 22. Adjustments to the various configurations shown can be accomplished quickly since spring-loaded, snap-lock pins are employed for positioning the tailgate/scoop, wheels, and ladder. Collet-type, friction locks are used for positioning the handles. The handles and the spotlight can be removed from the ladder and attached to the body of the Travois or used separately.

The equipment box is to be used to carry small items and also to provide for the attachment of devices such as winches and reels for wire laying. Mounting points also are located in other positions for attaching fixtures such as a push broom or roller as a part of or in place of the tailgate/scoop.

A more extensive adaptation is shown in Figure 22, where conversion to a hand powered fork lift has been effected. This was accomplished by the addition of:

1. an adapter to attach the ladder
2. a sliding adapter for mounting the tailgate/scoop on the ladder
3. an adapter for attaching the pulley system and cable guide to the top of the ladder
4. a hand winch with cable mounted on the equipment box

The additional pieces weigh 7.6 kilometers (16.75 pounds). An extended lifting height of approximately 3.35 meters (11 feet) can be obtained by adding another ladder in series with the one ladder and using a longer cable. Obviously, the fork lift arrangement also can serve as an overhead hoist.

Another variation of the Travois, which has not been fully explored, is accomplished by the addition of a small power pack. Some of the apparent uses would be to drive the winch described above, to serve as a drilling rig attachment, or to provide limited mobility. The latter item is envisioned as providing an assist to the astronaut in pushing or pulling the Travois up grades or over rough terrain. A limited riding capability would be available in emergencies, but not to the extent proposed for the MULE described in a later section.

Some growth potentials of the Travois are covered in the sections describing the MULE and CAMUL.

3.2.2 MULE

The Travois can be converted to a mobile carrier by adding a seat, power pack, steering mechanism, tail skids, and replacing the wheels with larger, motorized wheels. The net weight increase is estimated at 82 kilograms (180 pounds) for a total vehicle weight (less man) of 93 kilograms (205 pounds). The lunar weight would be 15.5 kilograms (34.2 pounds). A large contribution to the vehicle weight is the 22.7 kilograms (50 pounds) power pack. This weight of sealed, rechargeable, Ag-Zn batteries would provide approximately 500 watt-hours of energy.

Two views of the MULE are shown in Figure 23. As can be seen, most of the weight is well forward over the driving wheels for better traction. This also leaves considerable room in the rear of the bed for equipment or another man.

One of the deployable shields or covers described in another section could be attached for micrometeorite protection and/or shade, if necessary.

An extended mobility range, as well as cargo carrying ability, can be realized by pulling a trailer with additional power packs and life support back packs behind the MULE. This would also be true for other lunar vehicles (LSSM, MOLAB).

3.2.3 CAMUL

The CAMUL (cabin MULE) is shown in Figure 24. This configuration is obtained by attaching a self-contained, semi-inflatable cabin system to the MULE vehicle. This same concept could be applied to other lunar vehicle designs, such as LSSM.

The inflatable portion of the cabin would be made of a sealed fabric material with double walls and stress hoops evenly spaced. The double wall construction allows continuous pressure to be applied to prevent cabin collapse when the inner volume is evacuated for airlock operation. Aluminum hemispheres close each end of the cabin with the access door and viewing port forming a part of the rear hemisphere. A transparent dome provides visibility for steering and observation. The forward hemisphere contains sealed interfaces and linkages for the steering mechanism and oxygen pressure tank attachment. Instruments would also be housed here.

This concept uses the whole cabin as an airlock, although there is room for an intermediate pressure divider and door which would permit using only the rear portion of the cabin as an airlock.

The inner volume of the cabin is 1.68 cubic meters (60 cubic feet) when extended to the 2.9 meter (9.5 feet) length. The cabin can be collapsed to 1.1 meters (3.6 feet) for storage. The estimated weight of the cabin system and empty O_2 bottle is 33.1 kilograms (67.3 pounds). The O_2 bottle provides 28,320 cubic centimeters (1.0 cubic feet) of volume and would contain approximately 4.1 kilograms (9 pounds) of oxygen.

3.2.4 MAN-POWERED TRICYCLE

There seems to be some question as to the need for a vehicle which is smaller than the Local Scientific Survey Module, but which would provide mobility capacities greater than that of the walking astronaut. Figure 25 illustrates a suggested design for such a vehicle, called a Man-Powered Tricycle. This design has three wheels that are attached to a torsion bar chassis. The one front wheel is in the shape of a long cylinder, and is 30.5 centimeters (12 inches) in diameter and 91.6 centimeters (36 inches) long. (A wheel of a larger diameter will be considered for future studies.) It is mounted on a fork which is foot-steerable. In the rear are two wire-spoked wheels that are 91.6 centimeters (36 inches) in diameter, and 30.5 centimeters (12 inches) wide.

The rear wheels are connected to the rear axle and are driven by an oscillating arm,quick-return crank type mechanism. This mechanism is powered by the astronaut through hand pump lever linkage. The driver is seated and strapped in so that he can provide push and pull power required for mobility.

The entire tricycle is 152 x 213 x 140 centimeters (60 x 81 x 55 inches), a size which will readily fit into the payload envelope. The module weighs 36.3 kilograms (80 pounds). It was designed to requirements presented in the ELMS report. The materials selected for this module were aluminum and steel; the aluminum is used for the superstructure and the steel for the internal drive mechanism.

The advantages of this specific design include the factors that no fuel is needed to power the vehicle, it can haul other equipment through the use of a hitch attachment, it can furnish the necessary exercise that a man should have under the influence of one-sixth g, and it will consist of fewer parts, such as brakes, etc.

3.3 SHELTERS

3.3.1 INFLATABLE SHELTERS

A preliminary design analysis indicates that a cross sectional thickness of one inch will meet the immediate needs for a shelter. The shelter wall will consist of an exterior wall of 0.152 centimeters (0.060 in.) of white silicone rubber, a 2.29 centimeters (0.90 in.) layer of insulated urethane foam, a 0.076 centimeters (0.03 in.) matrix of a stress filament with a polyurethane, elastomeric compound and a 0.025 centimeters (0.01 in.) internal gas pressure seal, butyl rubber wall. The first two layers will act as a micrometeoroid bumper, the filament layer will provide the necessary structural integrity, and the internal layer will seal the shelter against oxygen pressure leaks. Figure 26 illustrates a typical inflatable shelter wall cross section where the internal cabin configuration is pressurized at 3.5 to 4.0 psi.

Another shelter design presents a pressurized wall construction generally utilized as an emergency facility, shown in Figure 27. The wall cross section is 2.54 centimeters (one inch) thick and consists of an inner and outer wall both of which are tied together with a tension membrane to prevent wall separation. In this design the wall is pressurized until the shelter stands erect. The floor is constructed in the same manner; however, it is much thicker in order to support the weight of two men and their equipment. This shelter is capable of standing erect with or without pressurization of the inner cabin. A zipper with a pressure-seal type lip is provided around the door. In emergency service, the zipper is closed and the cabin is pressurized to 4.0 psi. The two-man emergency medical tent weighs 45.4 kilograms (100 pounds), has an expanded internal volume of 47.6 cubic meters (170 cubic feet), a stowage volume of 8.4 cubic meters (30 cubic feet), and a stowed size of 0.61 x 0.762 x 1.83 meters (2 x 2½ x 6 feet).

The single man emergency medical tent is shown in Figure 28 and is part of the astronauts' sortie equipment. In the stowed or rolled up package, the tent is 61 centimeters (24 inches) long by 30.5 centimeters (12 inches) in diameter and weighs 10 kilograms (22 pounds). The package contains several oxygen bottles, an air bottle, a suit repair kit, and an emergency signal control device. The tent is constructed in the same manner as the two-man medical facility.

This tent will provide protection for the astronaut in the event that his suit should be damaged. It will have sufficient oxygen and oxygen pressure for him to remove his visor if he should feel ill. Air (oxygen) is used to inflate the outer walls of the tent, then the man slides in, closes the zipper, and fills the interior with oxygen. He then is in a position to make the necessary suit repairs.

3.3.2 COLLAPSIBLE SHELTERS

In addition to providing shelter for astronauts, it also is important that equipment be protected from the lunar environment. These enclosures, called collapsible shelters, could provide protection for both. They are large in volume and small in weight, and, as shown in Figure 29, they are designed in various shapes so as to conform to the equipment contours and lunar stowage needs. The general construction is such that the outside material is an aluminized mylar supported at various intervals with metal braces of a scissors-type assembly. When the shelters are expanded, they will serve to protect equipment from the lunar dust, solar energy and radiation, and micrometeoroids. However, in order to protect equipment from the latter, lunar soil must be added around and over the shelter.

3.3.3 SHIELDS

In the category of shelters and shields, several other designs are presented which will protect the individual man from micrometeoroid showers during sorties. An extendable shield (buggy type) is shown in Figure 30. This shield is 0.686 meters (2.25 feet) wide, 0.838 meters (2.75 feet) high, 1.77 meters (5.8 feet) long, and weighs 12.2 kilograms (27 pounds). The shield segments are formed from 1.27 millimeter (0.050 in.) aluminum sheet (2219T87) and will fold into a package whose size is 39.6 X 91.4 X 94.5 centimeters (1.3 X 3.0 X 3.1 feet), as is shown by the cross-hatched section.

Another configuration is shown in Figure 31. This shield is extended around the astronaut while he is in the seated position. The cross section of wall shows an outside thickness of 1.52 millimeter (0.060 in.) aluminum, an insulating material thickness of 10.7 millimeters (0.42 in.), and an internal wall thickness of aluminum of 0.51 millimeters (0.02 in.). This package will be 24.2 kilograms (53.2 pounds) earth weight, and 4.0 kilograms (8.8 pounds) lunar weight. The expanded size will be 0.91 meters (3 feet) in diameter, and 1.07 meters (3.5 feet) high. The collapsed shield, as shown in Figure 31, will be J-shaped with a size of 0.46 X 1.07 X 0.49 meters (1.5 X 3.5 X 1.6 feet).

The two shields, when partially extended, can be mounted on the MULE, the man-powered tricycle, or other vehicles for protection while traversing the lunar surface. During blasting operations, the shields could be used to protect the astronauts as well as equipment in the vicinity from flying debris and dust.

The Travois, also, when turned upside down will provide a shield against micrometeoroid storms for one man in a prone or seated position. This application is illustrated in Figure 19.

3.4 MISCELLANEOUS EQUIPMENT

3.4.1 MARKER POLES

Marker poles were initially conceived for trail and site marking in the event the lunar surface is covered by a relatively deep dust layer. They could also be used to support flood lights, antennas, power and/or communication lines. In this case, a heavier pole would be required. Telescoping poles are proposed for compactness in storage and transporting. Two versions of the pole are presented.

The first is a very light-weight (magnesium) pole 1.9 centimeters (3/4 in.) in diameter by 1.53 meters (5 feet) long, which would extend to a height of 4.9 meters (16 feet) above the surface. It would weigh 0.366 kilograms (0.8 pounds) and would be manually emplaced.

A larger version is shown in Figure 32, and would have greater structural capacity. It is 7.6 centimeters (3 inches) in diameter by 1.9 meters (6¼ feet) long and would telescope to a height of 4.6 meters (15 feet) above the surface.

Its weight is 2.46 kilograms (5.42 lbs). It would be emplaced by activating an explosive cartridge which would drive the 0.6 meter (2 feet) spike into the lunar surface. In the case of a very hard surface, small shape charges could be used to form the emplacement holes. Some typical marker pole applications, such as trail and instrumentation sites marking, are depicted in Figure 33. The lines strung between the poles provide power for lights, instruments, and battery recharging. A switch in the pole light circuit at the shelter would allow visual signalling with the lights. An alternate use for the line would be as a telephone circuit. This would reduce the power required for communications or would be a back-up system.

3.4.2 UTILITY ROCKETS

Small missiles or projectiles could perform many useful functions, particularly for emergency or back-up modes of operation. Some of the obvious uses are as signaling devices and quick delivery of written messages or small articles such as tools, medical supplies, or lunar samples. Other applications will be enumerated below.

The two most likely methods of propelling the projectiles are the use of rockets or firing from guns. Each method has certain advantages; however, rockets are favored because the infrequent use of these devices would not warrant the development cost nor delivery weight of gun type launchers. If other uses for a gun-type launcher could be shown, such as for drilling or riveting, then the gun should be reconsidered.

Figure 34 typifies a missile configuration. The sections are integral, interchangeable modules so that the building block technique can be used to achieve the appropriate assembled configuration for a given application. For example, a signal missile would be composed of:

1. A spiked-nose section for stand-off from the surface upon impact.

2. A payload section consisting of a prepackaged pyrotechnic or pressurized, colored gas display which would be released during flight along the trajectory and continue to eject upward for a period after impact.

Besides the visual signal, an audible signal in the form of a radio beeper or tone from a small transmitter in the missile would alert the astronaut on the receiving end to look for the visual signal.

Since the signal missile could be used because the receiving astronauts' radio receiver was out, he also would not hear the missile-transmitted signal. Therefore, a better audible (vibration) signal would be the detonation of a small explosive charge in the spike tip just after the spike penetrates the lunar surface upon impact. This method of alerting the man to look for the visual signal would depend on the propagation characteristics of the lunar surface.

Various sized rockets could be used depending on the application. A typical rocket would be 12.8 centimeters (5 inches) in diameter by one meter (39 inches) long. The rocket motor and nozzle would account for about half the length and would weigh about 10 kilograms (22 pounds) of which 7.4 kilograms (16 pounds) would be solid propellant fuel. The weight of the forward sections would be 0.73 kilograms (1.6 pounds) depending on the configuration being applied plus any added cargo weight.

Propulsion would produce around 45 kilograms (100 pounds) of thrust for several seconds. Velocities in the region of 152 to 305 meters/second (500 to 1000 feet/second) would be attained with the range depending on the launch angle. A simple tube or rail-type launcher would be used with spin-up of the rocket prior to launch as a consideration for stabilizing the missile during flight.

Figure 35 depicts various applications for utility rockets. The simpler versions would use only the initial pointing azimuth and elevation angle for achieving the desired range and direction. More complex versions could employ wire or radar guidance with jet vane or fluid injection steering devices.

3.4.3 ANTENNA

An applicable existing antenna mast design which can be used on the lunar surface weighs 29.1 kilograms (65 pounds) and extends to a height of 22.86 meters (75 feet). This antenna has been designed for the Army and can be erected by two men in a short time.[8] Figure 46 depicts the erection method and the assembled mast arrangement. There are fifteen sections to the tubular mast plus nine mast guy-wire cables. Although a parabolic antenna is depicted, other devices may be substituted.

3.5 CONVERSION AND UTILIZATION OF EXISTING LUNAR EQUIPMENT

3.5.1 TRAILERS

Trailers can be fabricated from the abandoned descent stage internal superstructure, tankage and piping. A module of this description is shown in Figure 36. The large, cylindrical, hemispherical-ended tanks are utilized as wheels and are supported by a chassis that is fabricated from the superstructure or the internal bracing members of the abandoned LEM-Truck. To complete the unit, it is necessary to add jack shafts, wheel support and a trailer hitch. Trailers with either 3 or 4 wheels can be assembled, depending on the need. The modules can be towed by a MOLAB, LSSM, or other vehicles.

The trailers will have many uses such as hauling large sections of walls for shelters, replacement tanks, engines, antennas, radiators, and other superstructures.

3.5.2 SHELTERS

After landing, the abandoned LEM-Truck, as shown in Figure 37, can be revamped for utilization as a different type of module. The descent stage can be disassembled by first removing all piping and the tankage, then the inner vertical wall sections. Tools needed in the disassembly process are an electric arc-cutting tool, an electric or battery-powered saber saw, a manual saw, and possibly a bolt remover. The internal descent engine, tankage, piping, and hardware will be set aside in a protected area or enclosure for reusage at a later date. As will be shown, almost all of the components will be utilized.

Figure 38, the modified LEM-Truck, shows a design that may be incorporated into the early LEM-Trucks, or later, the initial lunar landings. This design, if instituted before or during the fabrication of the 20 "Lunar Bugs" which NASA has under contract, would simplify the utilization of the greatest part of the Moon-Landing Vehicle's payload. Figures 38, 39, and 40 show a hinge and hinge-pin design which have been added to the 12 joints of the LEM-Truck. The descent engine can be removed and set aside. The hinge-pins can be removed manually or by remote control; the pins will be used for levers and other purposes. The eight internal wall panels can then be swung toward the outer walls and locked into position. This new dual exterior wall thickness will provide additional mass for more radiation and meteorite protection.

A physical facility module is shown in Figure 4. This design is accomplished by the addition of a dome liner and base plate to the modified LEM-Truck. The roof sections may be of a double thickness cross-section and the floor may be made of a honeycomb wall section with the proper insulation bonded to it. The design can also include such features as environmental control and ingress/egress provisions.

Similarly, facilities for an astronomical observatory, medical, and TV station can be constructed. By inserting a pressurized bladder-wall type structure into a modified LEM-Truck shell, the module can be converted into a useful system, as shown in Figure 42. The pressurized enclosure will consist of a collapsible vertical wall, a floor section, and a top. The top may be transparent or an opaque shell with a small observation blister. Connections for the environmental control system and power supply can be made through an interface panel located on the vertical face of the LEM-Truck. Radiators and solar cells may be added at any convenient location.

Further studies show that by redesigning the LEM-Truck with all pin joints, many different-sized enclosures may be fabricated. One in particular, called a Dodecagon Shelter, is shown in Figure 43. In order to fabricate such a shelter, it is necessary that two or more lunar missions be performed to land LEM-Trucks in or near a predetermined, designated area. These abandoned LEM-Trucks can be partially disassembled for the purpose of refabricating them into shelters. The tankage again can be stored for future usage with other components. By removing several of the pins at the pin-joints, various sizes and various-sided (Figure 44) shelters or modules can be assembled. During the AES missions, additional equipment and superstructures can be delivered for the purpose of completing the shelter module. Upper and lower side walls (panels) can be made from the internal structure of the LEM-Truck. The roof and floor of the shelter can be fabricated from superstructure panels. The floor then is reinforced with support trusses. To provide ingress and egress to the multipurpose shelter, an airlock and hatch door are installed at the bottom of the shelter. After assembly of the shelter, protection from all types of radiation, micrometeoroids, and extremes of lunar temperature can be provided by piling lunar surface material around the shelter.

3.5.3 ANTENNAS

Lunar antennas can be erected and assembled from the legs (landing gear) of the LEM-Truck descent stage. The hinge-pins can be removed from the pin joints which will allow the legs to be assembled in a tripod (LAR) as shown in Figure 45. This arrangement allows for a triangular area at the center from which the antenna mast is extended upward. The mast can be made of thin-walled metal tubing and assembled in a telescoping design. As the mast is raised, the sections will be bolted or will automatically lock into place by the use of a ball detent lock design. The parabolic antenna and mast will be delivered to the lunar surface via one of the missions. Mast concept design could be similar to that used in the state-of-the-art as shown in Figure 46.

4.0 SUMMARY AND CONCLUSIONS

This study was rather broad in scope with numerous and diverse areas available for exploitation. Consequently, it was not possible to investigate and develop fully all of the potentials afforded by the sub-task scope within the time allowed. One of the problems was that of selecting and limiting the coverage so that some of the more promising results could be presented.

The study indicated that many menial or routine types of tasks will be necessary to support the various major tasks and could require a variety of different equipment for accomplishing them. Further, the nature of the lunar surface will influence the types, quantities, and detailed design of the special purpose equipment that will be needed. The number of different items can be reduced by designing items of equipment that perform multiple functions. This same philosophy should be extended to all material to be delivered to the lunar surface.

Generally, special purpose equipment will be small in size and quantity for the early manned lunar missions and will become progressively larger and more numerous for the subsequent mission phases. The extent to which lunar surface bases will be developed, as well as the environment, will have a great influence.

5.0 RECOMMENDATIONS

1. The more promising conceptual designs that have resulted from this study should be carried on through detailed analysis and design, mockup and prototype hardware, testing, and evaluation stages of development.

2. This study should be continued, or subdivided into several studies, to obtain a more detailed analysis of the various mission requirements and concepts of special multipurpose equipment. Some examples of additional studies are:

   a. Studies and evaluations should be made on vehicles smaller than the LSSM, such as the Travois, MULE, tricycle, etc. Considerations for maximum utility, type of power, steering, adaptations, environment, etc., should be investigated more completely.

   b. Further studies should be conducted on the inflatable/extendable structures, cabins, and shields for emergency uses. Also, their application to conversion of existing vehicles, shelters, and other lunar equipment should be explored more fully.

   c. Redesign of the LEM Truck should be considered for the purpose of shelter utilization. All lunar equipment designs should be reviewed from the standpoint of serving multiple functions as is or by subsequent modifications.

d. Additional studies on the types and applications of tools should be conducted. The need for power tools versus hand tools and the type of power to be used should be considered. Investigation of the frequency of use would form the basis for determining this, as well as the quantity and detailed design of a given type of tool.

e. Interface studies are required for determining the package envelope availability, tie-down, deployment and other aspects of physical and functional compatibility with existing and planned designs for other equipment. This is especially true of the Travois, expandable shelters, and other large items of equipment which have been presented in this study.

3. The studies should have continuing effort applied or be periodically reviewed and revised to reflect changes in mission operations, other equipment designs, and information on the nature of the lunar surface.

ILLUSTRATIONS

ESTIMATED SCHEDULE

MANNED LUNAR EXPLORATION & BASE DEVELOPMENT

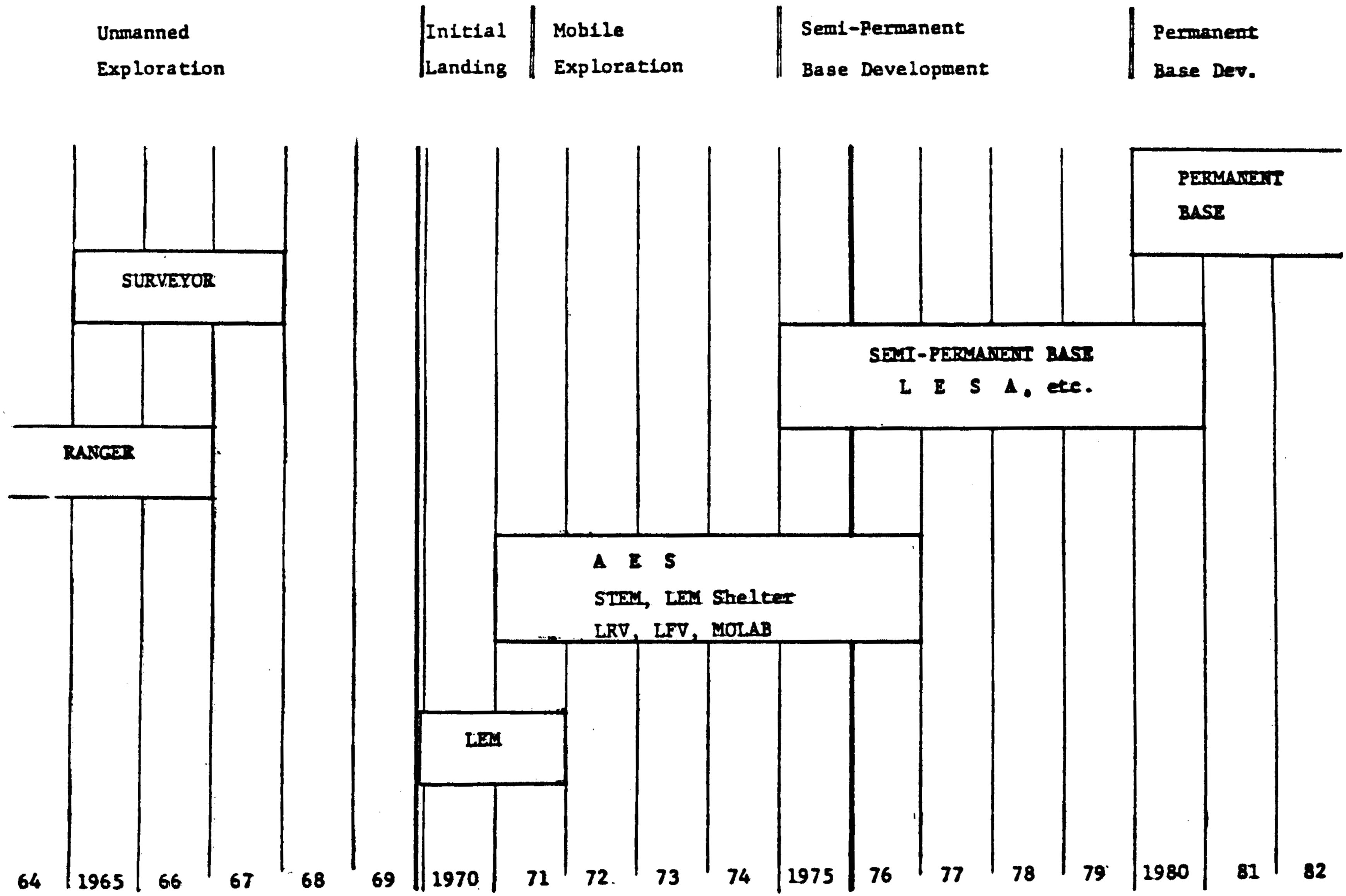


FIGURE 1

TIME - YEARS

	SITE ESTABLISHM'T					SCIENTIFIC TASKS					EXPLORATION						CONSTRUCTION					EMERGENCIES					
EQUIPMENT / TASKS	Clearing	Measuring	Unloading	Marking	Leveling	Instrument Emplacement	Deploy Instr/TLM Modules	Collect Samples	Transport Materials	Mark Locations	Trailmarking	Climbing	Spanning	Observing	Mapping	Hauling	Erect Beacons, Antenna	Shelters	Future Sites	Retaining Walls	Improvise Equipment	Space Suit Leaks	Injuries	Radio Failure	Micrometeorite Storms	Spaceship Leaks	Equipment Repair
Shovel	X						X	X			X							X	X		X						
Broom	X										X								X								
Wheelbarrow	X																		X								
Tape Measure		X				X		X																			
Sling			X					X																			
Sheet Panels				X														X	X	X							
Marker Poles				X						X	X						X		X								
Lever					X			X								X											X
Jack					X																						X
Auger						X	X	X									X										
Pick/Hammer						X		X										X	X	X							
Explosives						X		X									X		X								
Rocket							X						X											X			
Deployable Covers							X			X												X					
Hack Saw								X													X						X
Wagon									X		X					X											
Pathfinder											X																
Ladder			X									X														X	
Cord			X					X				X					X				X			X			X
Grapple												X															
Bridge													X														
Transit				X											X												
Wire							X										X				X						X
Rods/Stakes						X											X	X	X	X	X						
Stretcher																							X				
Flashlight														X										X			
Signal Bombs				X																				X			
Mirror				X										X										X			
Shield																									X		
Patch Kit																						X				X	
Fasteners																					X						X
Hand Tools						X		X									X				X						X
Multimeter						X											X										X
Camera														X													
Containers			X					X								X											

FIGURE 2 - EQUIPMENT VERSUS TASKS - LEM

EQUIPMENT \ TASKS	SITE ESTABLISHM'T					SCIENTIFIC TASKS				EXPLORATION						CONSTRUCTION						EMERGENCIES					
	Clearing	Marking	Unloading	Leveling	Linking	Insert Instruments	Sample Collecting	Haul Material	Load Samples	Traveling	Trailmarking	Observing	Climbing	Spanning	Hauling	Shelters	Erect Beacons, Antennas	Future Sites	Vehicle Conversion	Dust Retainers	Improvise Equipment	Space Suit Leaks	Injuries	Radio Failure	Micrometeorite Storms	Shelter Leaks	Equipment Repair
Scoop	X																	X									
Push Broom	X																	X									
Sheet Panels		X														X		X		X	X						
Marker Poles		X			X	X					X		X	X			X	X									
Ramp			X										X														
Lift/Hoist			X						X																		
Lever/Jack				X																							
Pathfinder					X					X	X																
Wire					X						X						X				X						X
Auger						X	X										X										
Shovel						X	X									X	X	X									
Pick							X									X											
Explosives						X	X									X	X	X									
Trailer								X							X			X					X				
Rocket						X		X					X	X										X			
Power Vehicle	X									X					X			X									
Transit/Telescope		X									X	X															
Ladder													X	X			X										
Cord			X								X		X	X		X											
Grapple													X														
Bridge														X													
Lights		X									X	X															
Deployable Covers																X									X		
Sledge						X										X	X			X							
Stakes/Rods														X		X	X			X	X						X
Shield																			X						X		
Inflatable Cabins																X			X			X	X				
Fasteners																				X	X						X
Sheet Metal																					X					X	X
Hack Saw							X														X						X
Welder																					X					X	X
Patch Kit																						X				X	
Hand Tools						X	X									X	X		X		X					X	X
Drill						X	X									X	X		X		X					X	X
Multimeter					X												X		X								X
Camera												X															
Containers			X				X		X												X						

FIGURE 3 - EQUIPMENT VERSUS TASKS - AES

EQUIPMENT \ TASKS	Road Systems	Power Distrib.	Communication System	Lighting System	Mobility Devices	Storage Facilities	Launch/Land. System	Shelter Conversions	Vehicle Conversions	Excavating/Mining	Hauling	Lifting	Processing	Testing	Repairing	Battery Charging
Transit	X															
Dozer	X					X	X									
Roller	X															
Poles	X	X	X	X												
Wires/Reels		X	X	X			X									X
Drill		X	X	X						X						
Shuttle Car					X											
Rover					X	X										
Expan. Structures						X										
Digger						X				X						
Beacons							X									
Antennas			X				X									
Floodlights				X			X			X						
Welder/Cutter								X	X							
Inflat. Cabins								X	X							
Tubing/Fitting								X	X							
Explosives										X						
Power Shovel	X									X						
Tractor	X				X						X					
Trailer	X	X	X	X	X						X					
Fork Lift												X				
Dredge										X						
Furnace													X			
Chemicals													X	X		
Metall. Instr.														X		
Hand Tools		X	X	X				X	X						X	
Power Tools		X	X	X				X	X						X	
Fasteners		X	X	X				X	X						X	
Spare Parts															X	
Converter																X
Airlocks								X	X							
Utility Rockets			X		X							X			X	

FIGURE 4 - EQUIPMENT VERSUS TASKS - SEMI-PERMANENT BASE

FIGURE 5

SPECIAL PURPOSE EQUIPMENT
PROPOSED FOR THE VARIOUS MISSIONS

LEM	AES	SEMI-PERMANENT BASE
Combination Tool	Combination Tool	The same types of items as listed under AES will be required plus the following:
Travois	Travois	Tractor/Dozer
Marker Poles	Mule	Power Lift
Cargo Sling	Lift/Hoist	Utility Poles
Cord/Wire	Cord/Wire	Wire/Reels
Sheet Panels	Sheet Panels	Tubing
Signal Bombs	Marker Poles	Shuttle Bus
Utility Rocket	Explosives	Excavating Tools
Explosives	Utility Rockets	Large Trailer
Utility Belt	Transit/Telescope	Launching/Landing System
Deployable Covers	Deployable Covers/Shield	LEM Truck Conversion Equipment
Transit/Telescope	Flood Lights	Excavated Shelter Kits (Airlocks, Bladders, Tanks, Etc.)
Multimeter	Inflatable Cabins	Battery Charger
Camera	CAMUL	Waste Reclamation and Disposal
Containers	Emergency	Repair Shop
	LSSM Conversion	Special Storage Areas
	Sheet Metal	Physical Conditioning Facility
	Fasteners	Heat Pumps
	Welder	Power Generators
	Drill	Furnace (Solar)
	Utility Belt	Chemicals
	Multimeter	
	Camera	
	Containers	

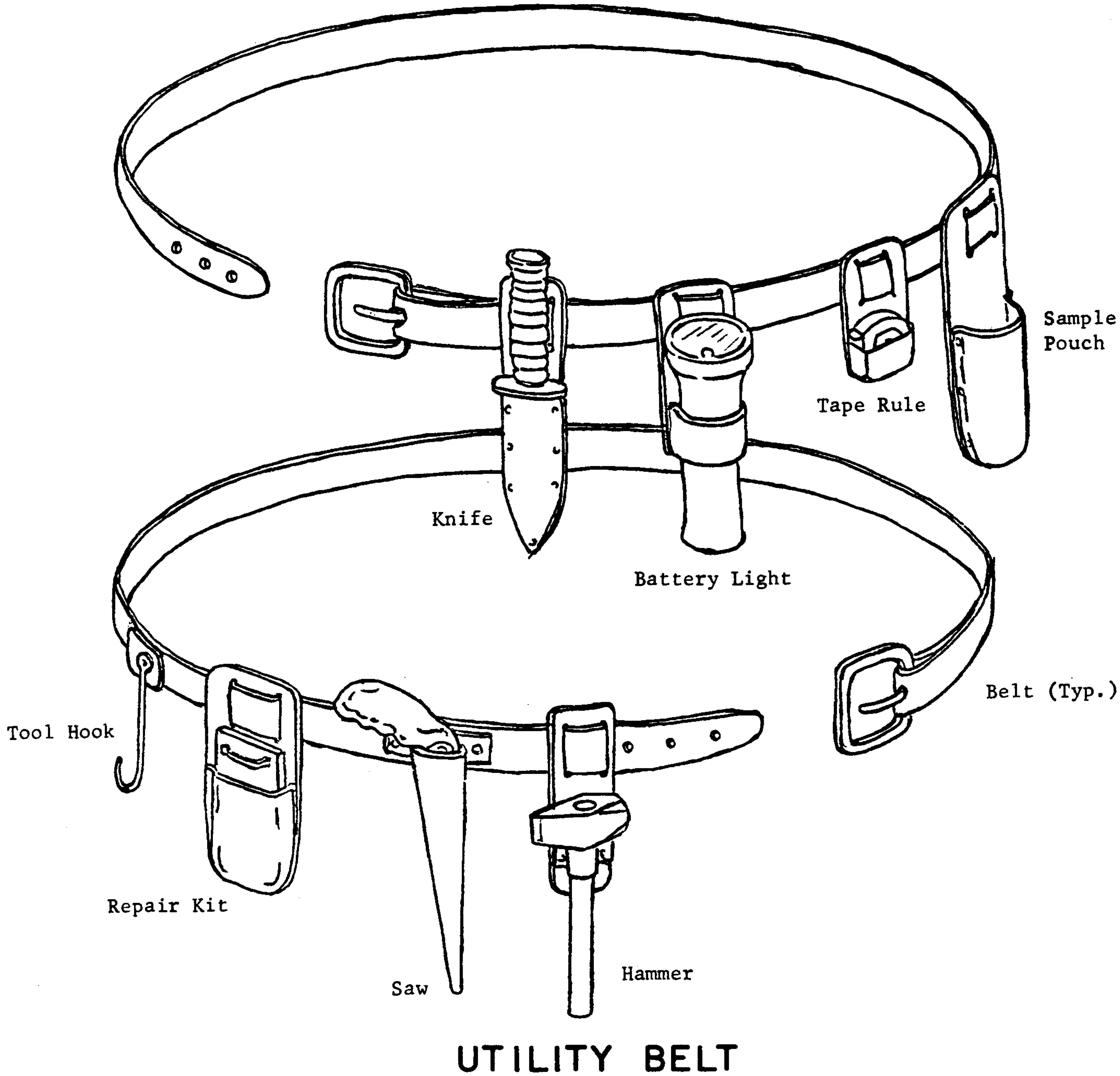
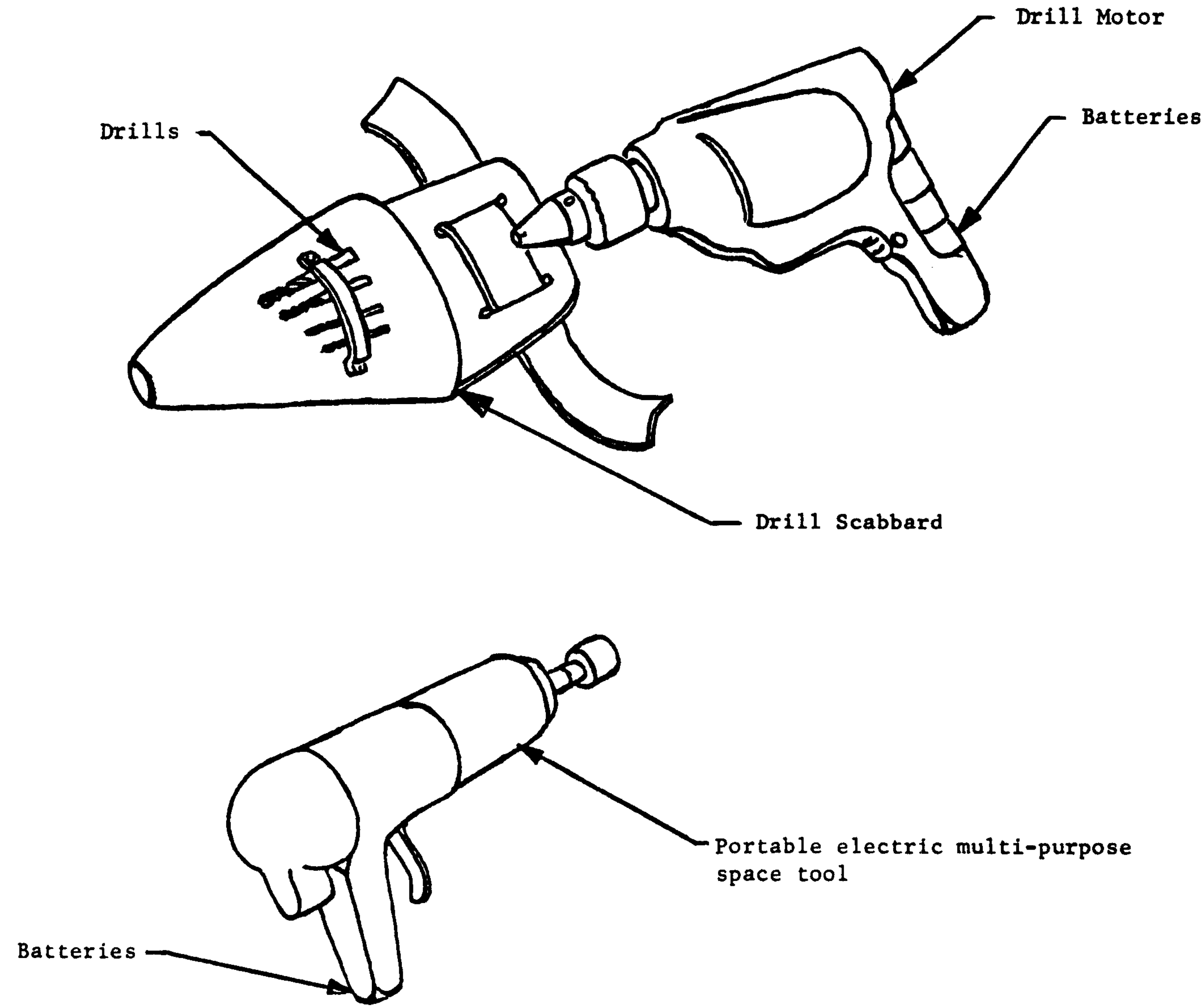


FIGURE 6 - UTILITY BELT



PORTABLE ELECTRIC SPACE TOOLS (PEST)

FIGURE 7 - PORTABLE ELECTRIC SPACE TOOLS

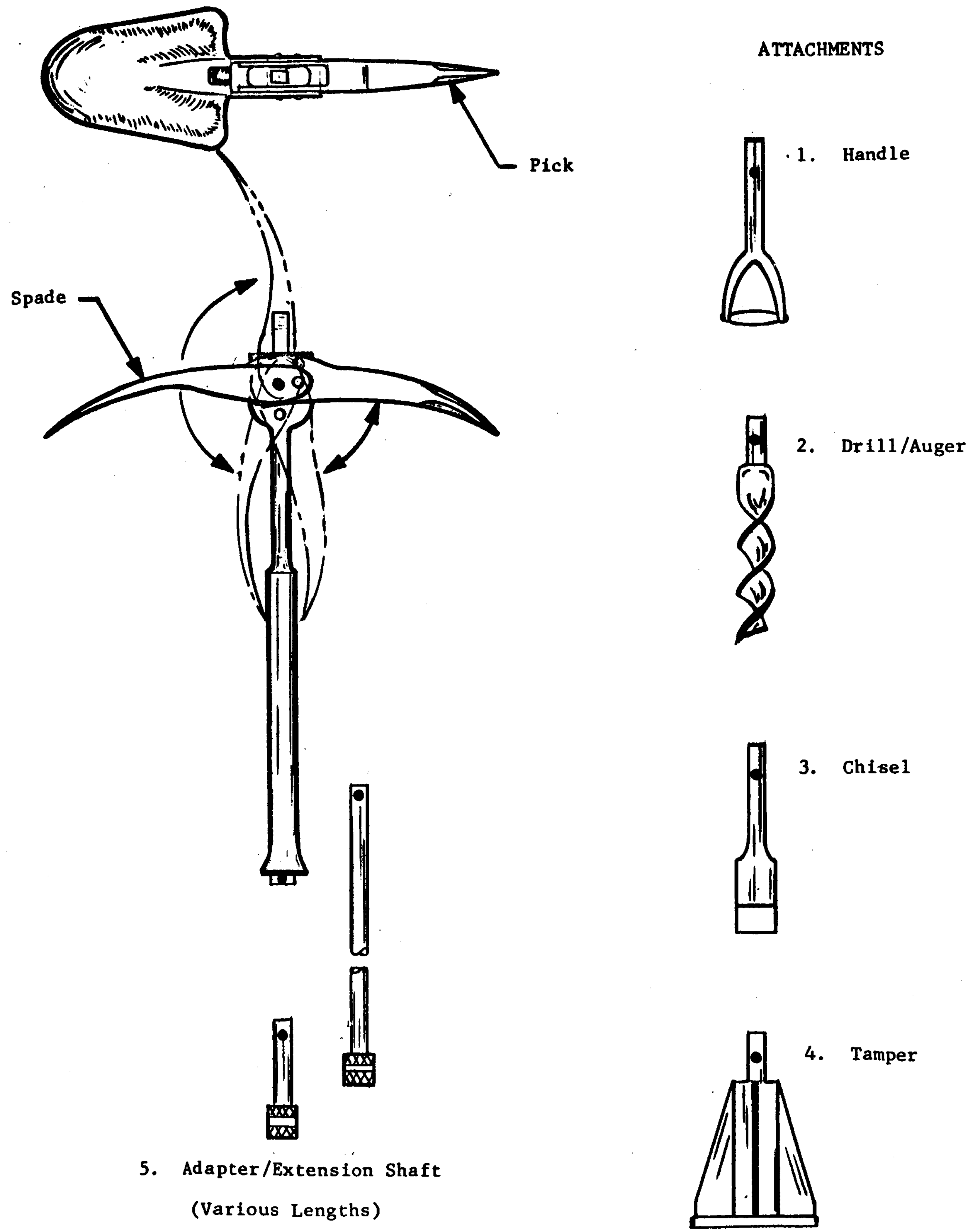
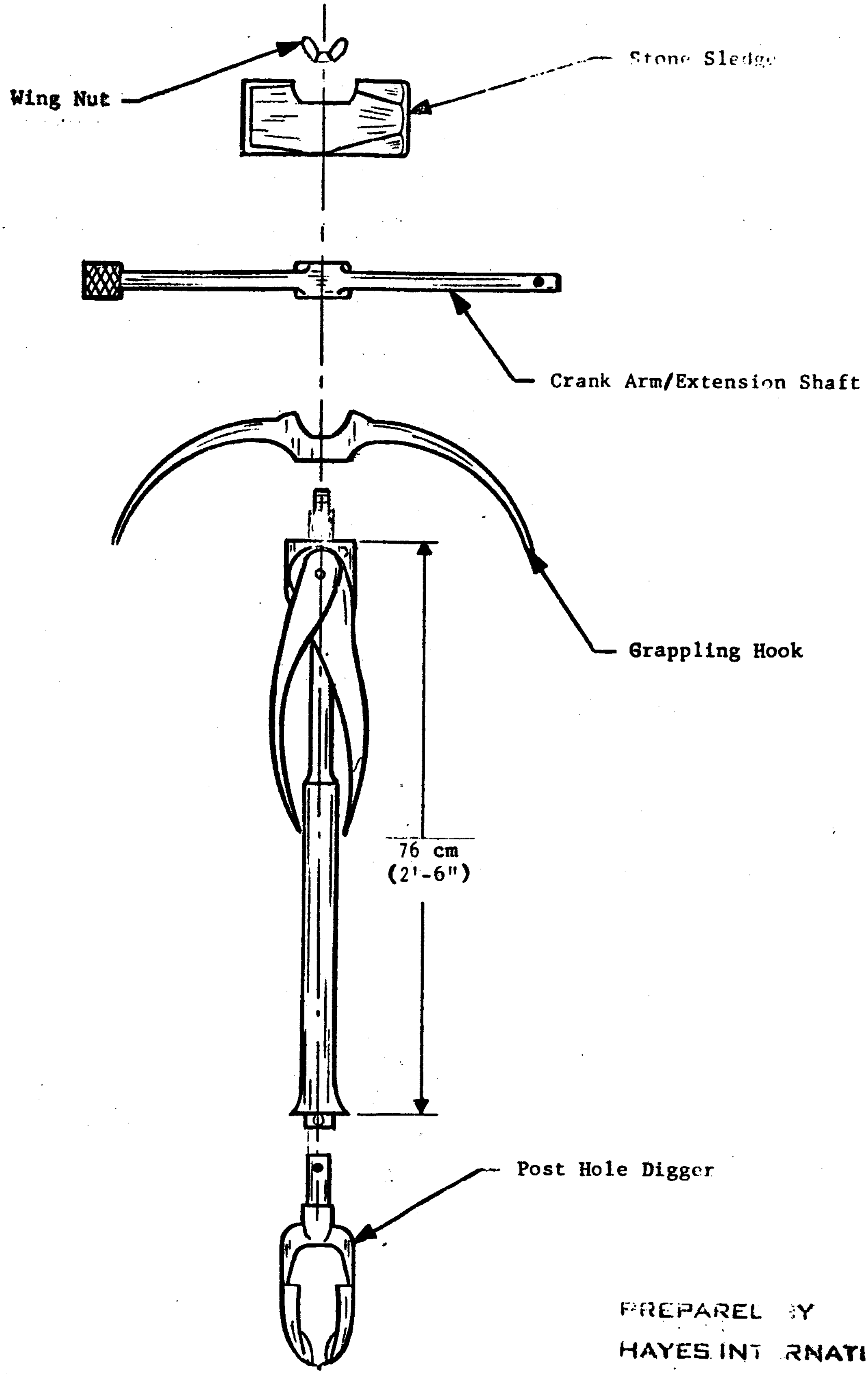


FIGURE 8
LUNAR COMBINATION HANDTOOL



PREPARED BY
HAYES INTERNATIONAL
HUNTSVILLE, ALABAMA

LUNAR COMBINATION HAND TOOL
FIGURE 9

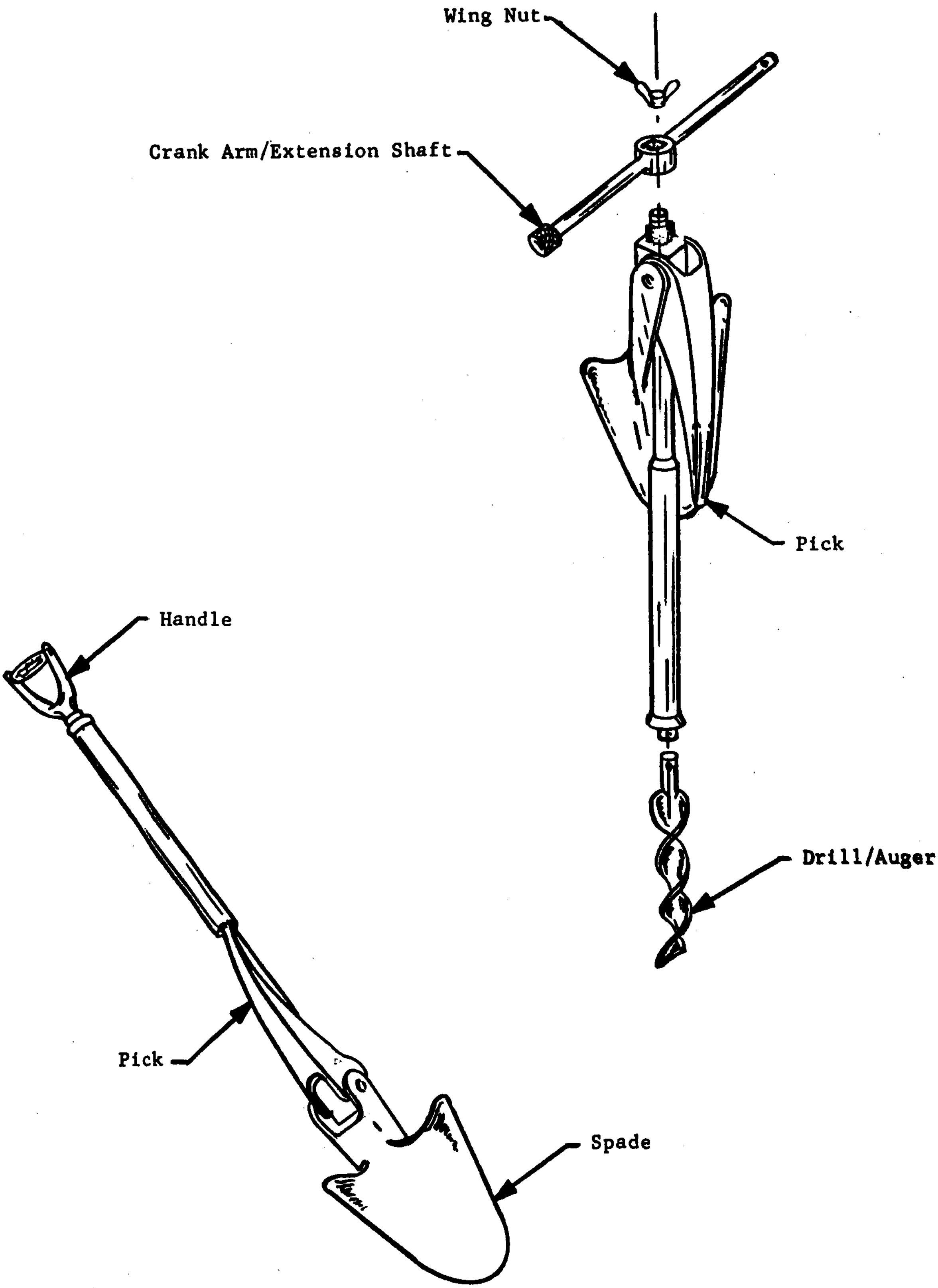


FIGURE 10

LUNAR COMBINATION HAND TOOL

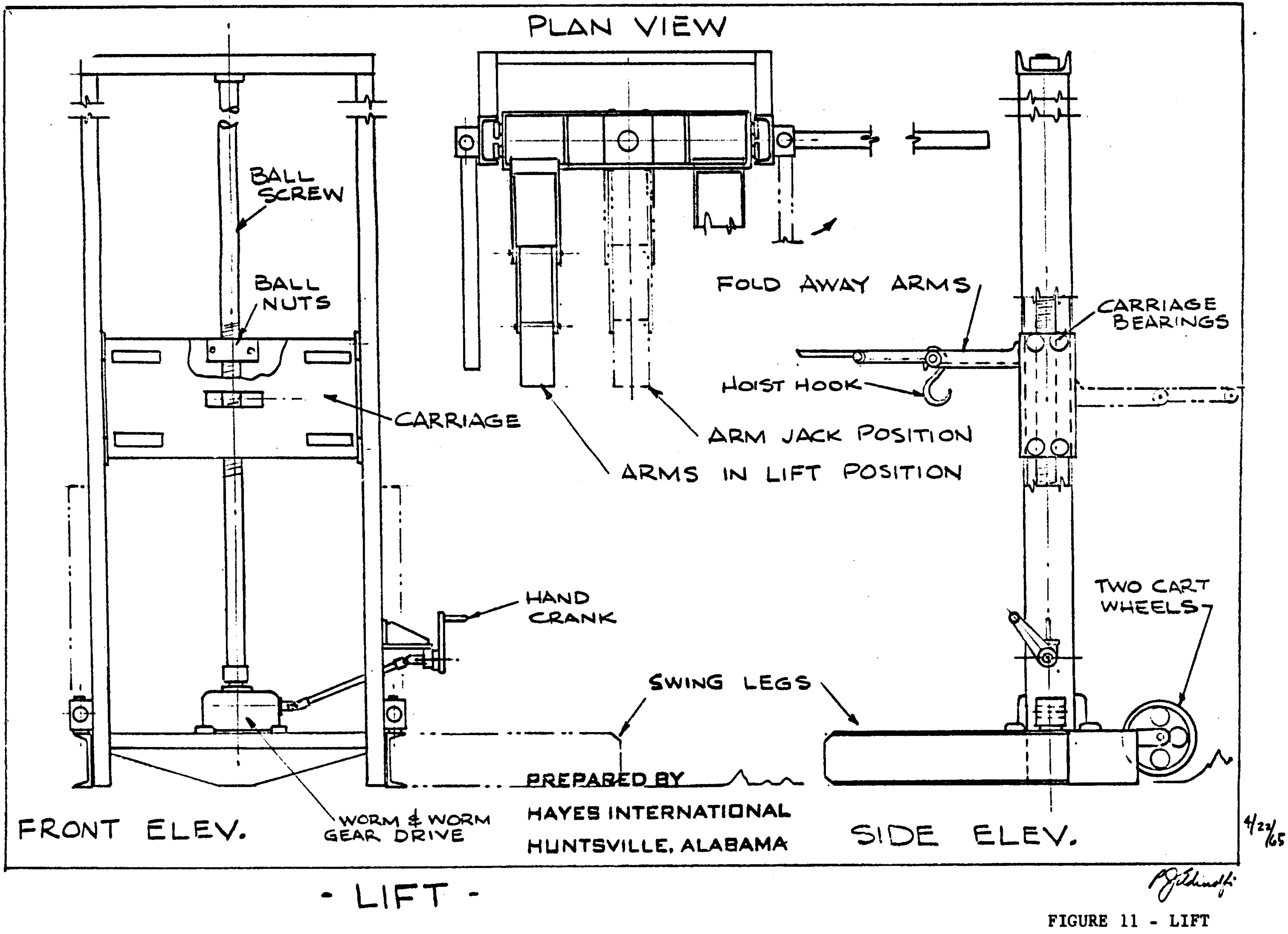


FIGURE 11 - LIFT

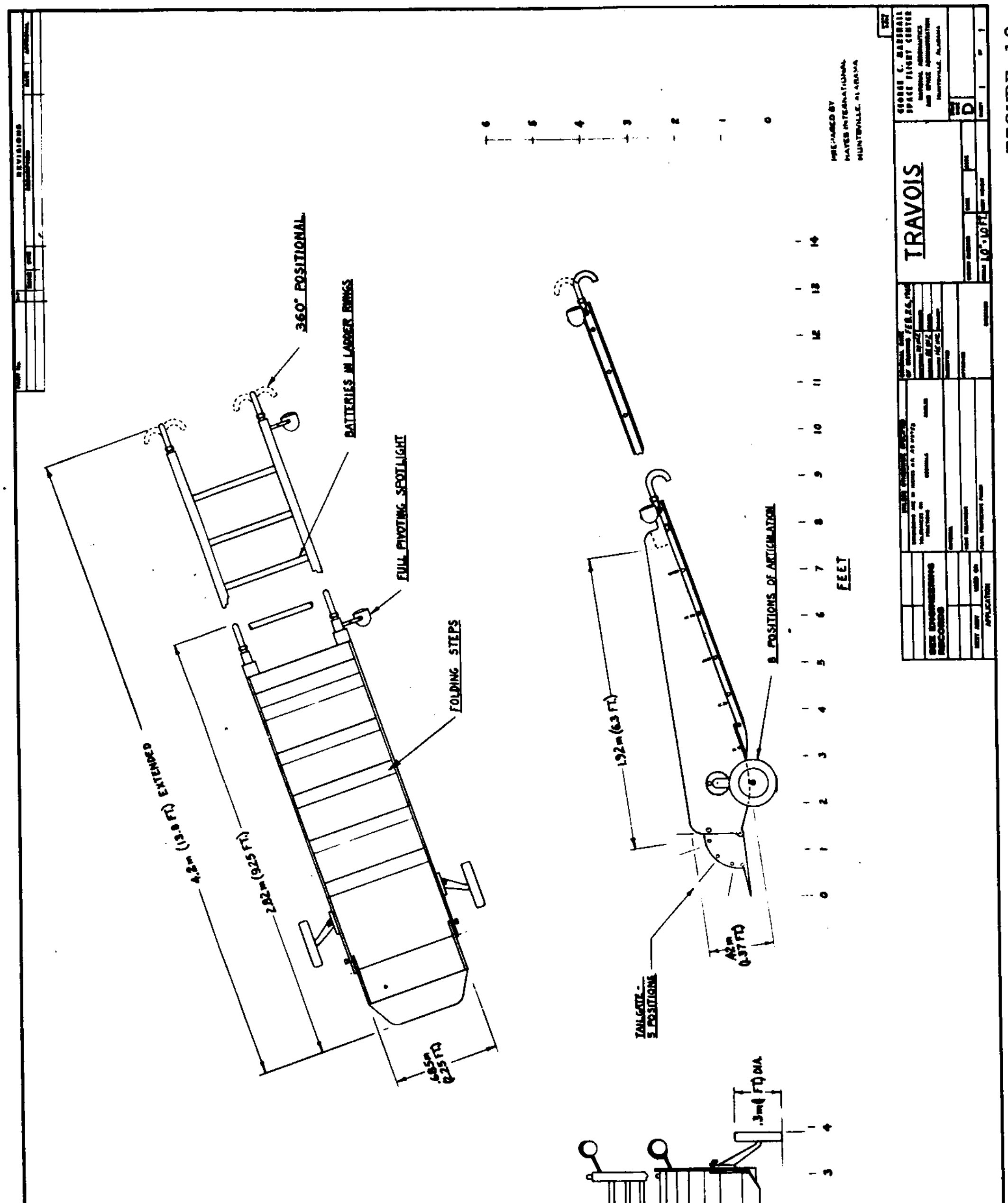

TRAVOIS
4.2m (13.8 FT) EXTENDED
2.82m (9.25 FT)
.68m (2.25 FT)
360° POSITIONAL
BATTERIES IN LADDER RINGS
FULL PIVOTING SPOTLIGHT
FOLDING STEPS
1.92m (6.3 FT)
8 POSITIONS OF ARTICULATION
TAILGATE - 5 POSITIONS
.42m (1.37 FT)
.3m (1 FT) DIA
FEET
PREPARED BY
HAYES INTERNATIONAL
HUNTSVILLE, ALABAMA
GEORGE C. MARSHALL
SPACE FLIGHT CENTER

FIGURE 17

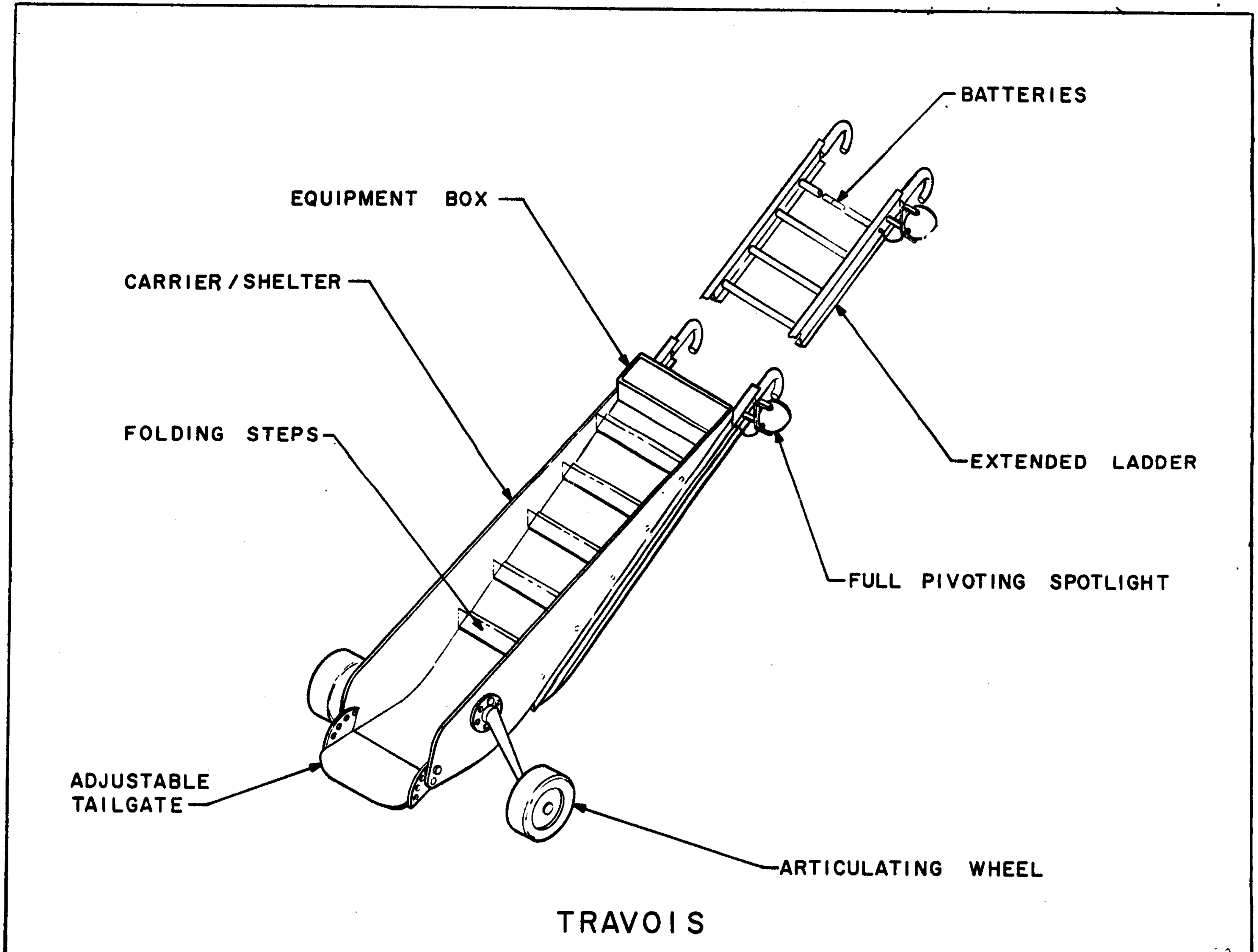


FIGURE 13 - TRAVOIS

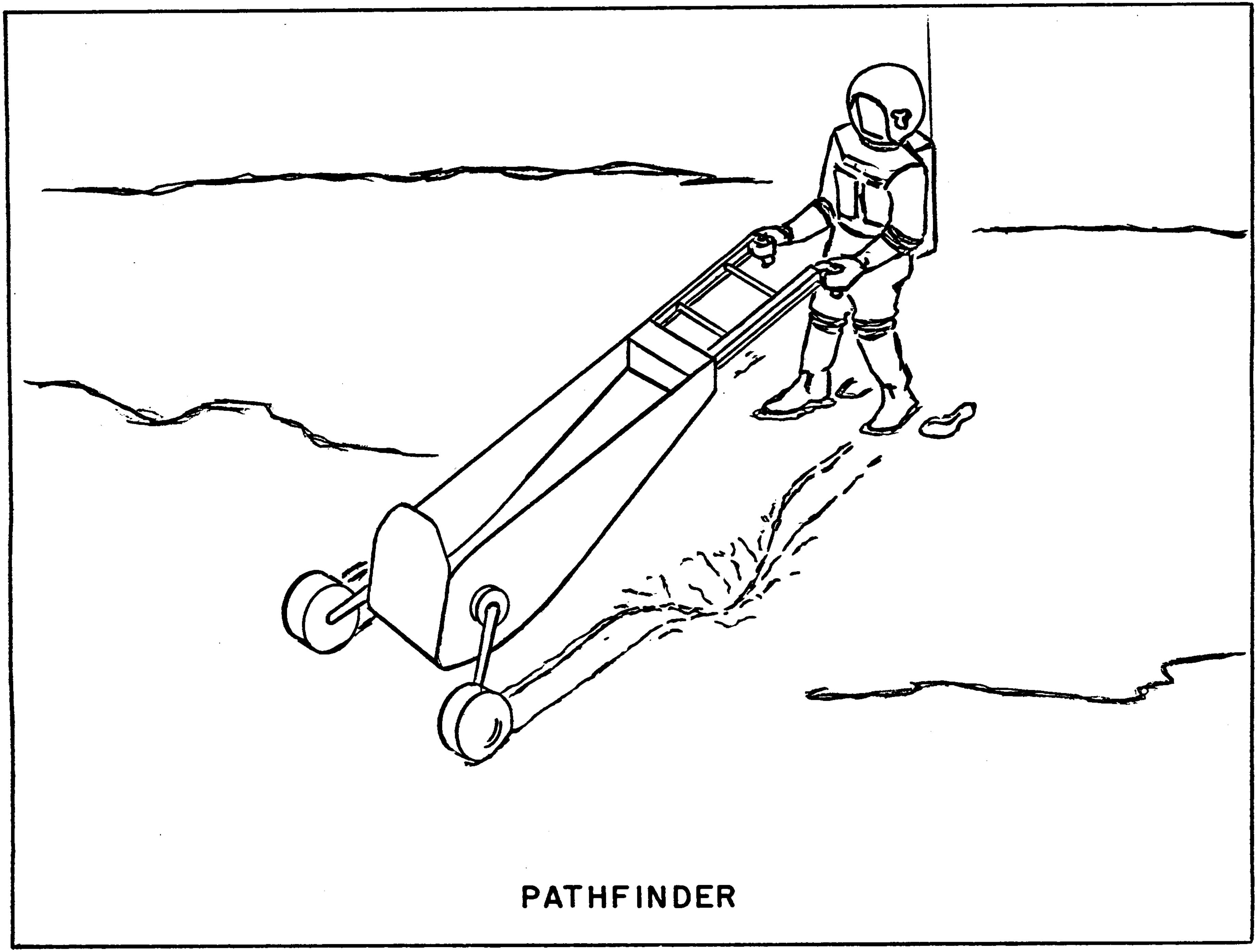


FIGURE 14 - PATHFINDER

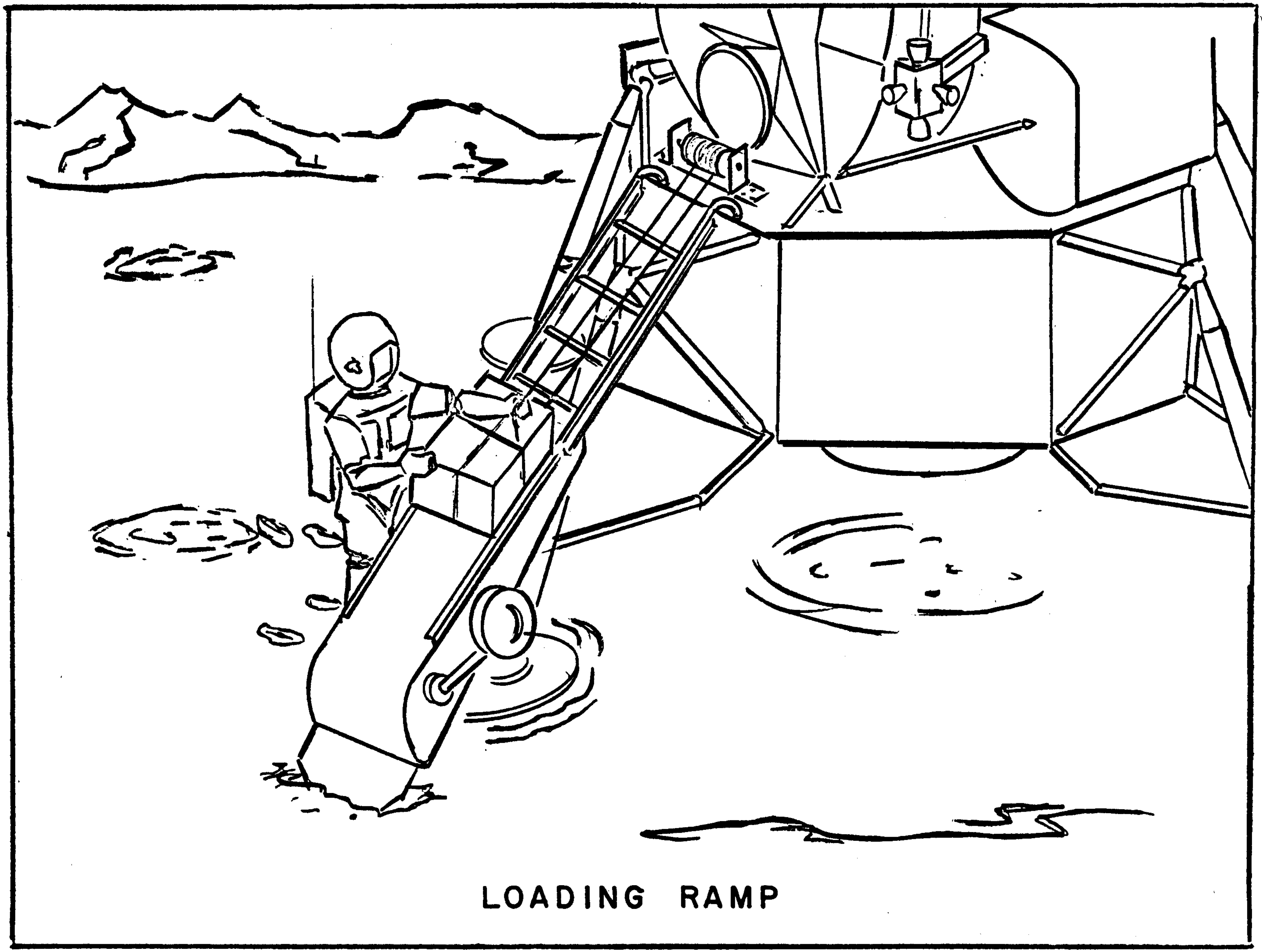


FIGURE 15 - LOADING RAMP

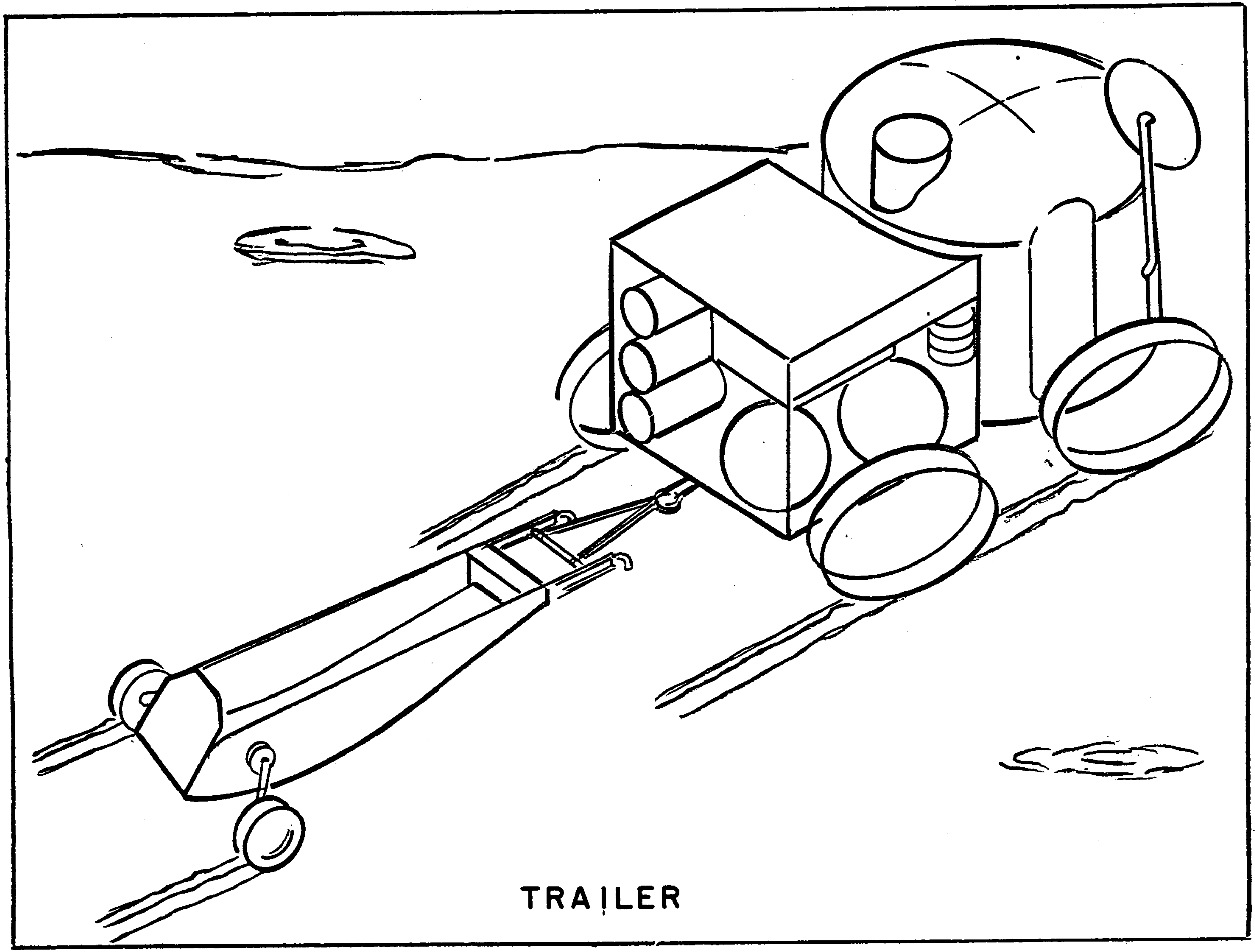
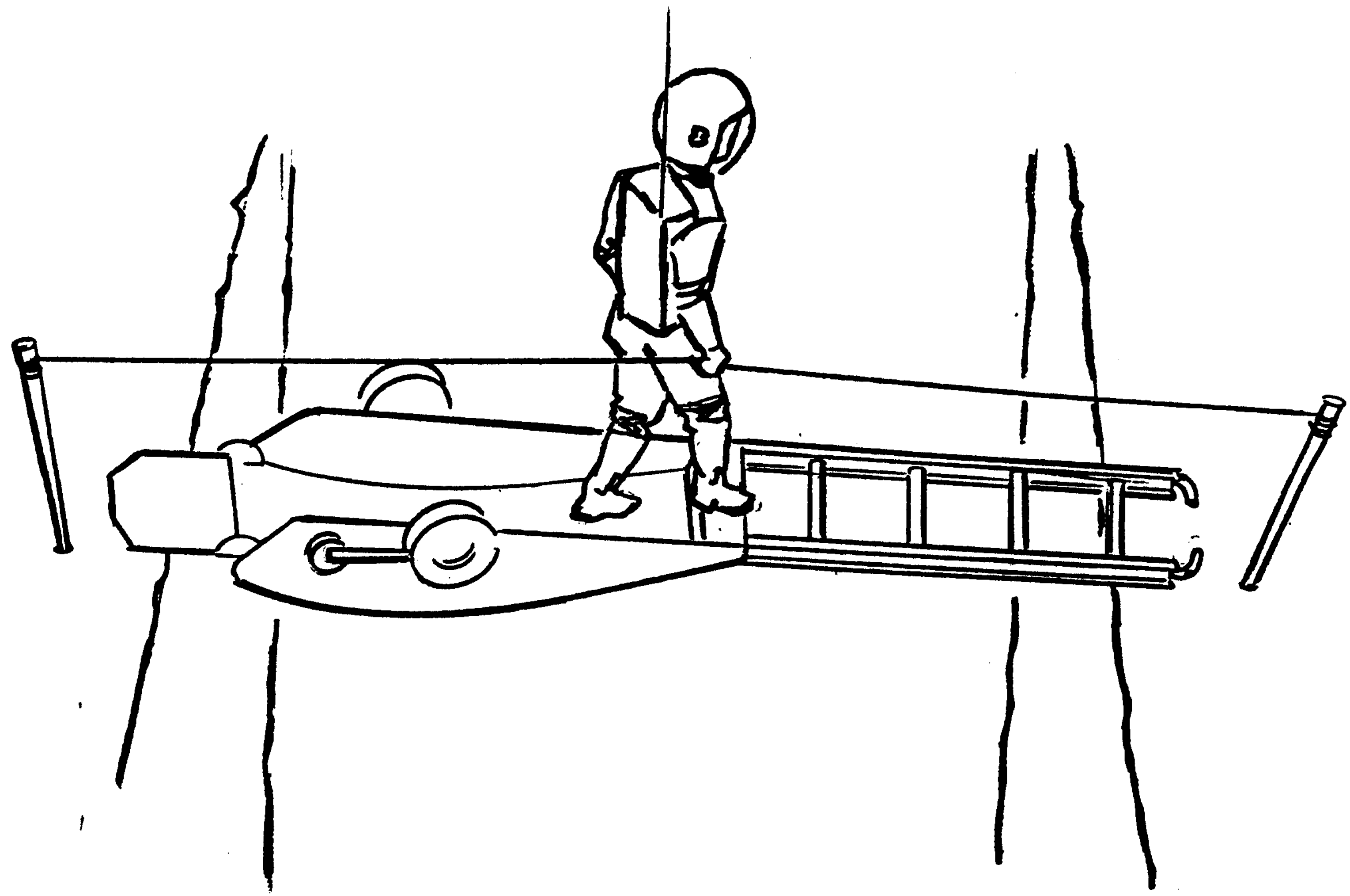


FIGURE 16 - TRAILER



BRIDGE

FIGURE 17 - BRIDGE

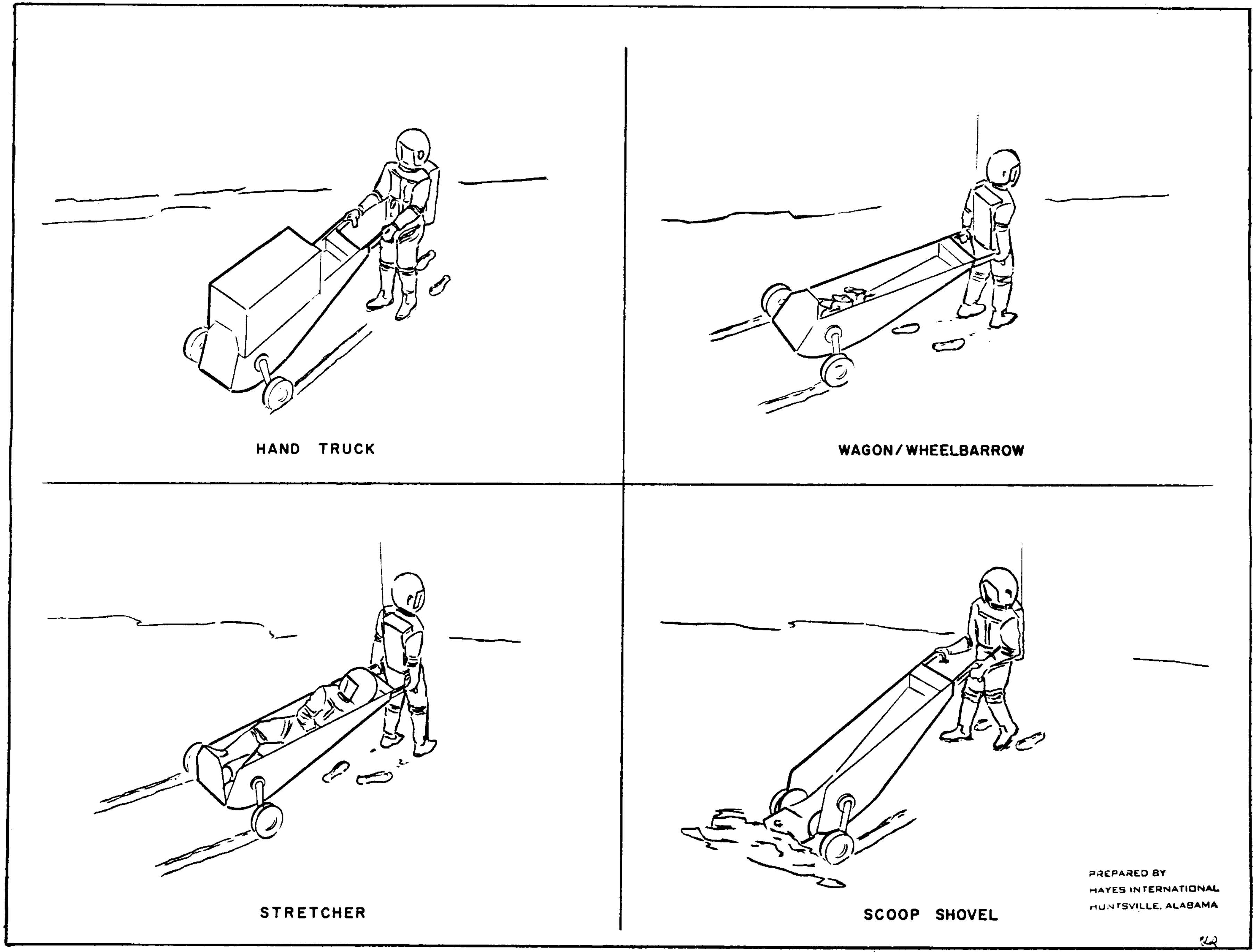


FIGURE 18 - TRAVOIS APPLICATIONS

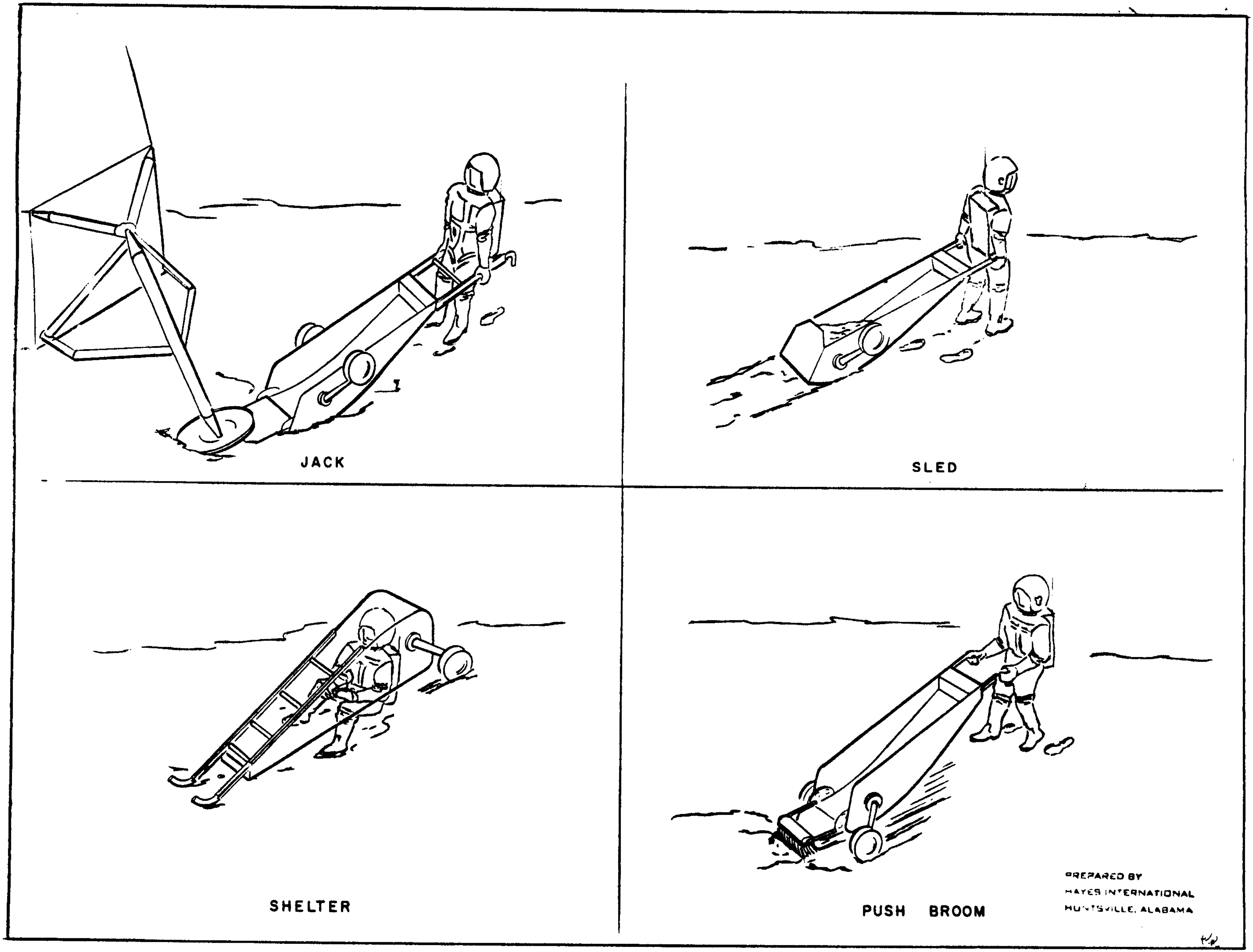


FIGURE 19 - TRAVOIS APPLICATIONS

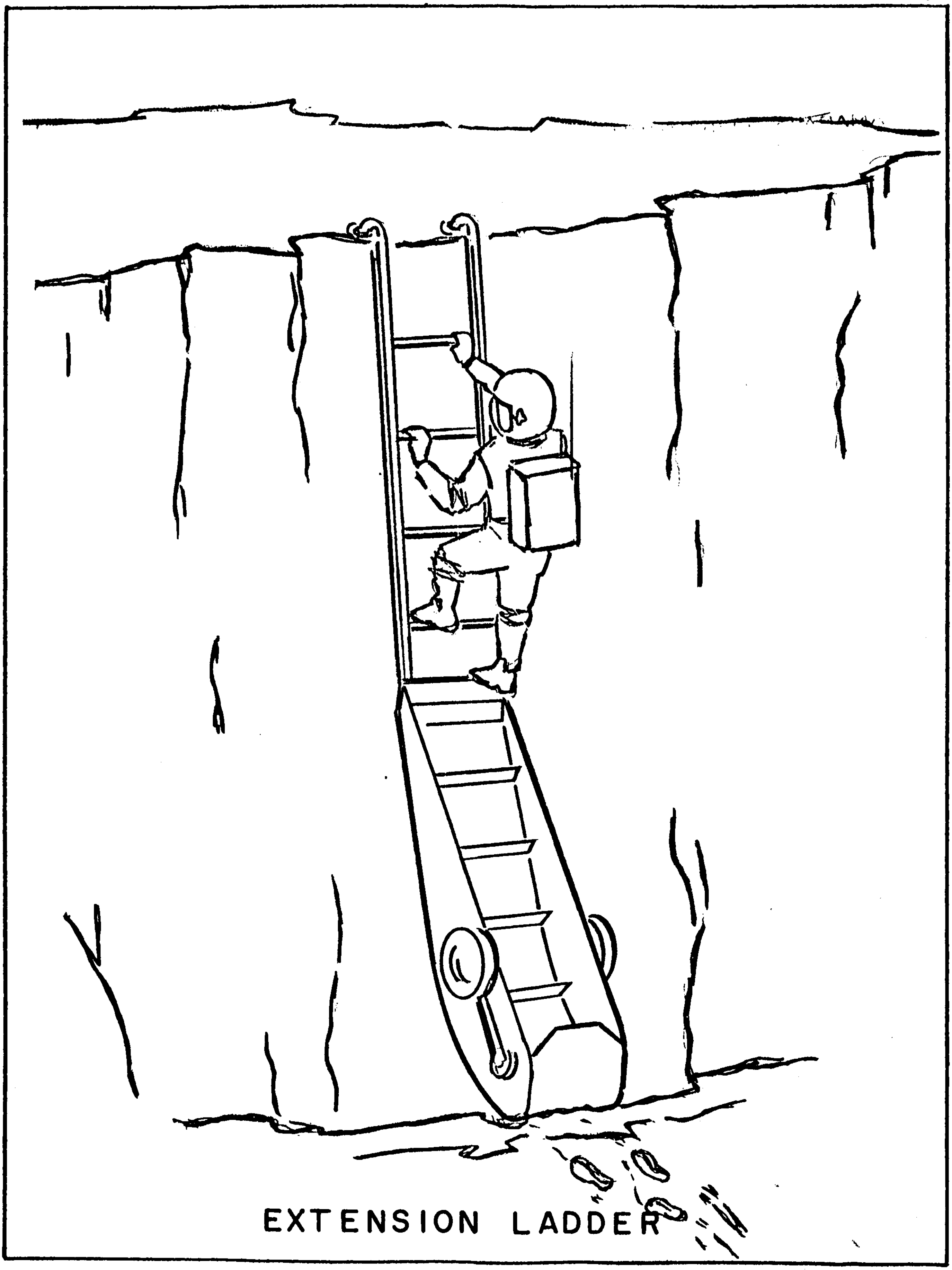


FIGURE 20 - EXTENSION LADDER

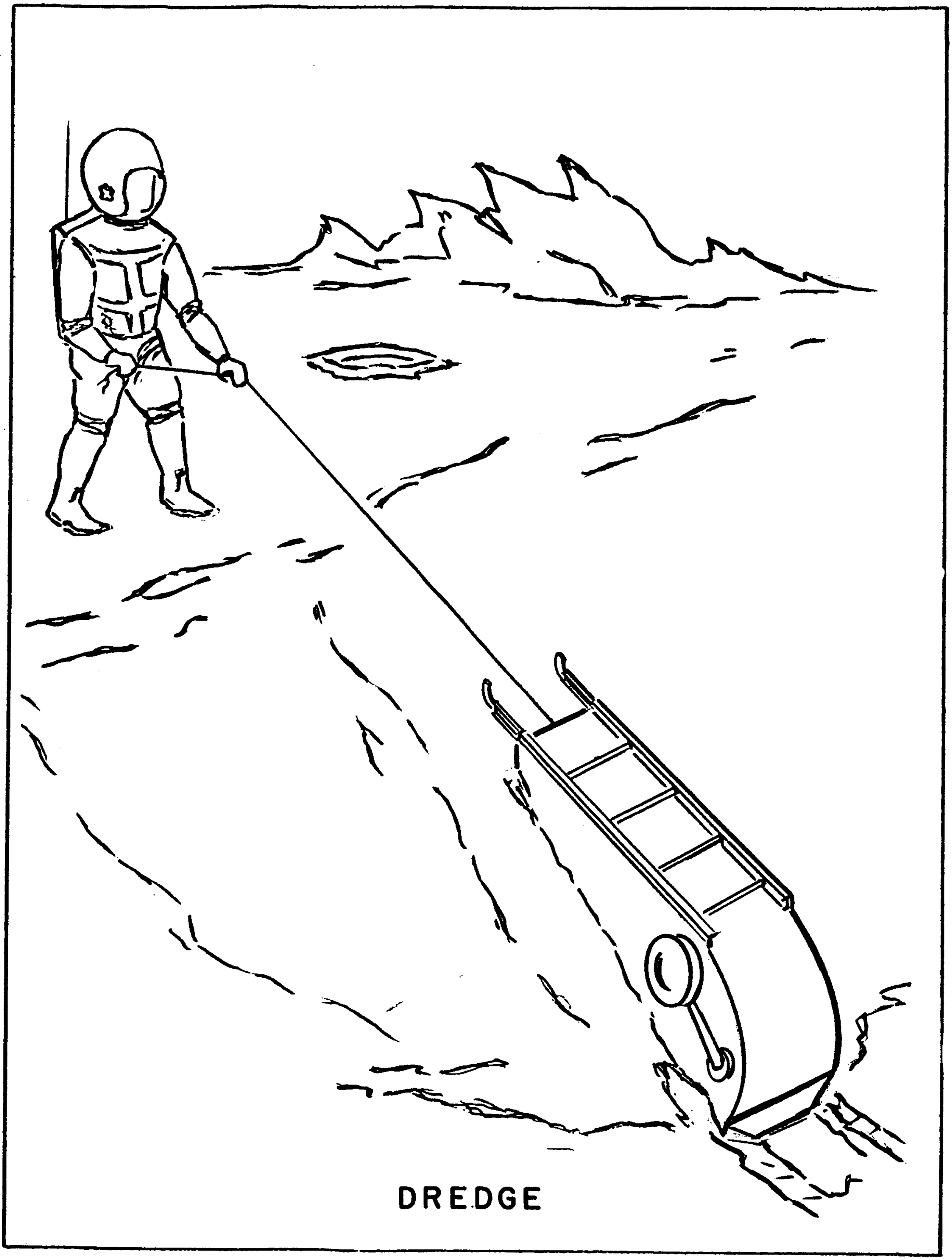


FIGURE 21 - DREDGE

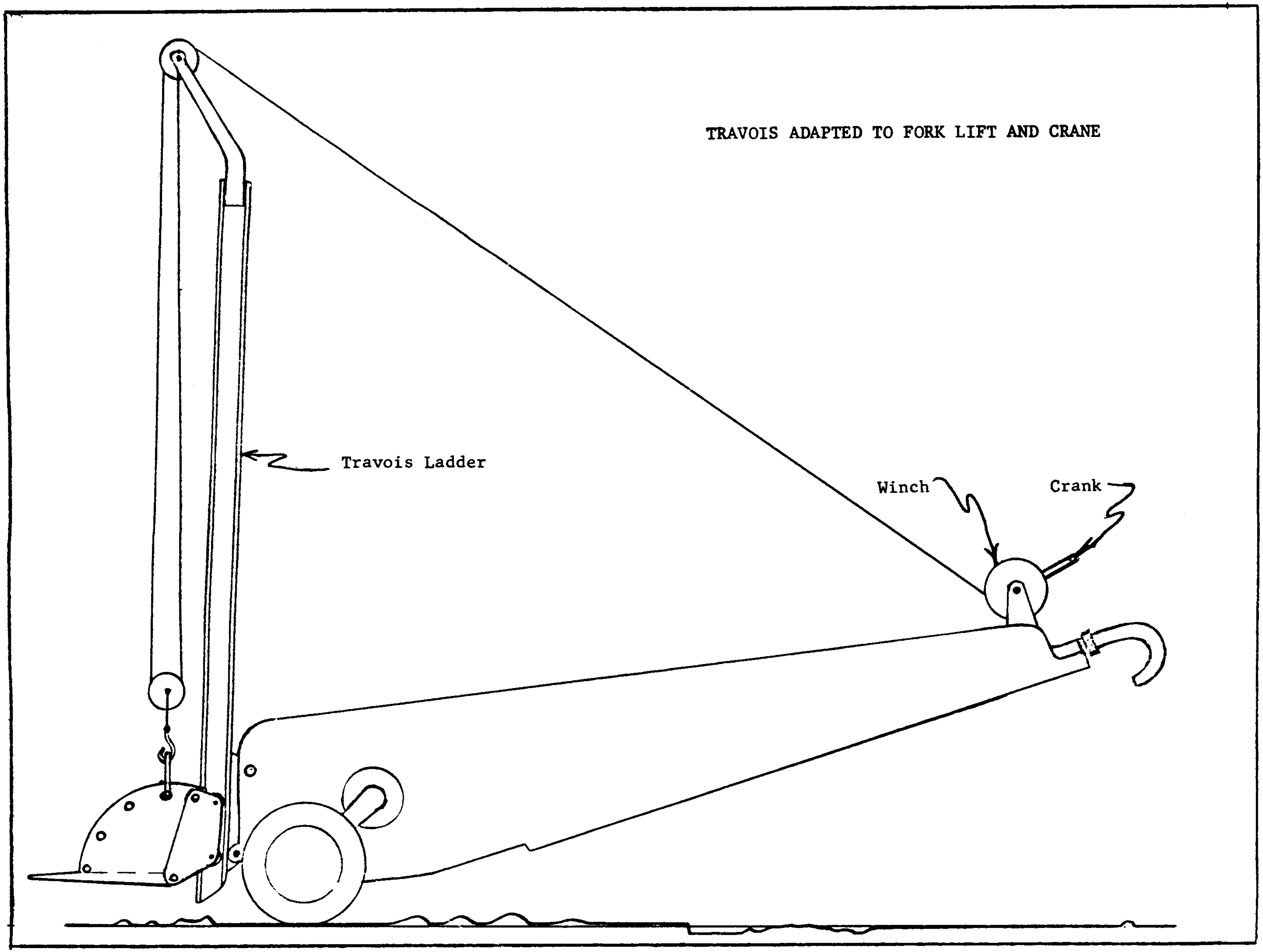
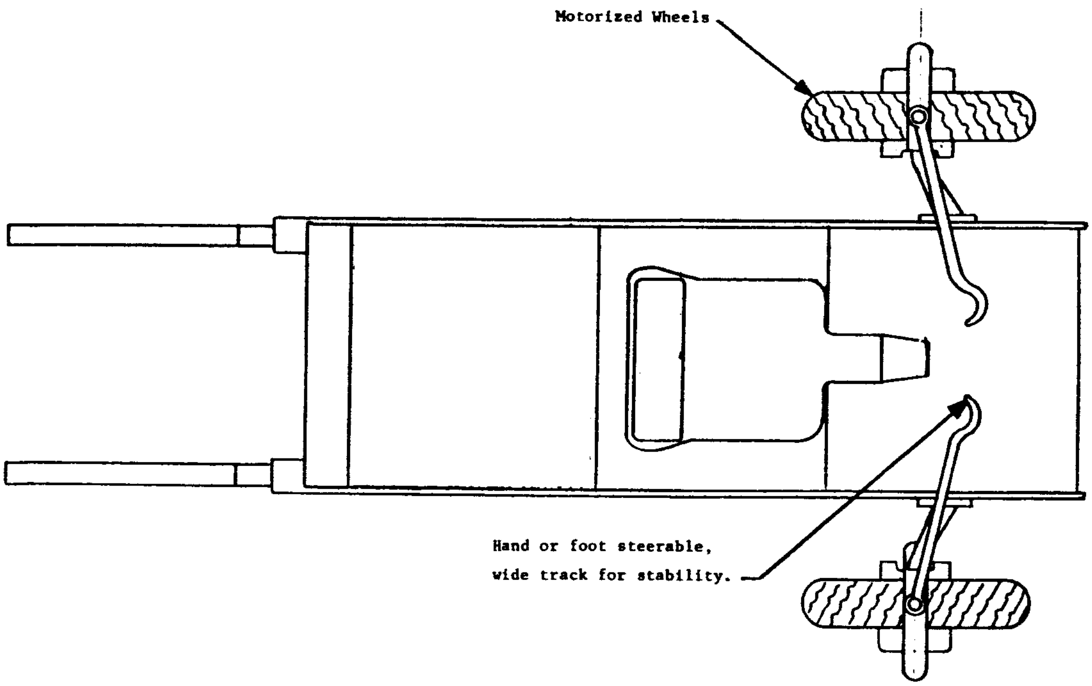
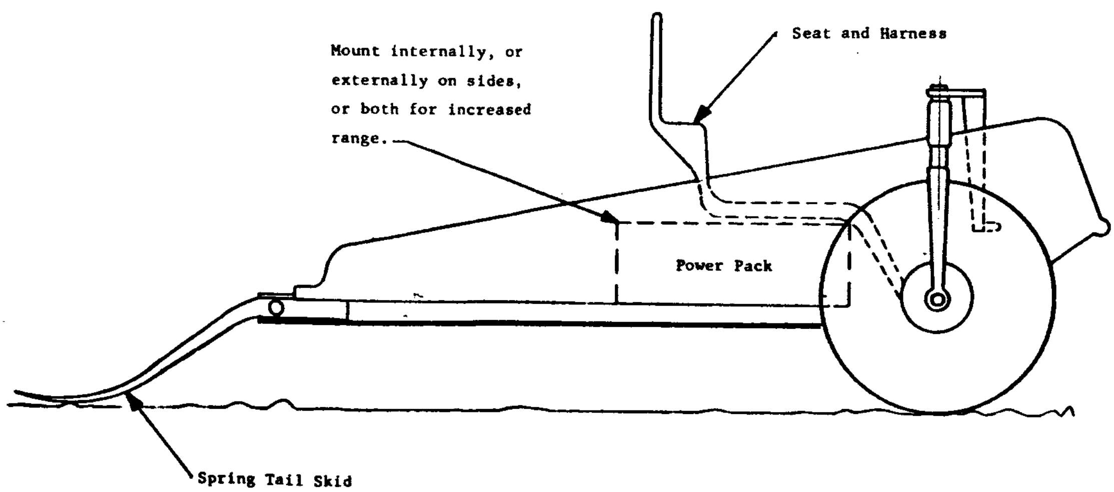


FIGURE 22 - TRAVOIS ADAPTED TO FORK LIFT AND CRANE



TOP VIEW



SIDE VIEW

MULE

FIGURE 23 - MULE

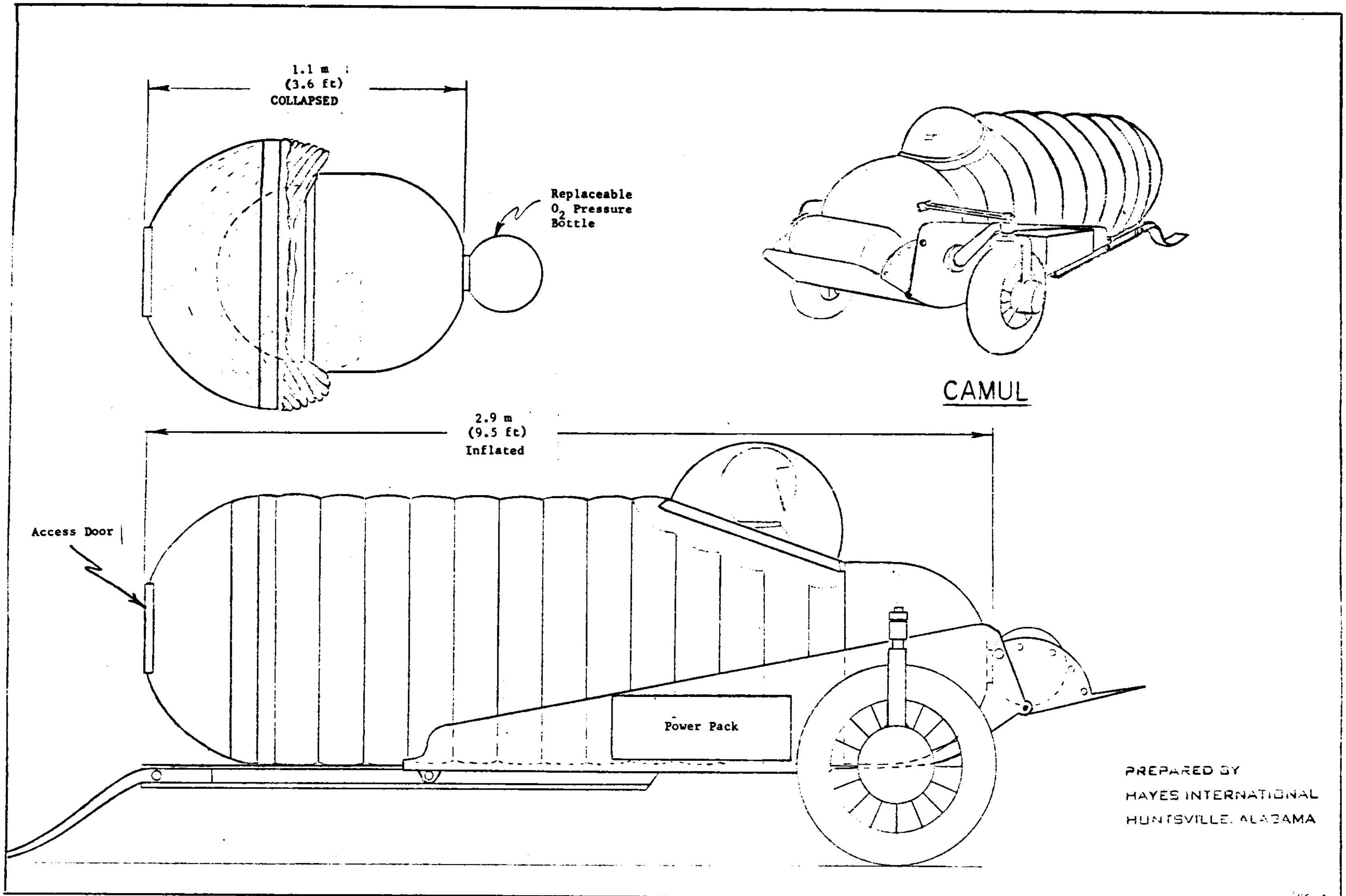
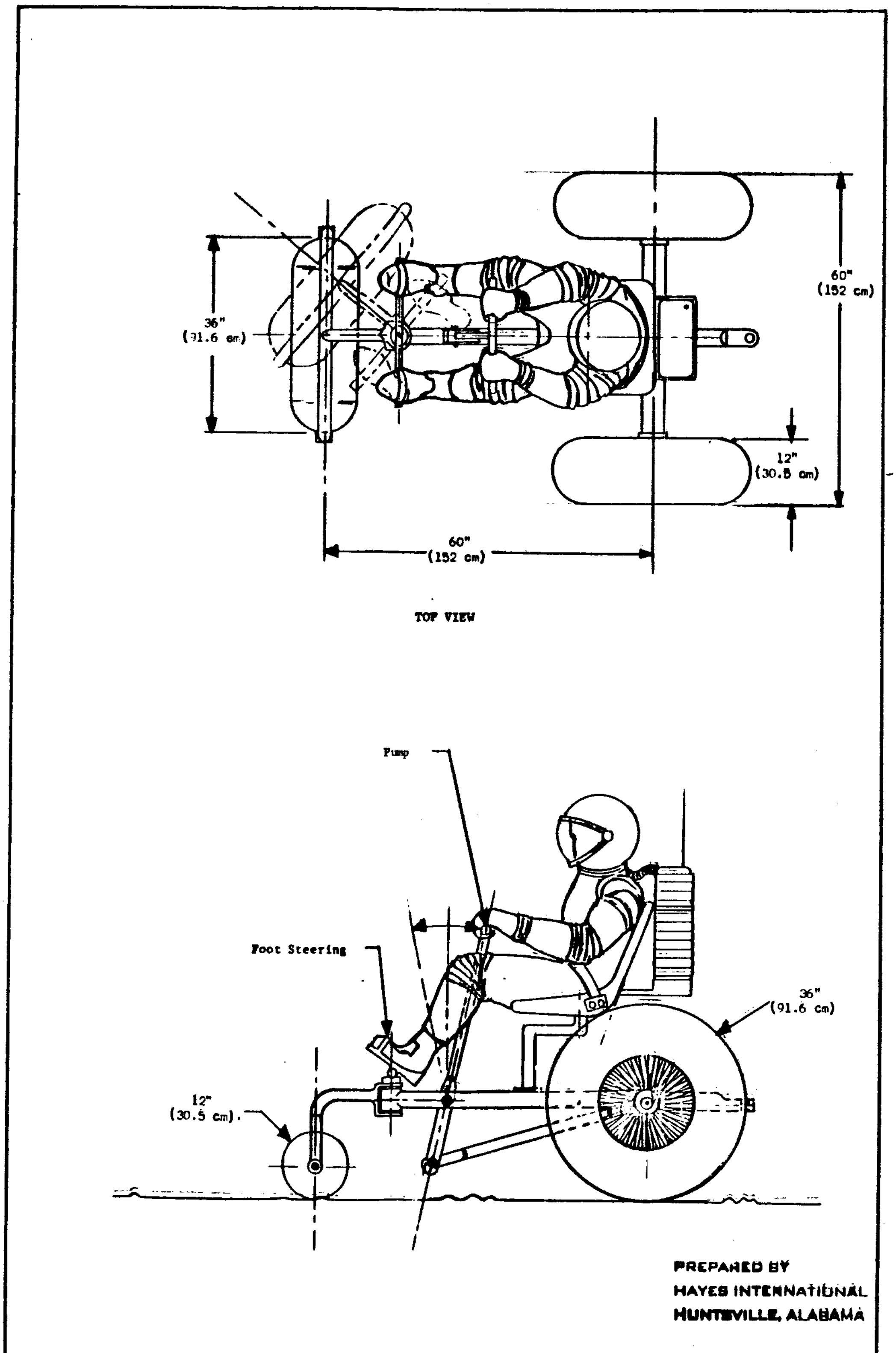
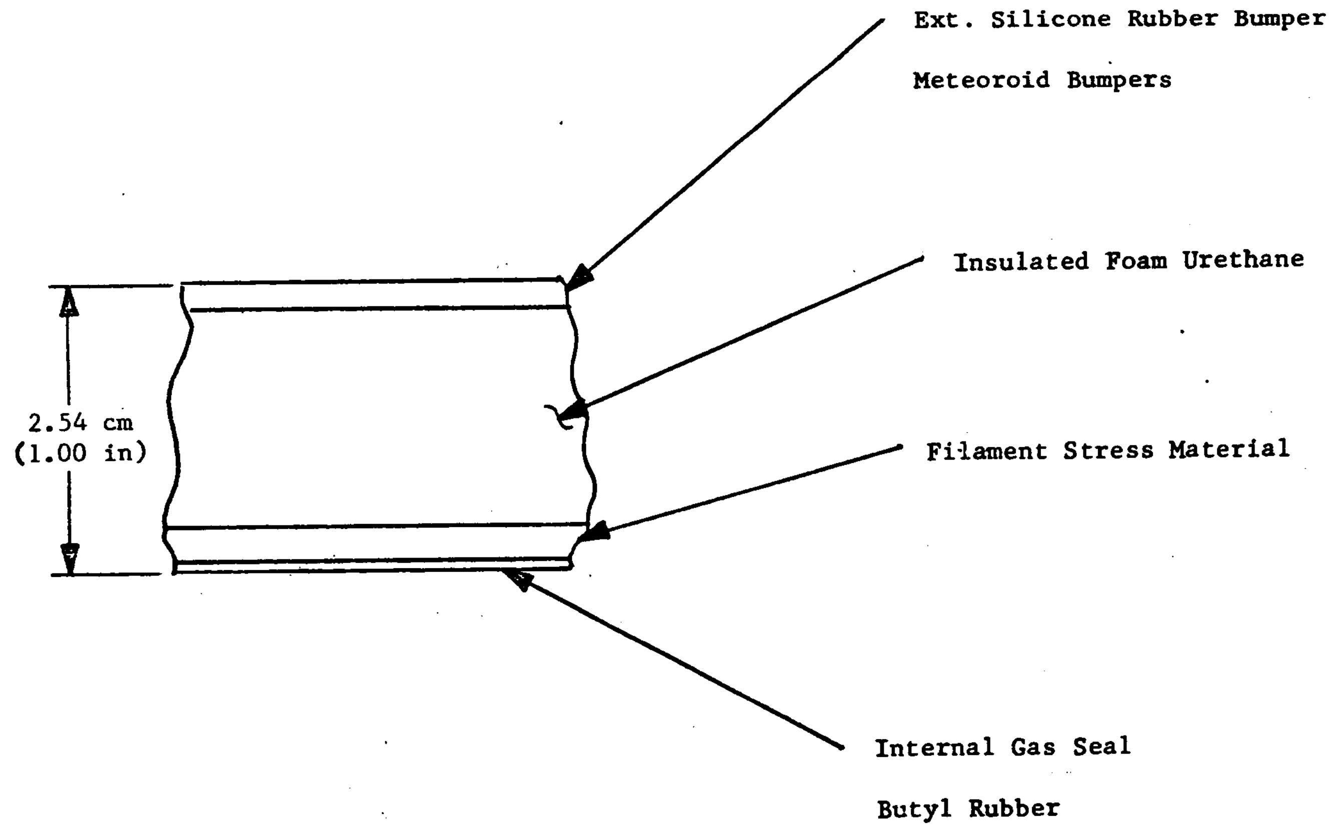


FIGURE 24 - CAMUL



60"
(152 cm)
36"
(91.6 cm)
12"
(30.5 cm)
60"
(152 cm)
TOP VIEW
Pump
Foot Steering
36"
(91.6 cm)
12"
(30.5 cm)
PREPARED BY
HAYES INTERNATIONAL
HUNTSVILLE, ALABAMA
MAN-POWERED TRICYCLE

FIGURE 25



PREPARED BY
HAYES INTERNATIONAL
HUNTSVILLE, ALABAMA

INFLATABLE SHELTER WALL SECTION

FIGURE 26

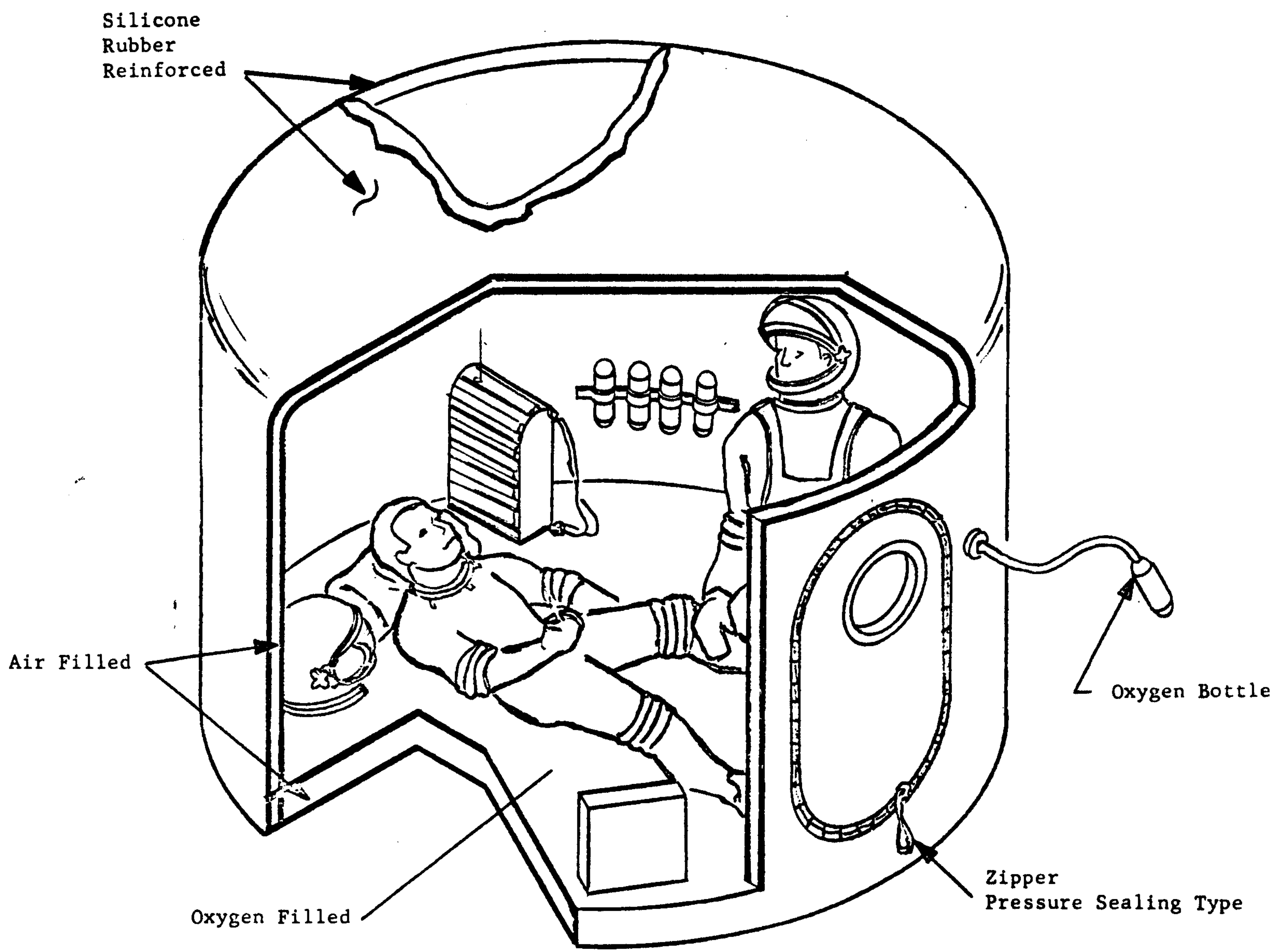


FIGURE 27 _ 2 MAN EMERGENCY MEDICAL TENT

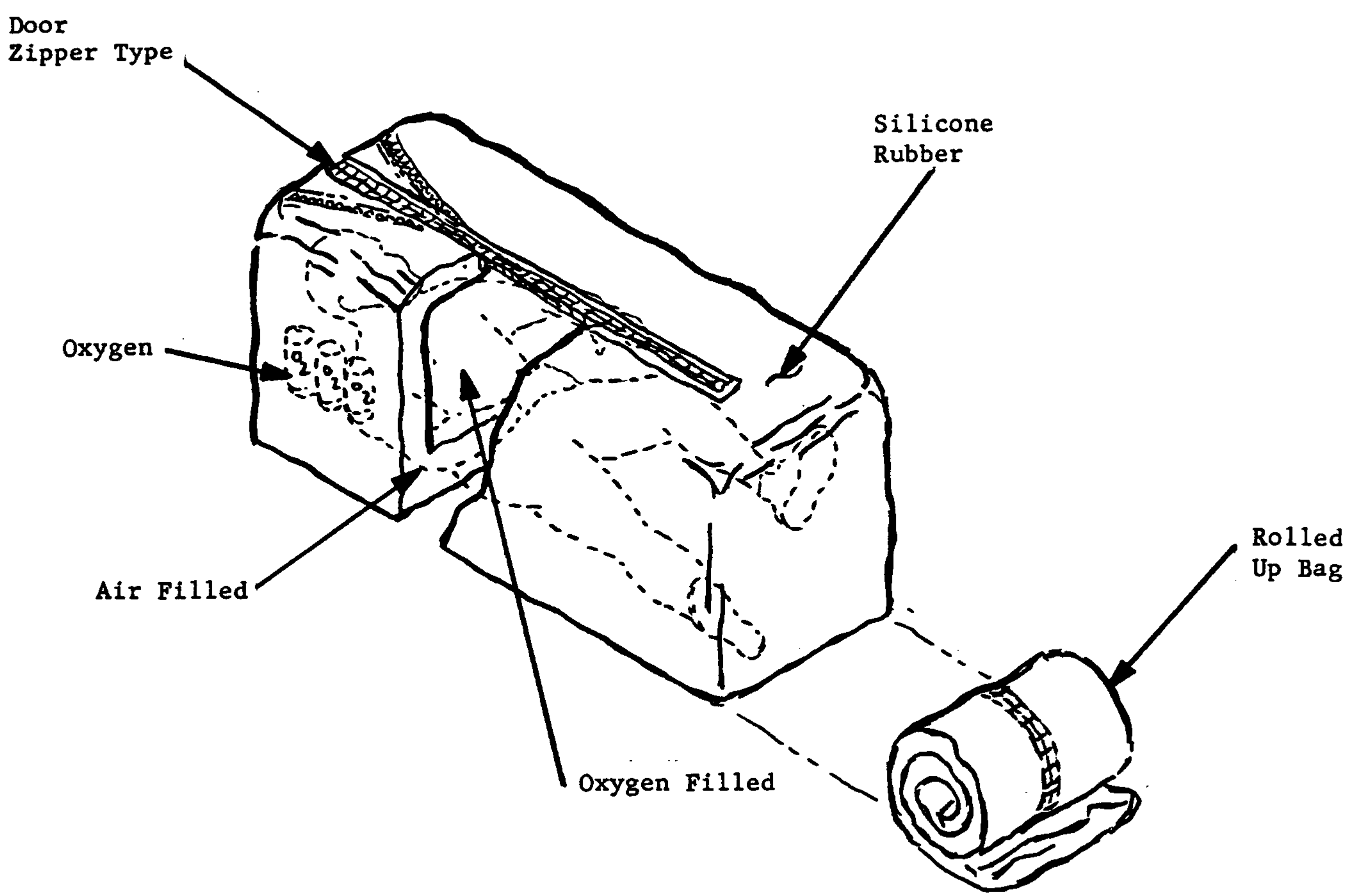


FIGURE 28
EMERGENCY MEDICAL TENT

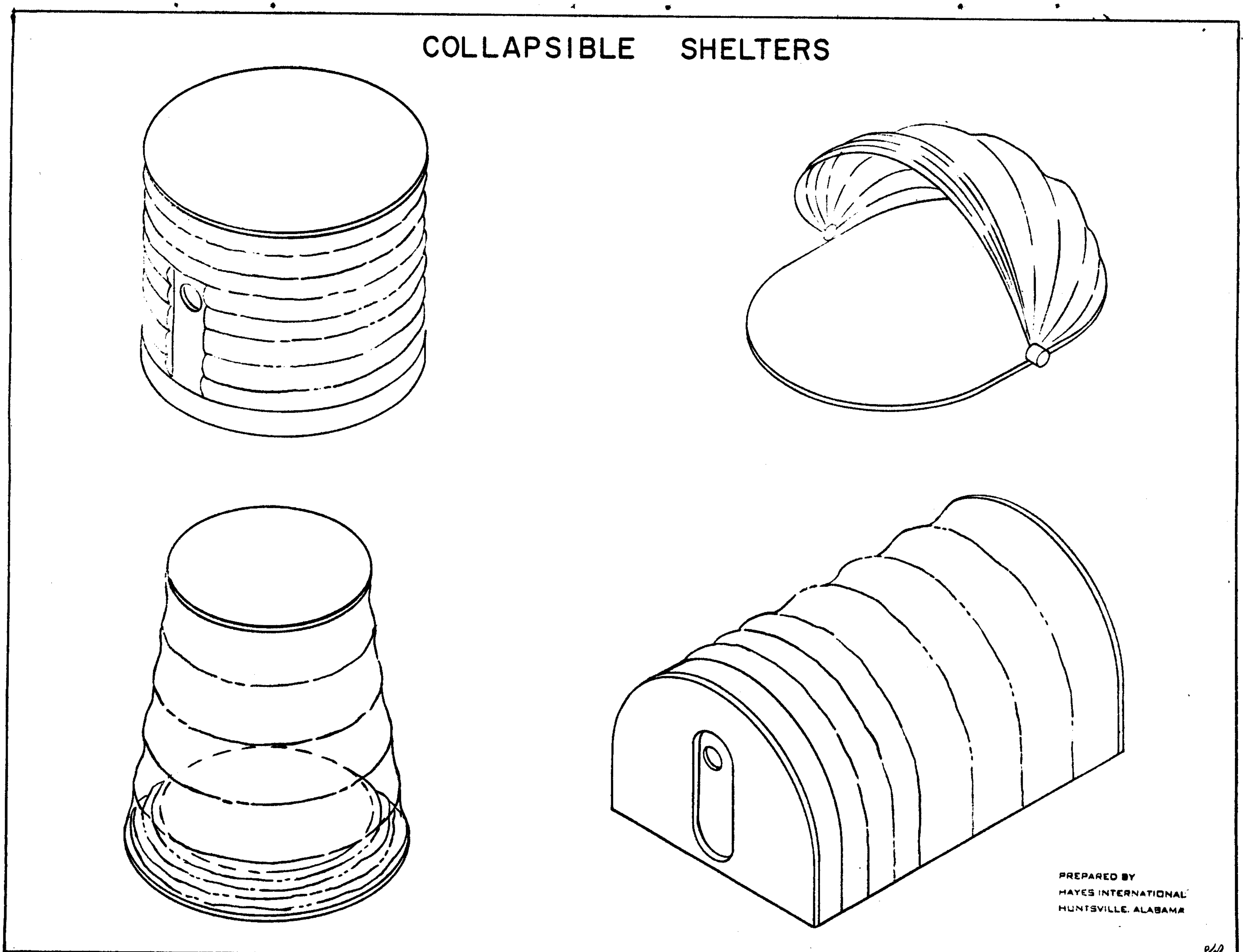
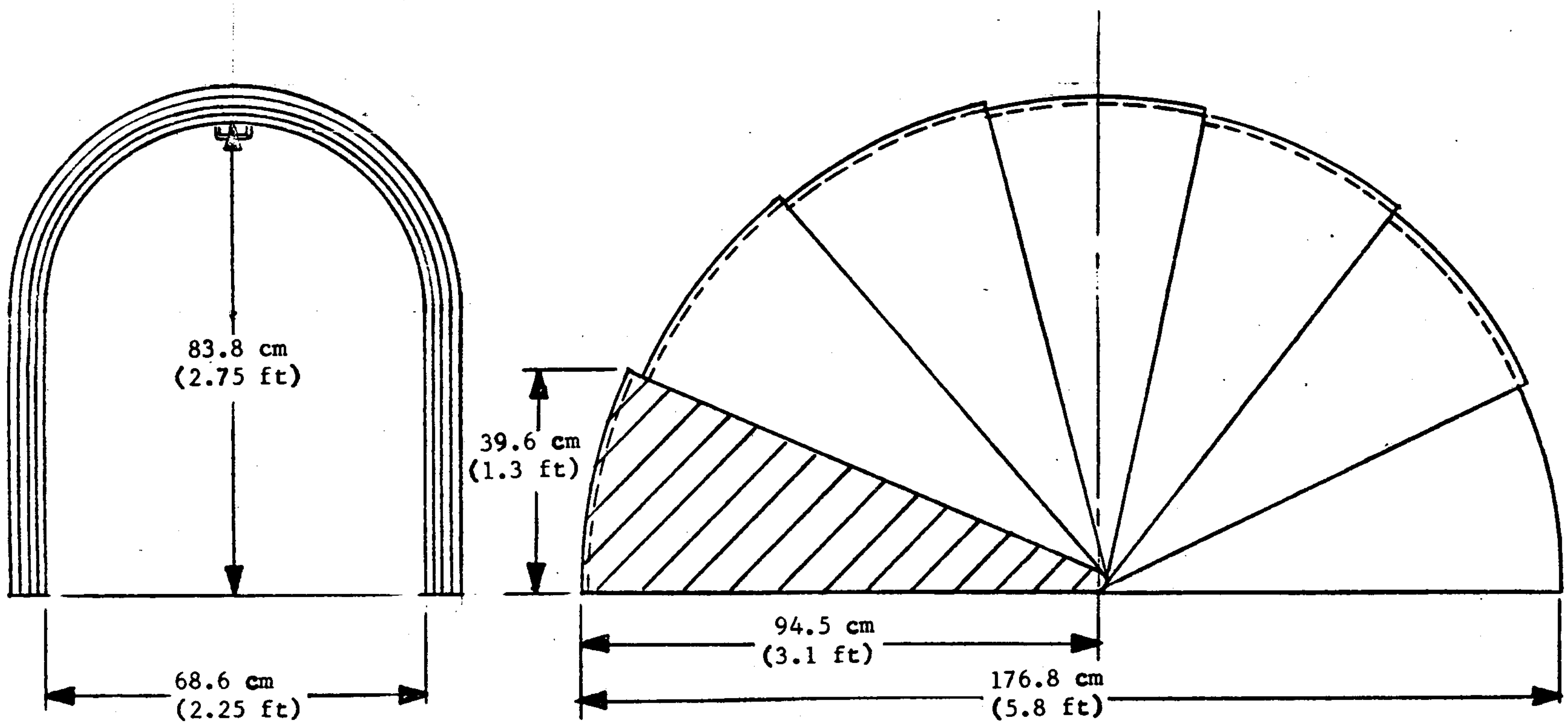


FIGURE 29 - COLLAPSIBLE SHELTERS

EXTENDABLE SHIELD (BUGGY TYPE)
FOR
MICROMETEORITE PROTECTION

FIGURE 30



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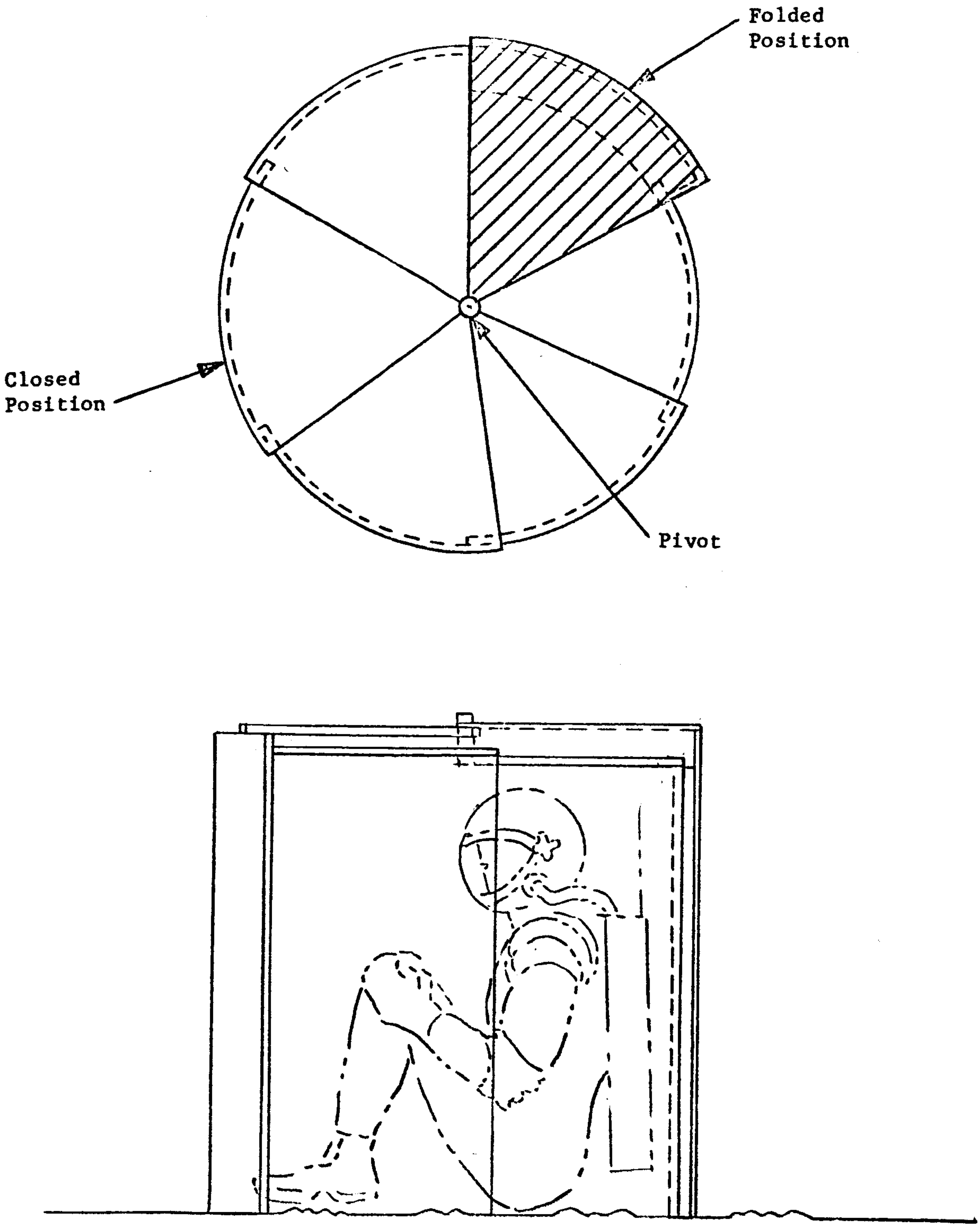


FIGURE 31

EXTENDABLE SHIELD

for

MICROMETEORITE PROTECTION

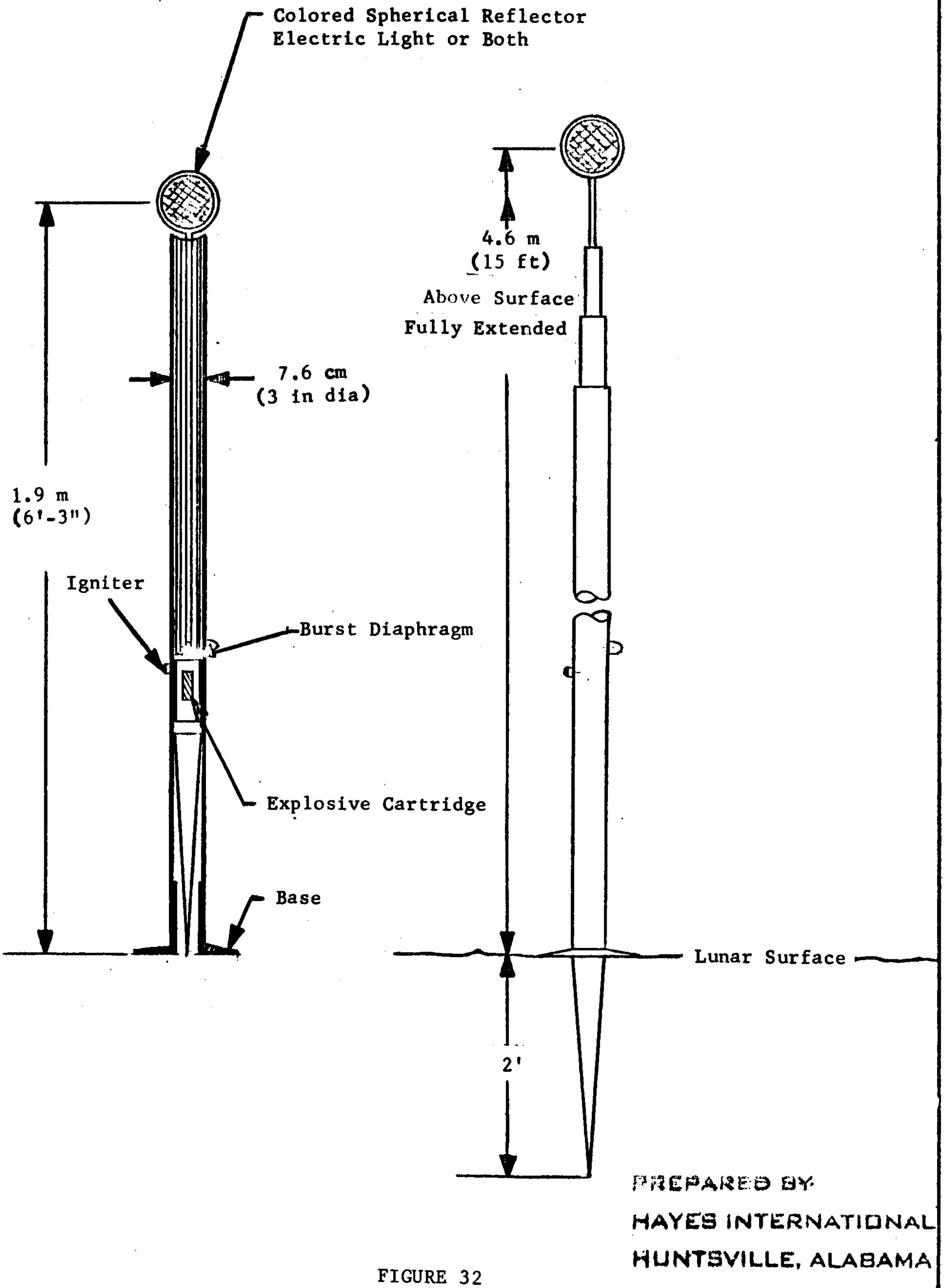


FIGURE 32

MARKER POLE

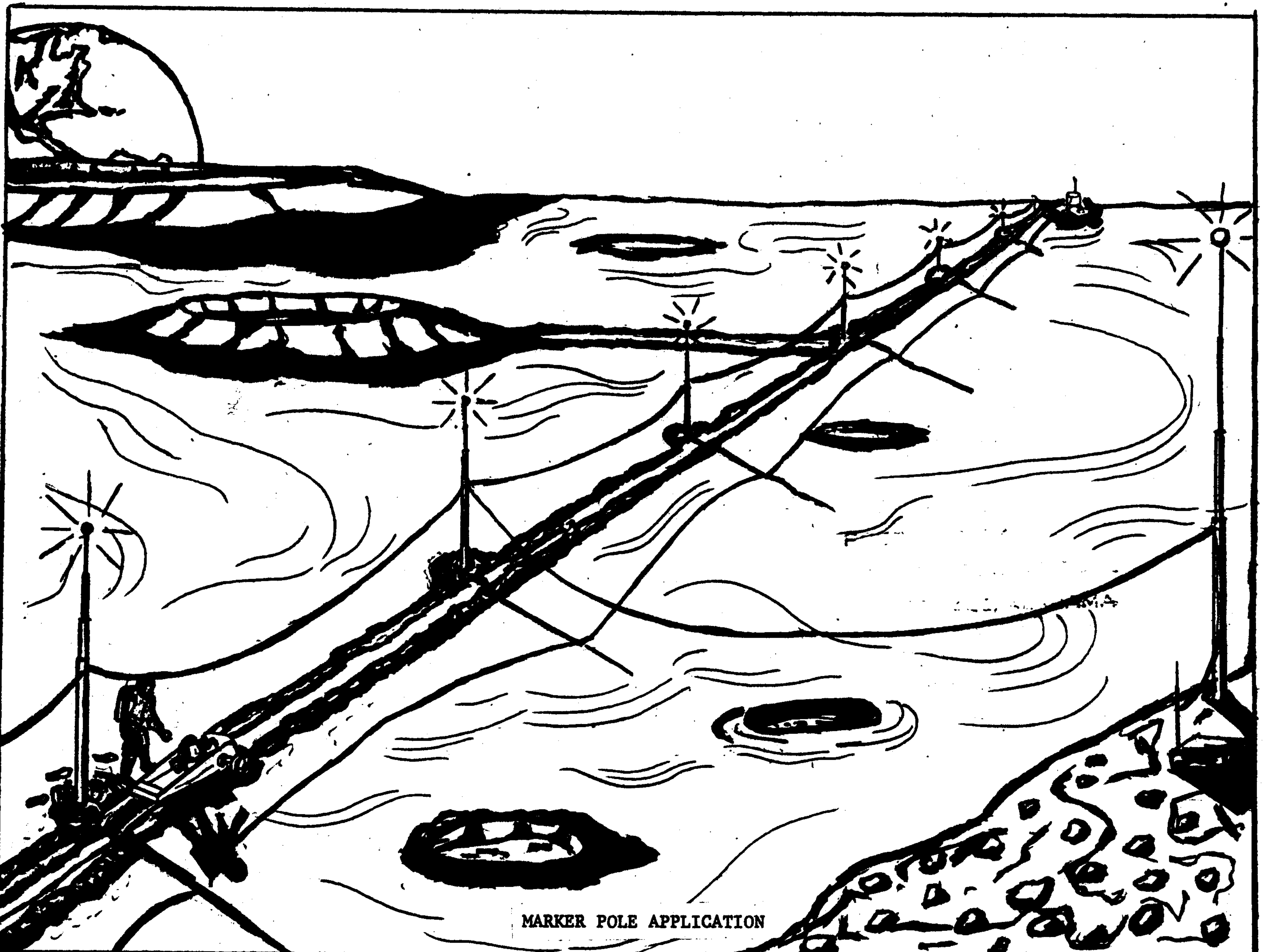


FIGURE 33 - MARKER POLE APPLICATION

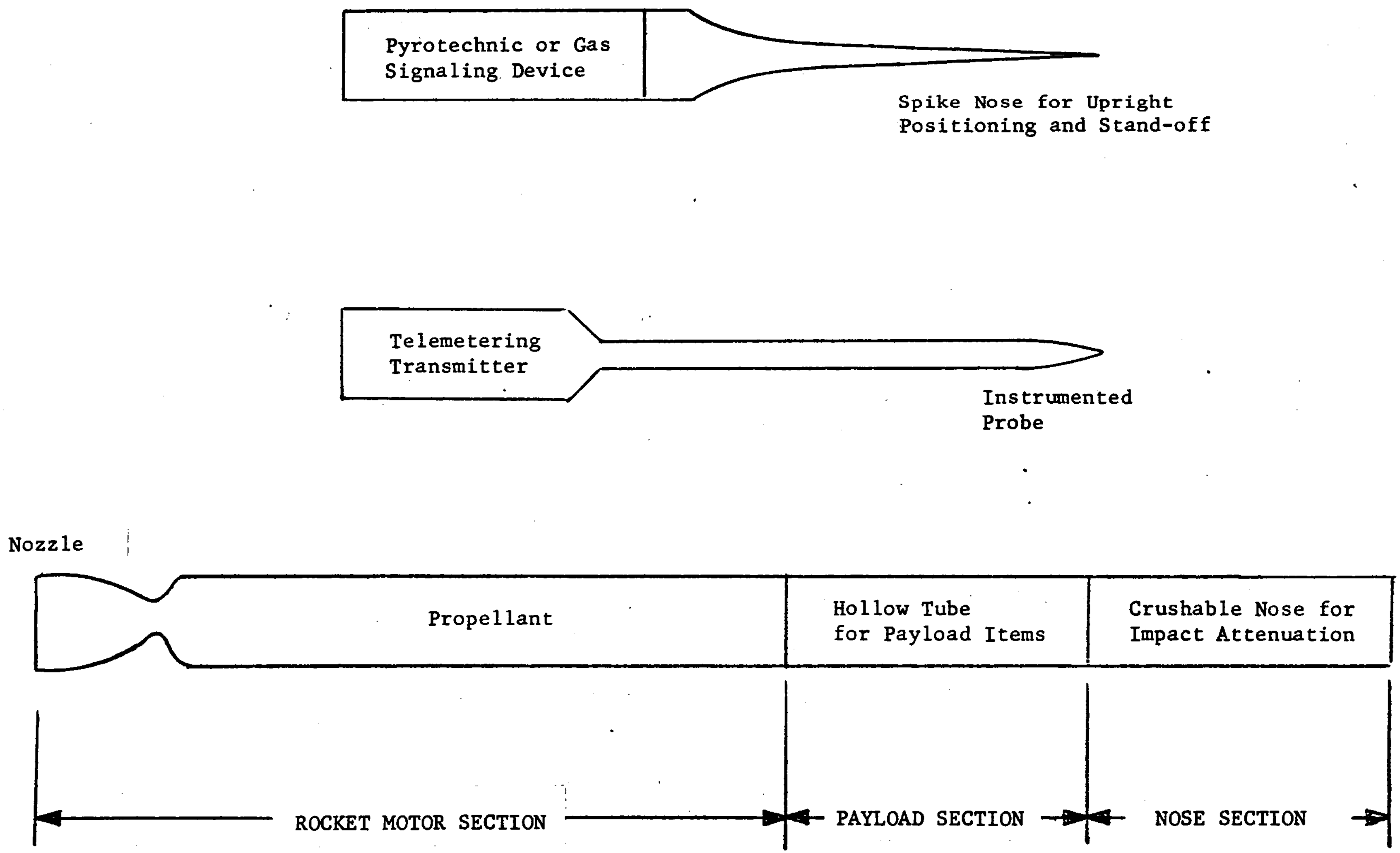
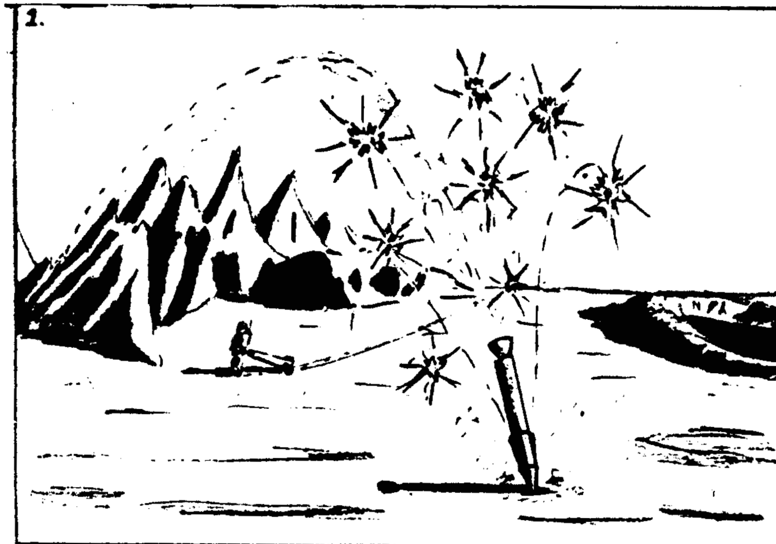
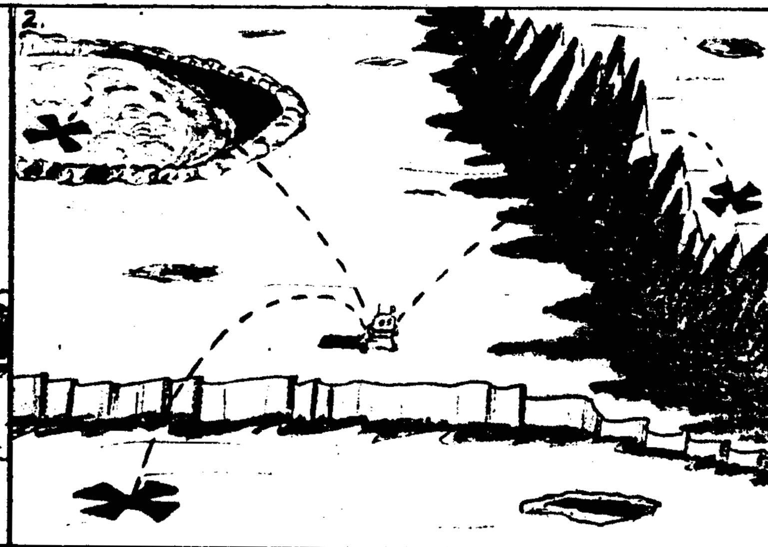


FIGURE 34

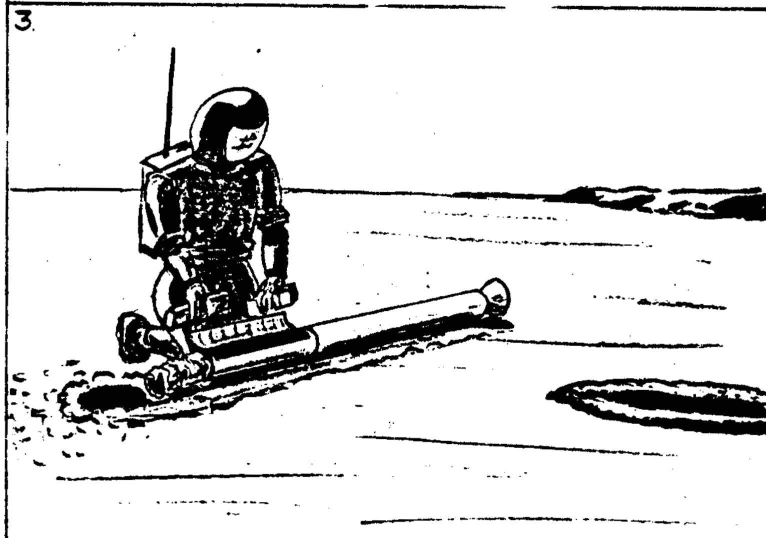
UTILITY MISSILE



<u>Signal Rocket</u> - For emergency messages by color-coded displays when out of radio range.



<u>Remote Data Collection</u> - Emplacement of sensing/telemetering probes in inaccessible or distant places.



<u>Quick Delivery</u> - of replacement parts, medicines or written messages in case of radio failure.

<u>Emergency Mobility</u> - Capability for transporting or lifting man or materials expediently.

FIGURE 35

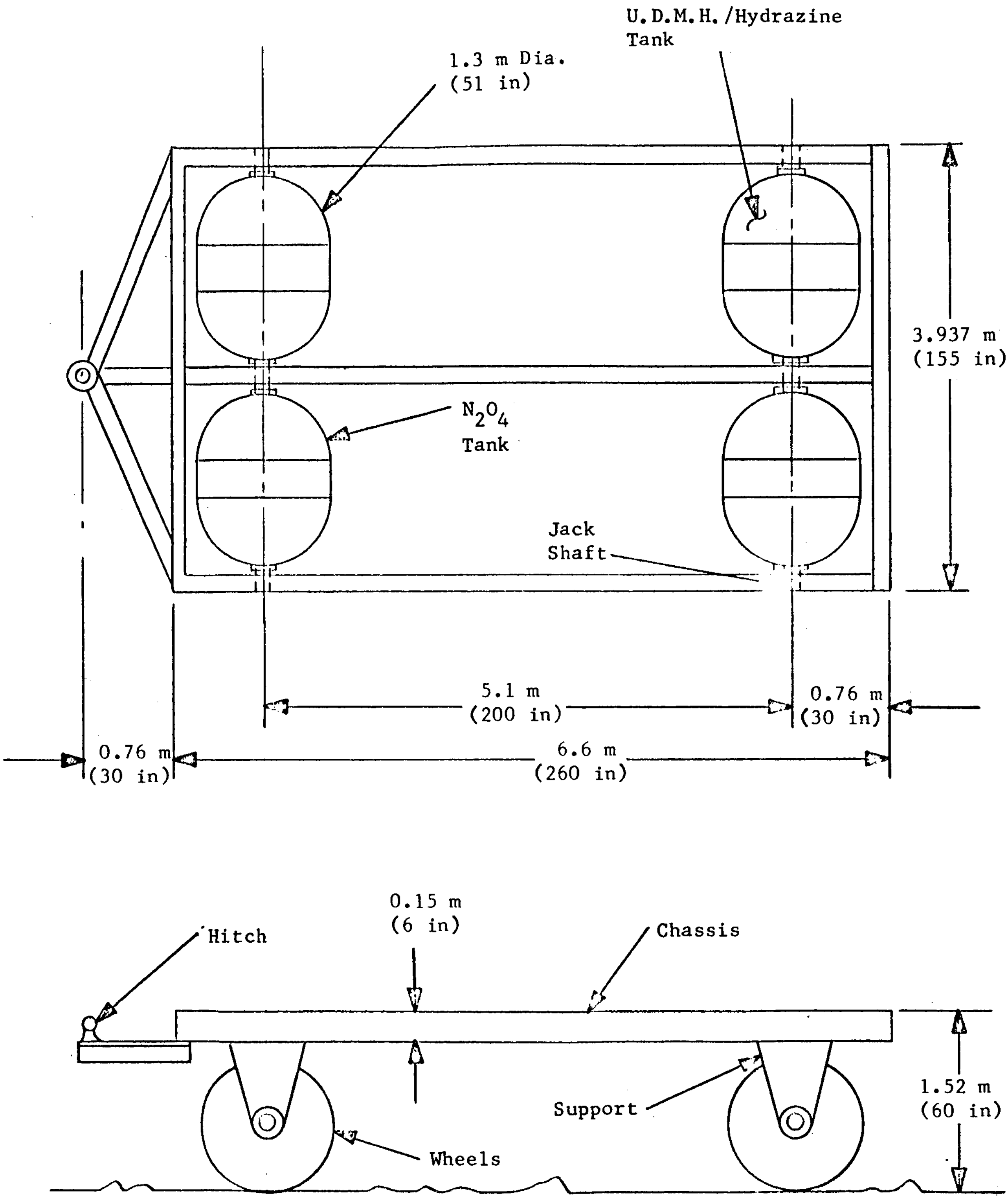


FIGURE 36

LUNAR TRAILER

REASSEMBLED TANKS

PREPARED BY
HAYES INTERNATIONAL
HUNTSVILLE, ALABAMA

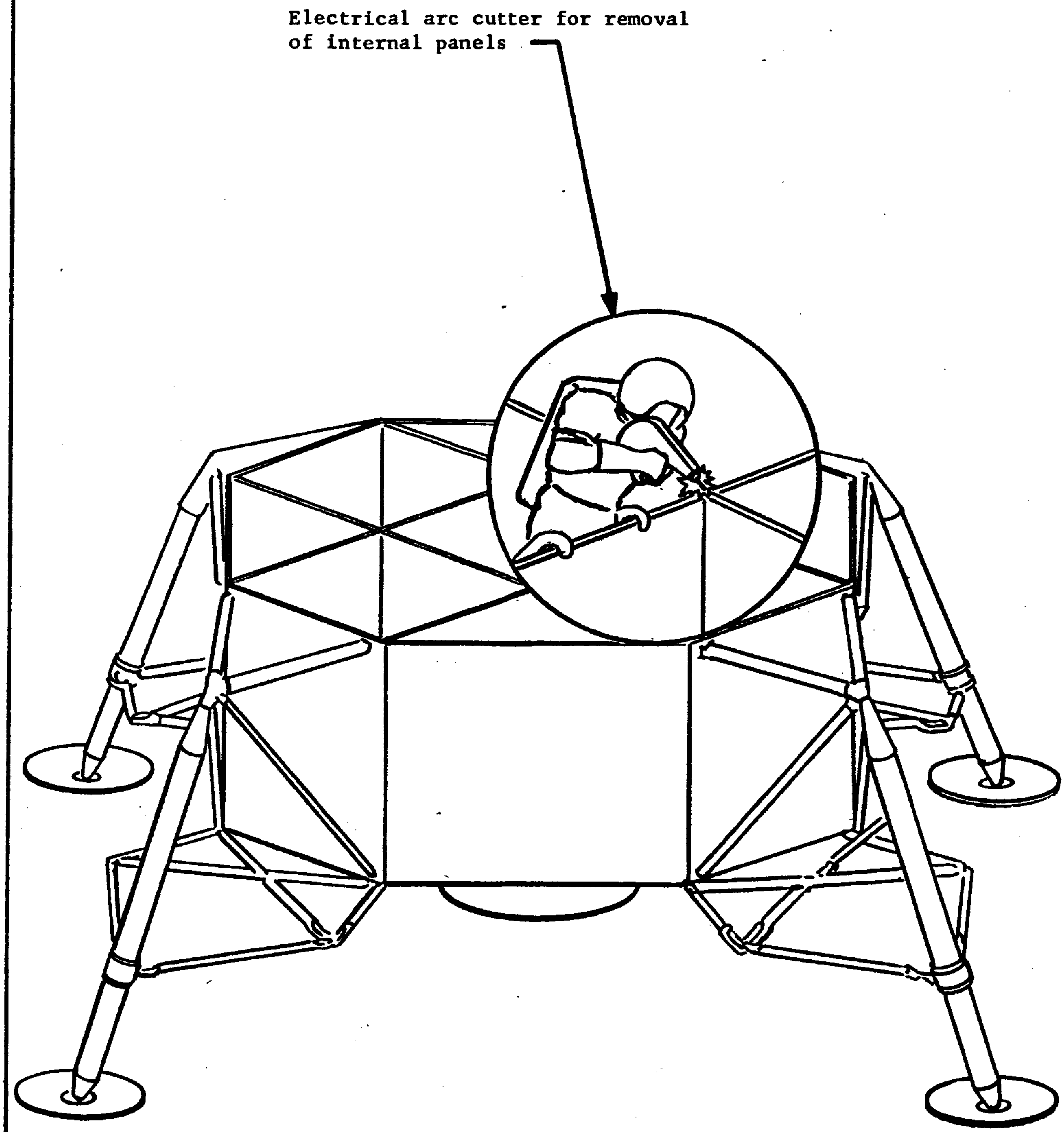


FIGURE 37

REMOVAL OF INNER SECTIONS OF LEM TRUCK,
FOR UTILIZATION OF FRAME

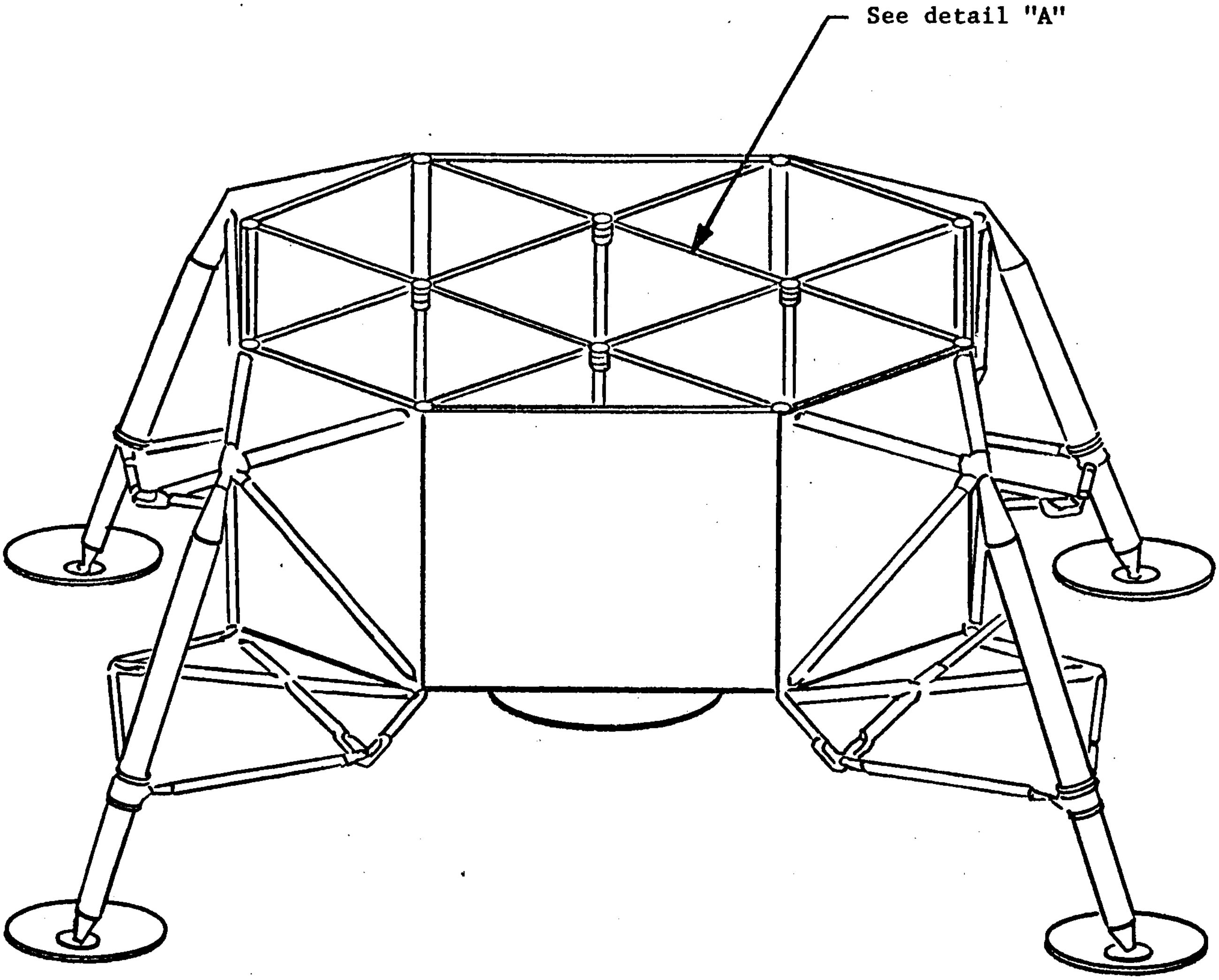


FIGURE 38

MODIFIED LEM TRUCK

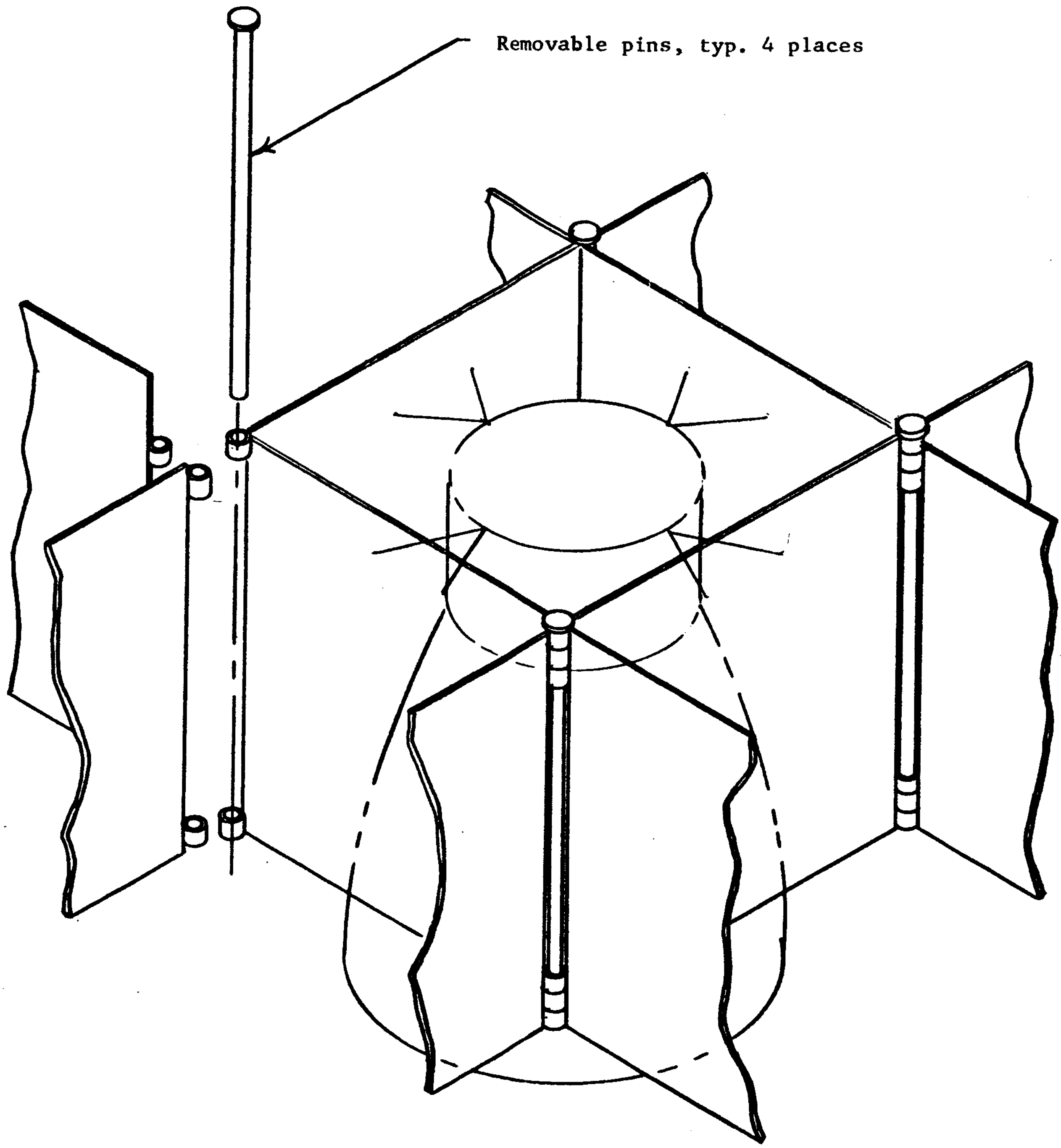


FIGURE 39

DETAIL "A"
REMOVABLE ENGINE AND HOUSING

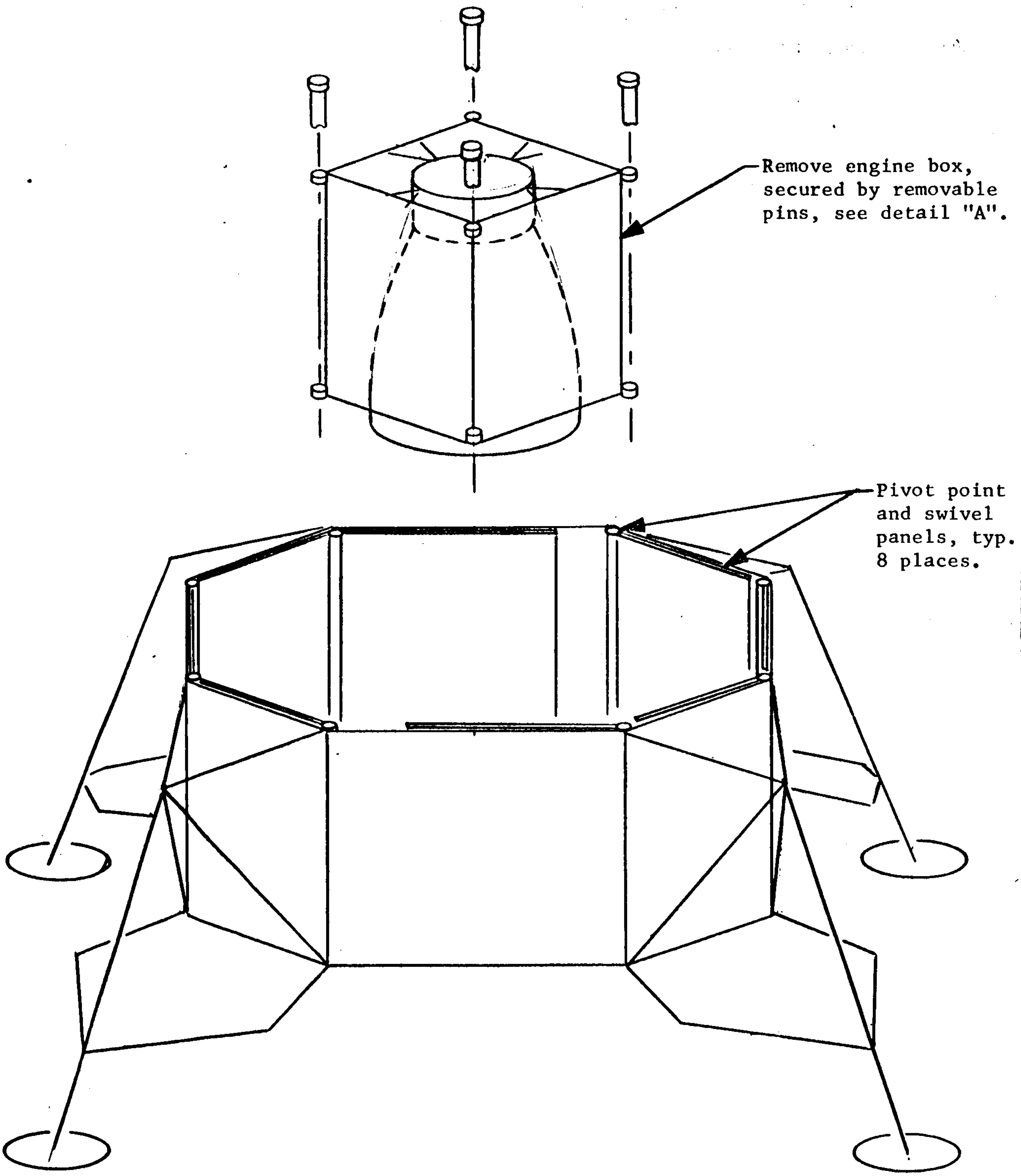


FIGURE 40
MODIFIED LEM/TRUCK

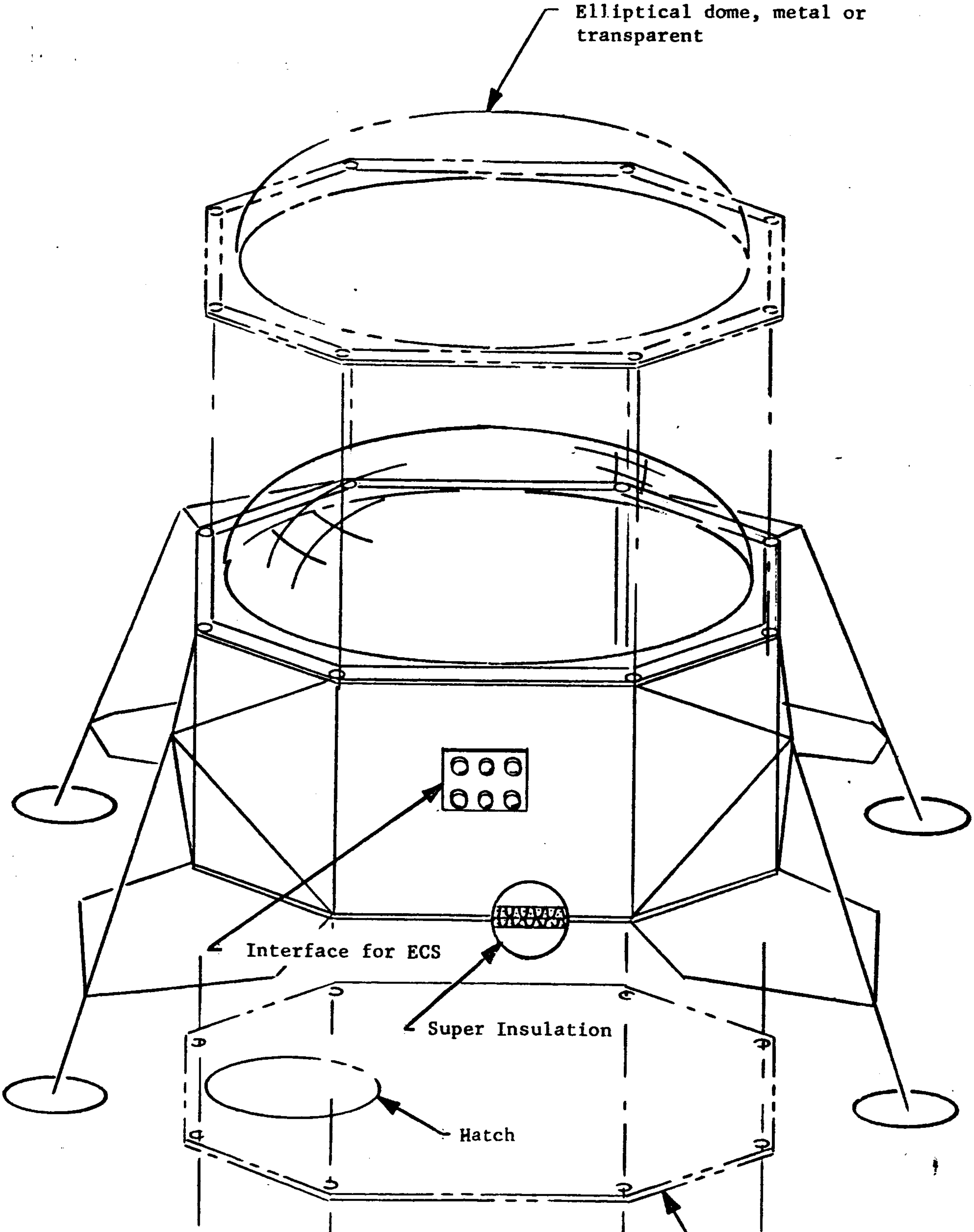


FIGURE 41
SOLARIUM - PHYSICAL FACILITY

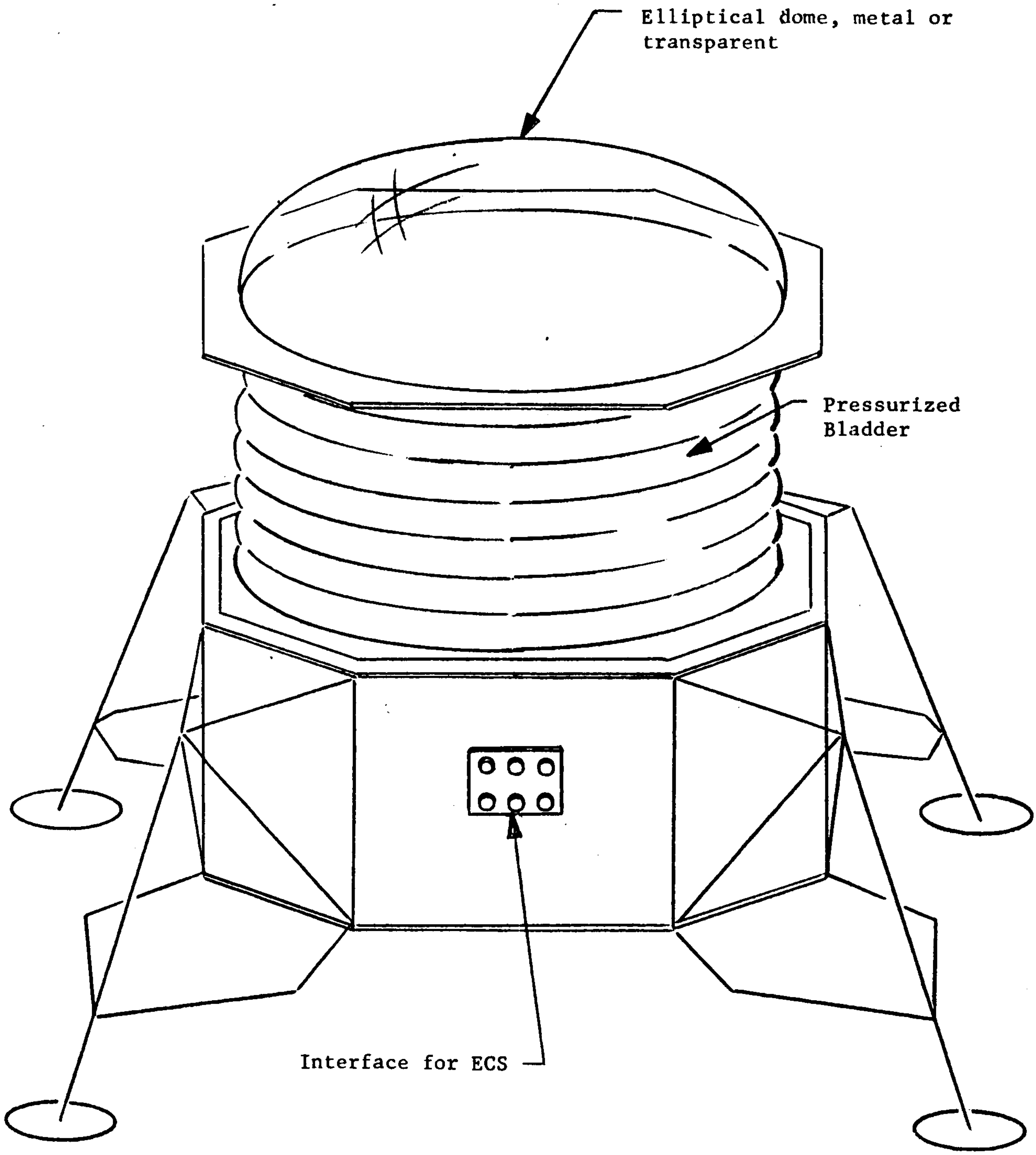
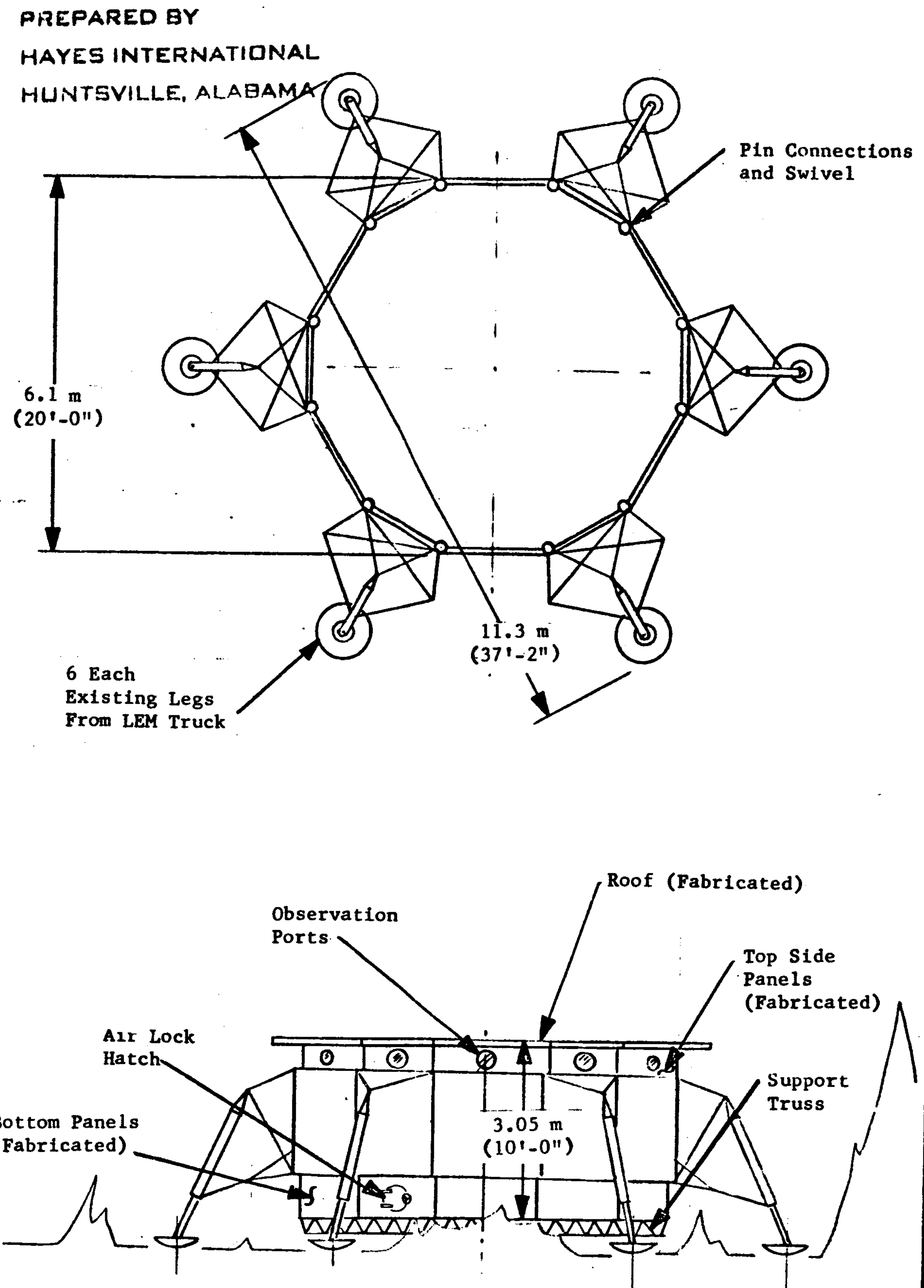


FIGURE 42

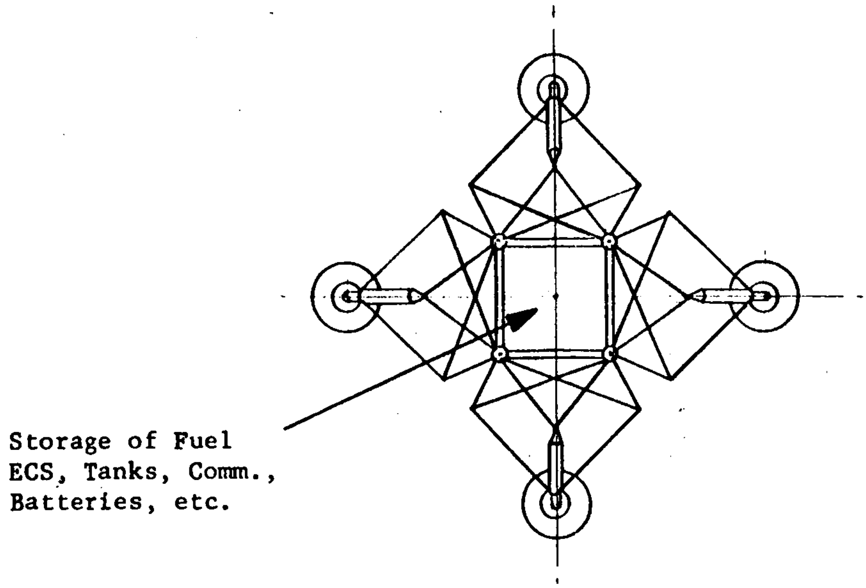
ASTRONOMICAL OBSERVATORY

MEDICAL FACILITY/TV STATION

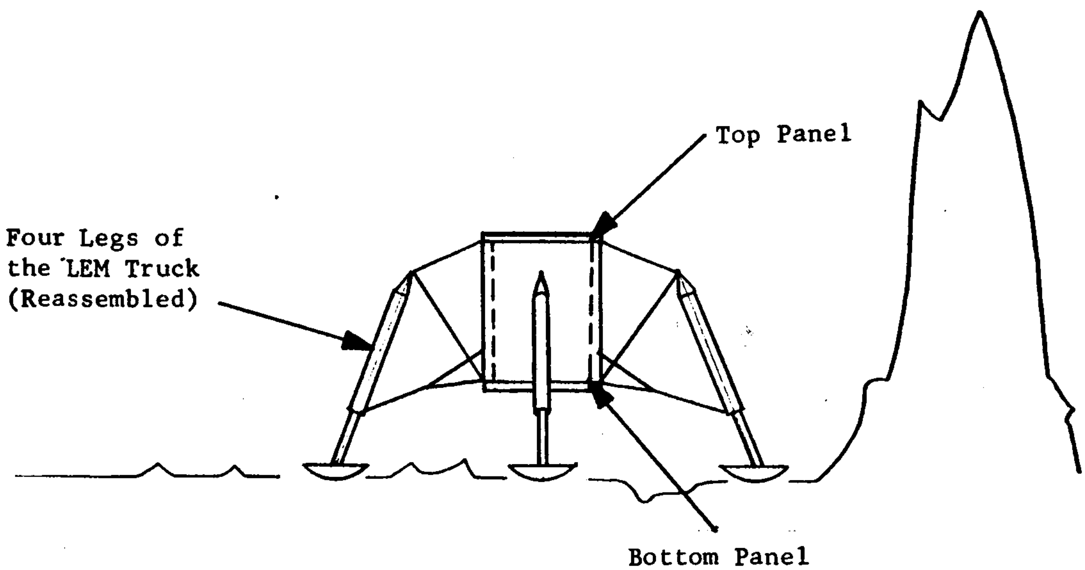


DODECAGON SHELTER

FIGURE 43



PLAN VIEW



ELEVATION VIEW

FIGURE 44

SMALL AREA STORAGE

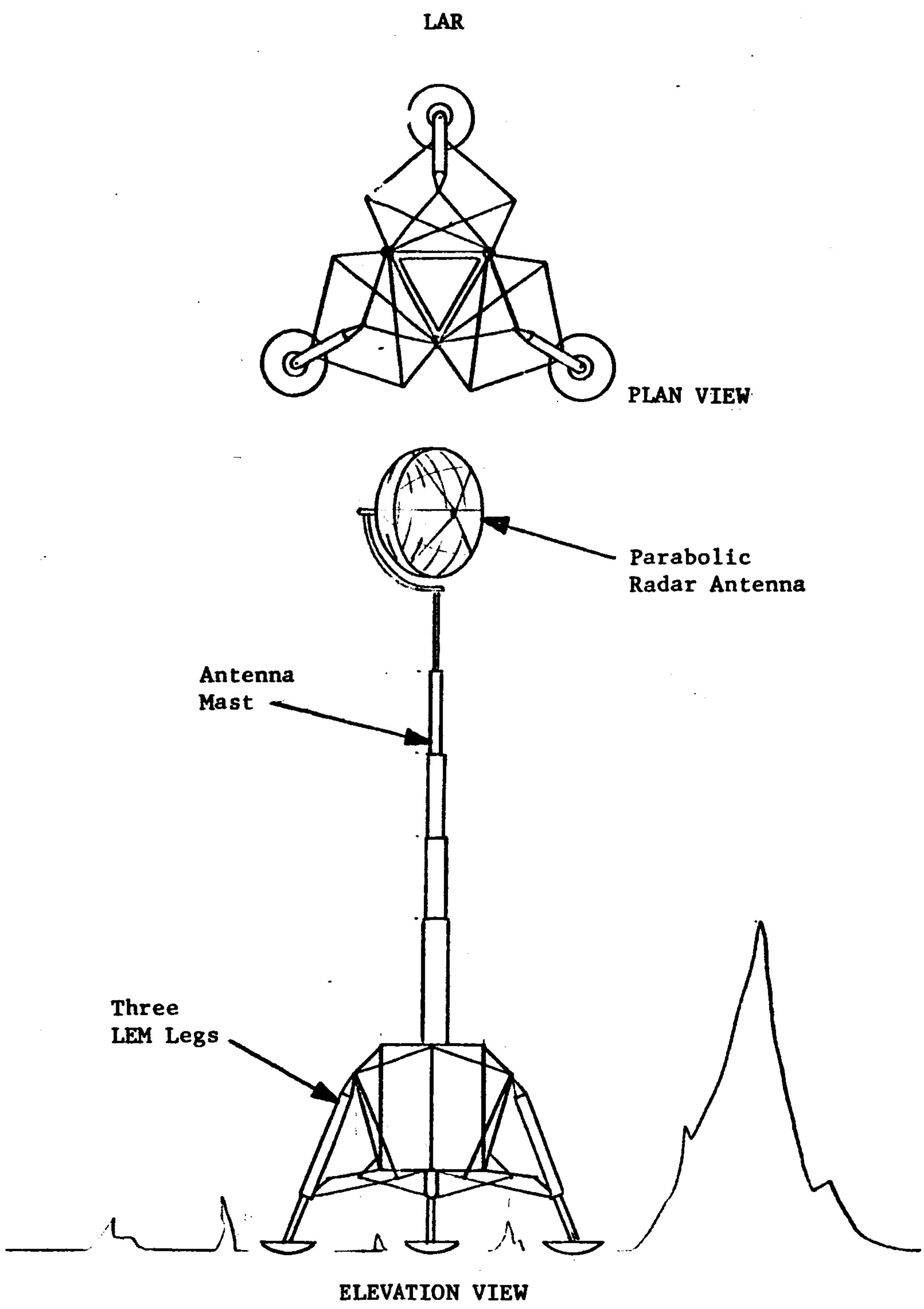


FIGURE 45

LUNAR ANTENNA REASSEMBLED

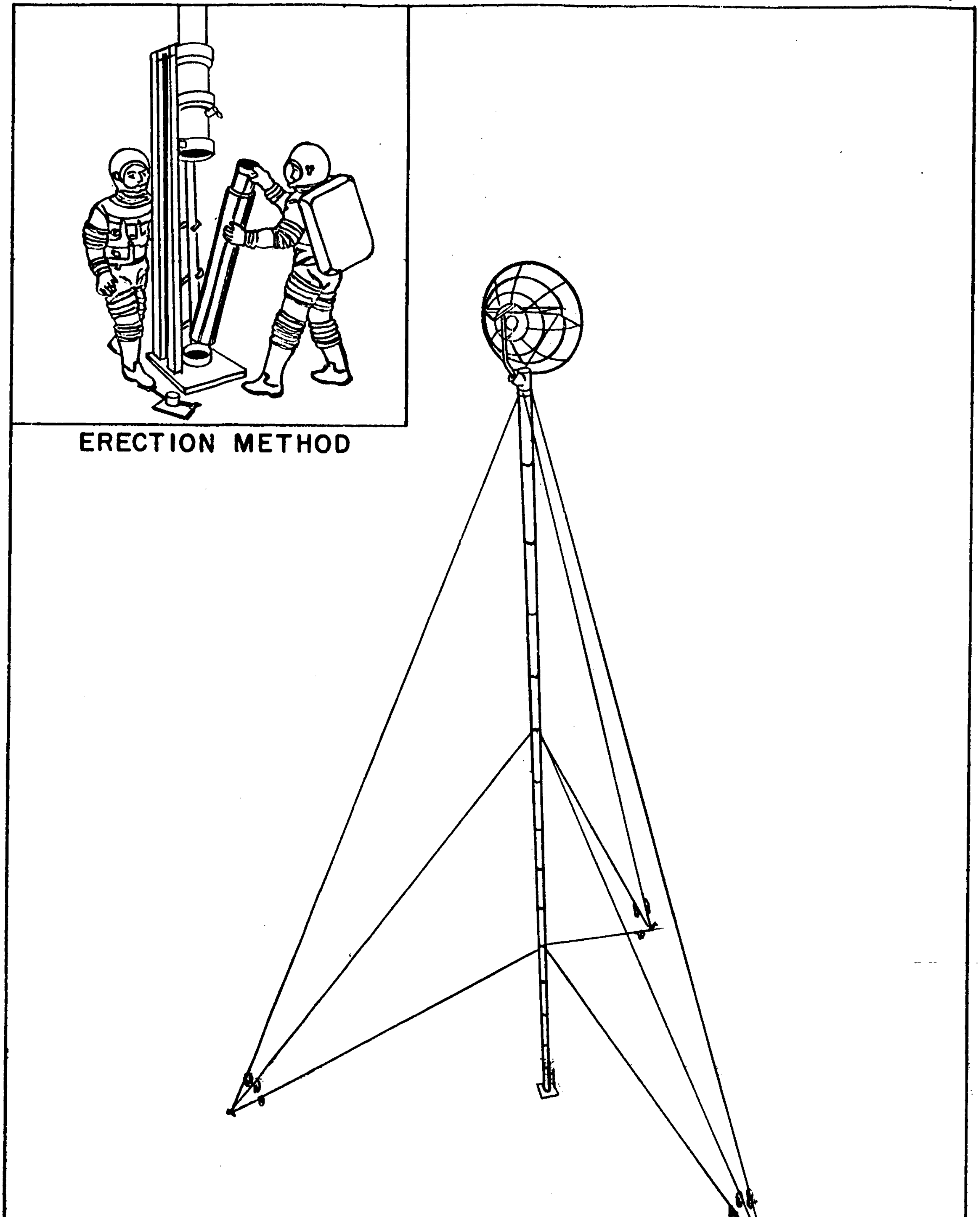


FIGURE 46 - ANTENNA MAST

APPENDIX A

POWERED VEHICLE CONFIGURATIONS

APPENDIX A

Several configuration variations of powered vehicles are represented in the attached sketches (Figures A-1 through A-9) which were furnished by R-P&VE-AB. These vehicles can be categorized in six groups: one-wheeled, or track-type vehicles; two-wheeled, side-by-side type vehicles; two-wheeled, fore-and-aft type vehicles; three wheeled; four wheeled; and multiples of these arrangements in trailer modules. In any of these vehicle design concepts, a final selection would be predicated on such as vehicle weight, manueverability, and packaging.

The last three sketches (Figure A-7, A-8, and A-9) show various types of drive components such as wheels, powerpod, controls, switches, fasteners, centerless wheel design, skids, hand trailer and some protective gear for the man on the moon.

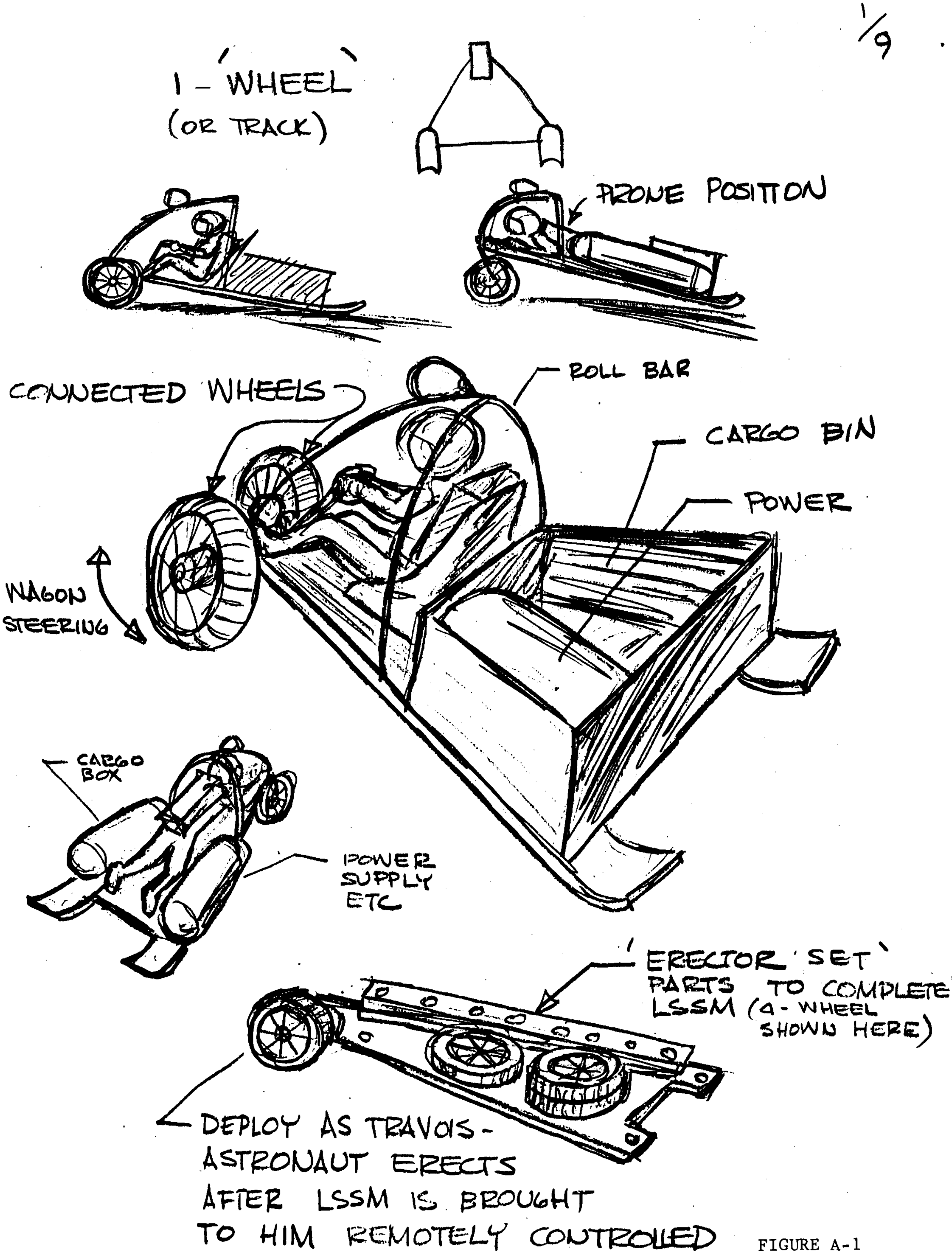

1/9
1-'WHEEL'
(OR TRACK)
PRONE POSITION
CONNECTED WHEELS
ROLL BAR
CARGO BIN
POWER
WAGON STEERING
CARGO BOX
POWER SUPPLY ETC
'ERECTOR' SET' PARTS TO COMPLETE LSSM (4-WHEEL SHOWN HERE)
DEPLOY AS TRAVOIS-
ASTRONAUT ERECTS
AFTER LSSM IS BROUGHT
TO HIM REMOTELY CONTROLLED

FIGURE A-1

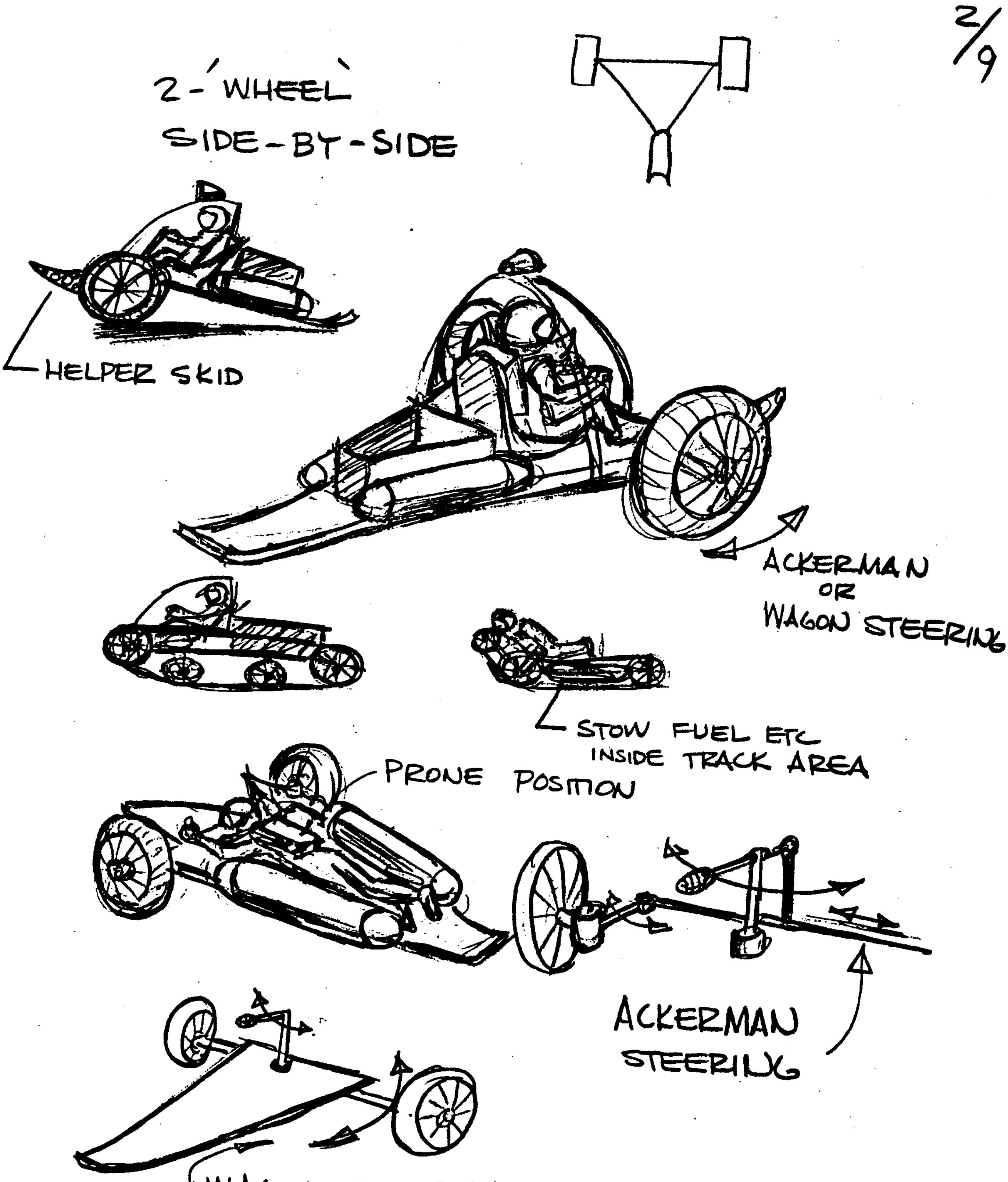

2/9
2-WHEEL
SIDE-BY-SIDE
HELPER SKID
ACKERMAN
OR
WAGON STEERING
STOW FUEL ETC
INSIDE TRACK AREA
PRONE POSITION
ACKERMAN
STEERING
WAGON STEERING

FIGURE A-2

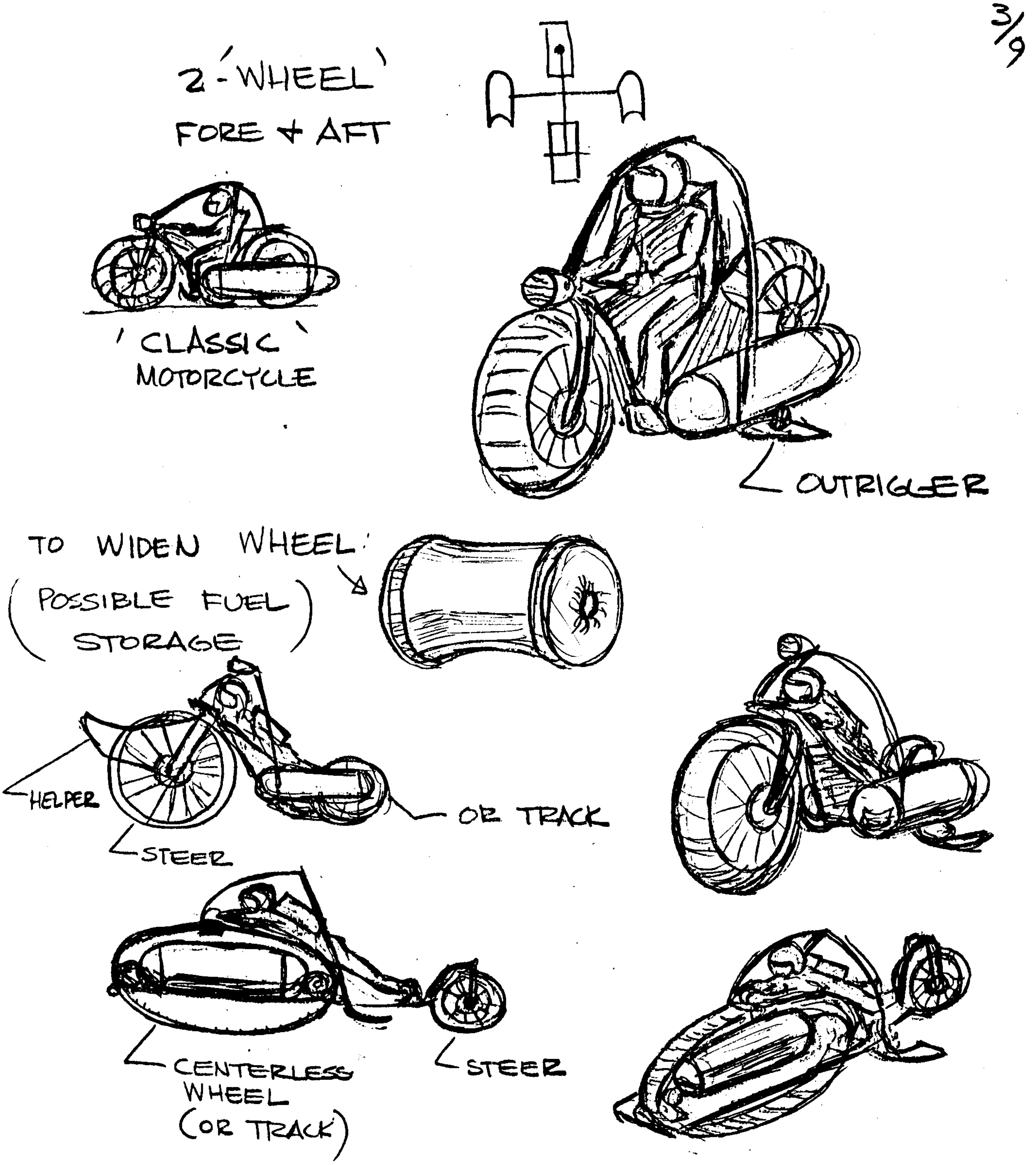

3/9
2-'WHEEL'
FORE & AFT
'CLASSIC'
MOTORCYCLE
OUTRIGGER
TO WIDEN WHEEL:
(POSSIBLE FUEL
STORAGE)
HELPER
STEER
OR TRACK
CENTERLESS
WHEEL
(OR TRACK)
STEER

FIGURE A-3

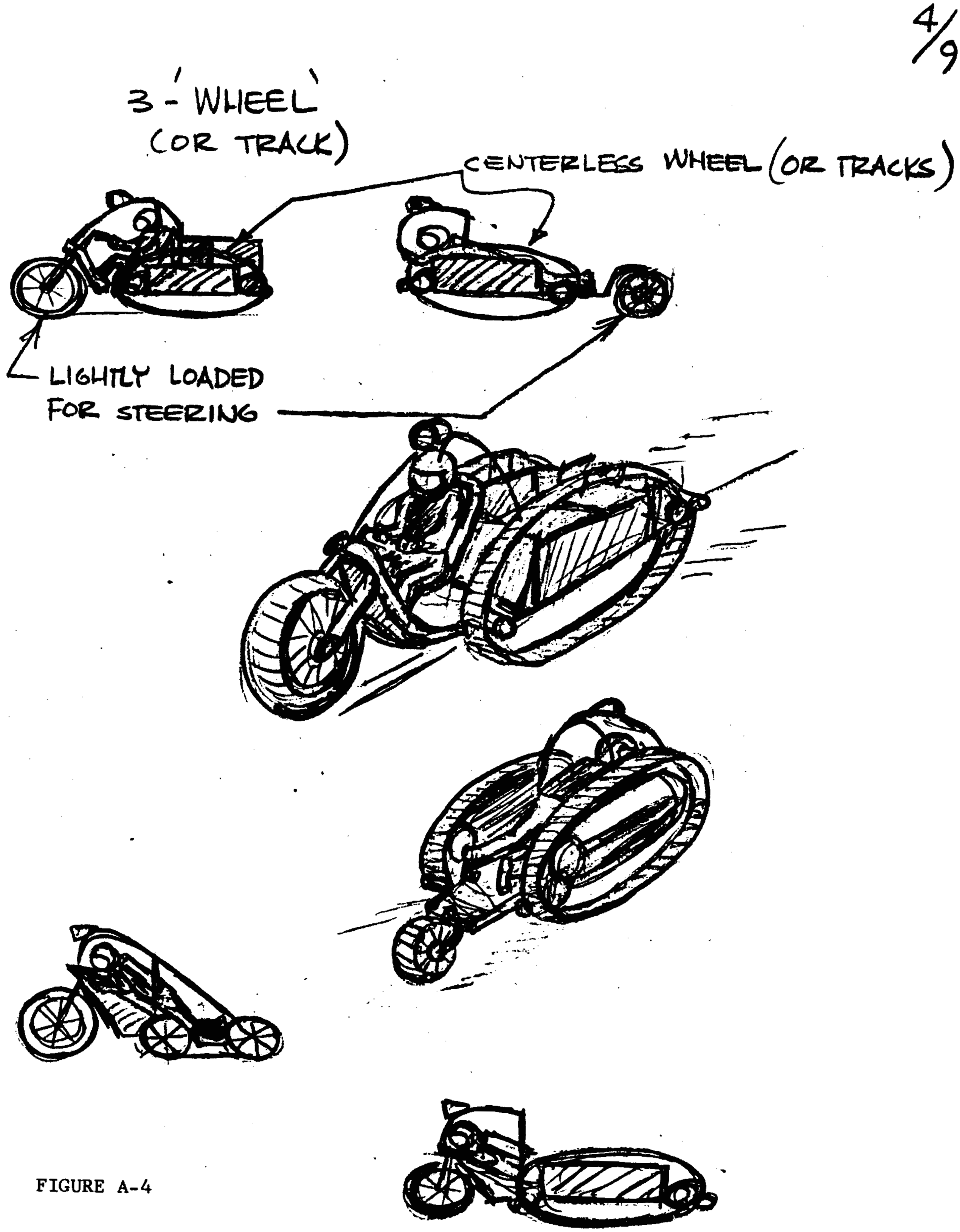

4/9
3-WHEEL
(OR TRACK)
CENTERLESS WHEEL (OR TRACKS)
LIGHTLY LOADED
FOR STEERING

FIGURE A-4

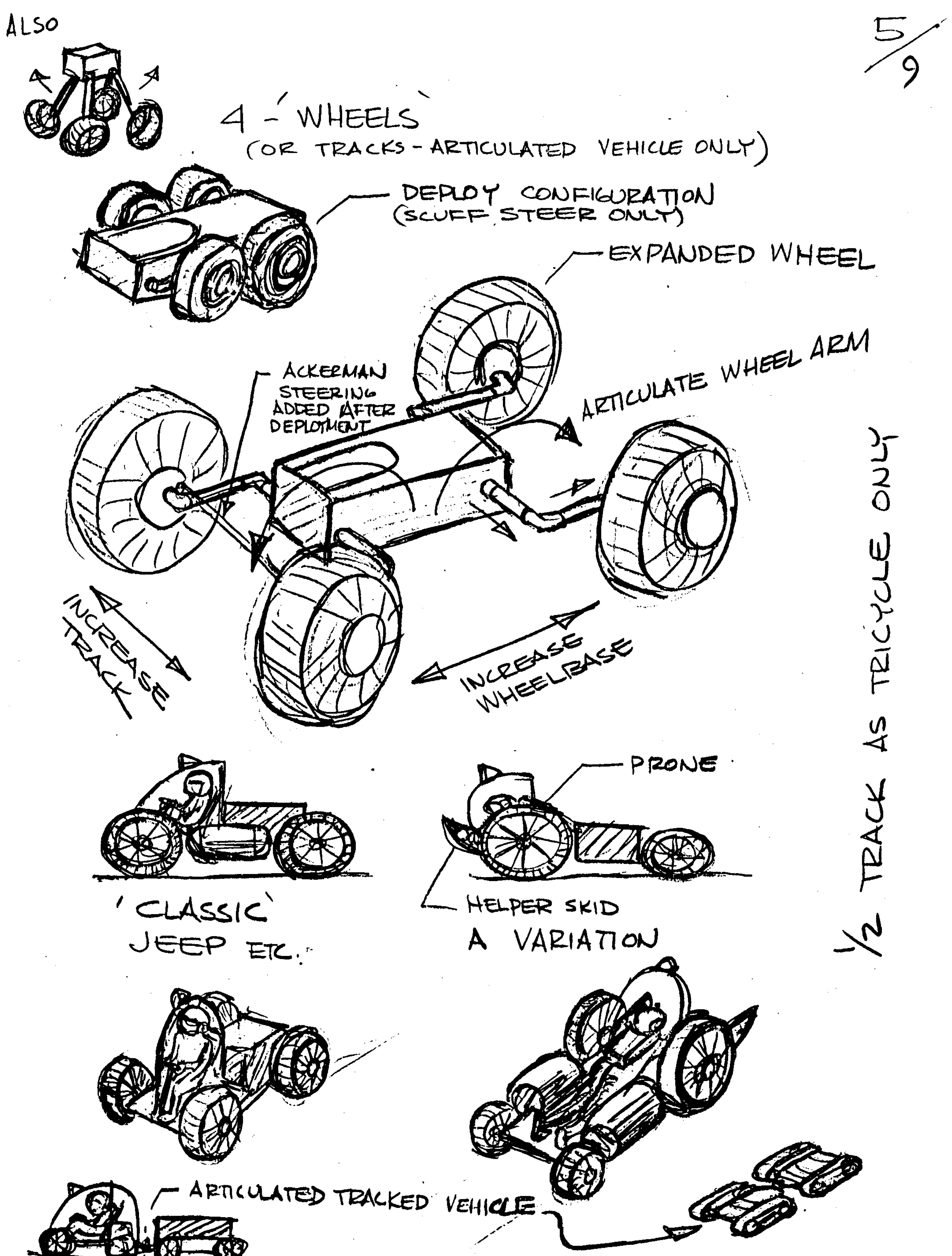
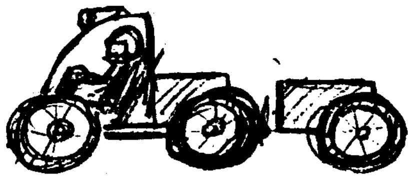

ALSO
5/9
4 - 'WHEELS'
(OR TRACKS - ARTICULATED VEHICLE ONLY)
DEPLOY CONFIGURATION
(SCUFF STEER ONLY)
EXPANDED WHEEL
ACKERMAN
STEERING
ADDED AFTER
DEPLOYMENT
ARTICULATE WHEEL ARM
1/2 TRACK AS TRICYCLE ONLY
INCREASE
TRACK
INCREASE
WHEELBASE
PRONE
'CLASSIC'
JEEP ETC.
HELPER SKID
A VARIATION
ARTICULATED TRACKED VEHICLE

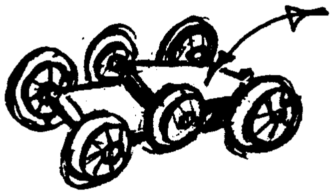
FIGURE A-5

6/9

6 - WHEELS (WHEELS ONLY CONSIDERED)



4 - WHEELS + TRAILER (COULD BE POWERED)

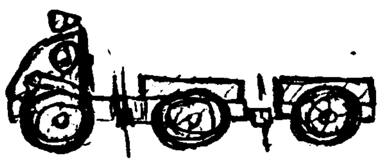


6 - WHEELER CAN BE ANY 4 - WHEELER + TRAILER

POSSIBLE STORAGE

8 - WHEELS & ON SIMILAR

MODULE CONCEPT



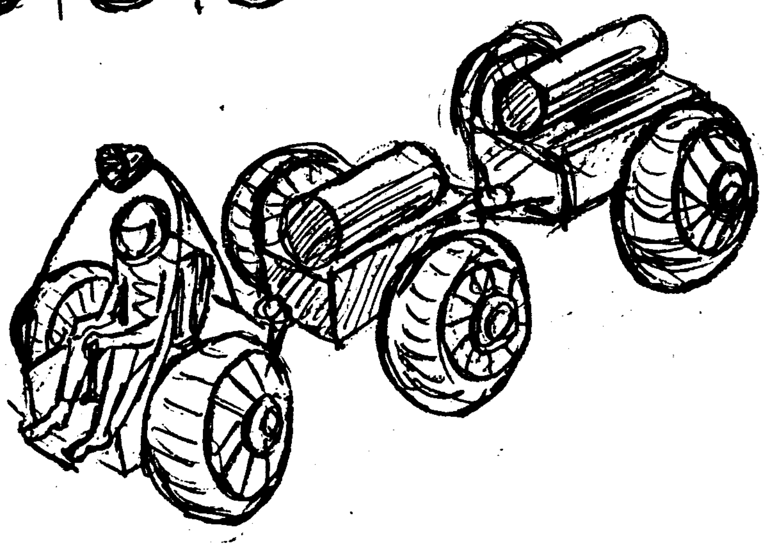
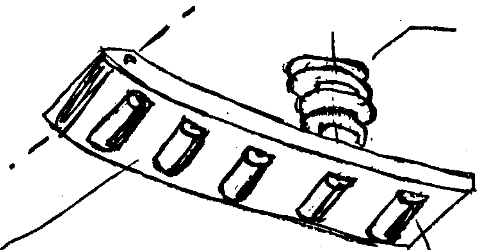


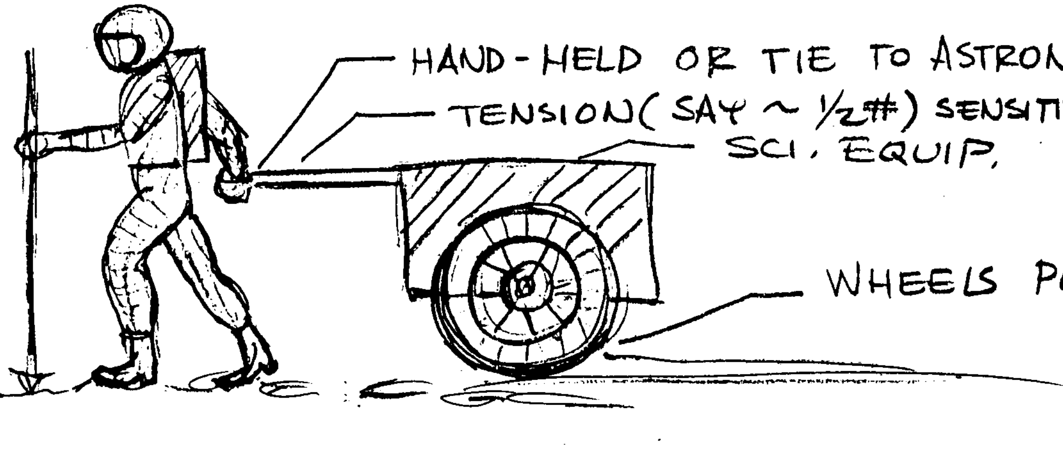
FIGURE A-6

DETAILS

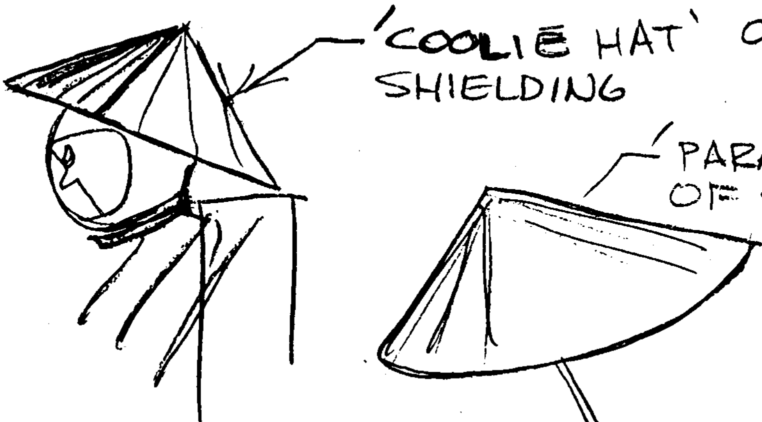
SKIDS



TRAILER (USED WITH ASTRONAUT OR ANY VEHICLE)



METEOROID SHIELD



MAKE REFLECTIVE FOR THERMAL PROTECTION IN SUNLIGHT

FIGURE A-7

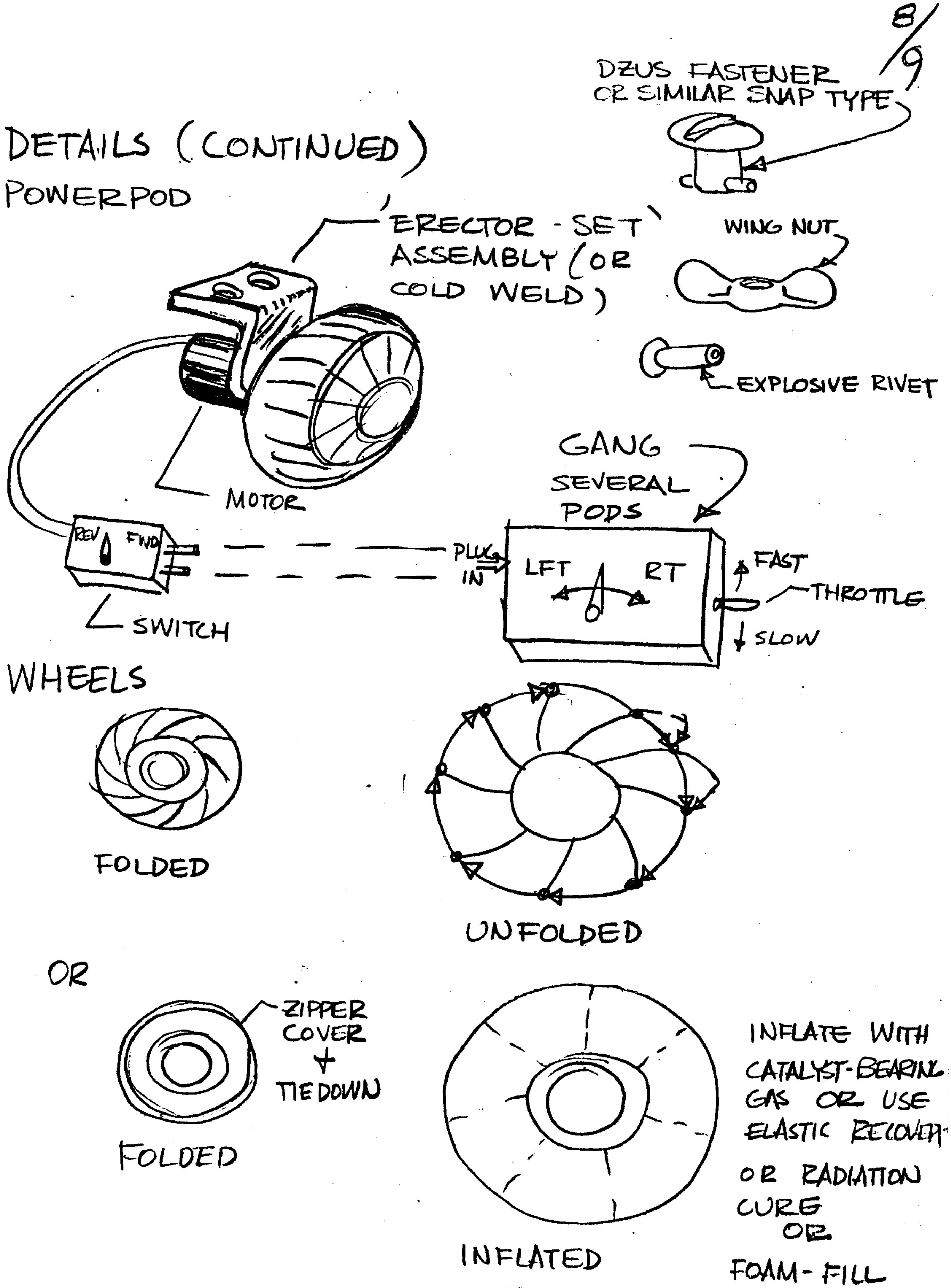
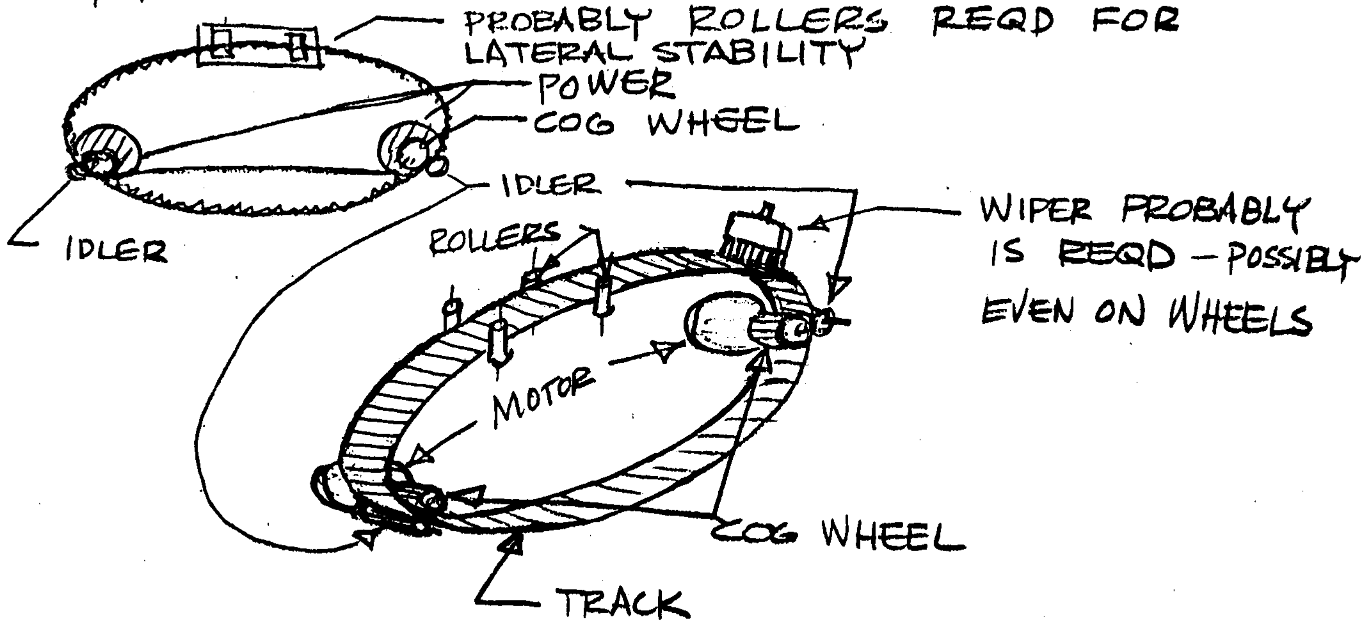

8/9
DETAILS (CONTINUED)
POWERPOD
ERECTOR - SET ASSEMBLY (OR COLD WELD)
DZUS FASTENER OR SIMILAR SNAP TYPE
WING NUT
EXPLOSIVE RIVET
MOTOR
GANG SEVERAL PODS
REV
FWD
SWITCH
PLUG IN
LFT
RT
FAST
THROTTLE
SLOW
WHEELS
FOLDED
UNFOLDED
OR
ZIPPER COVER + TIEDOWN
FOLDED
INFLATED
INFLATE WITH CATALYST-BEARING GAS OR USE ELASTIC RECOVERY OR RADIATION CURE OR FOAM-FILL

FIGURE A-8

CENTERLESS WHEEL



HELPERS

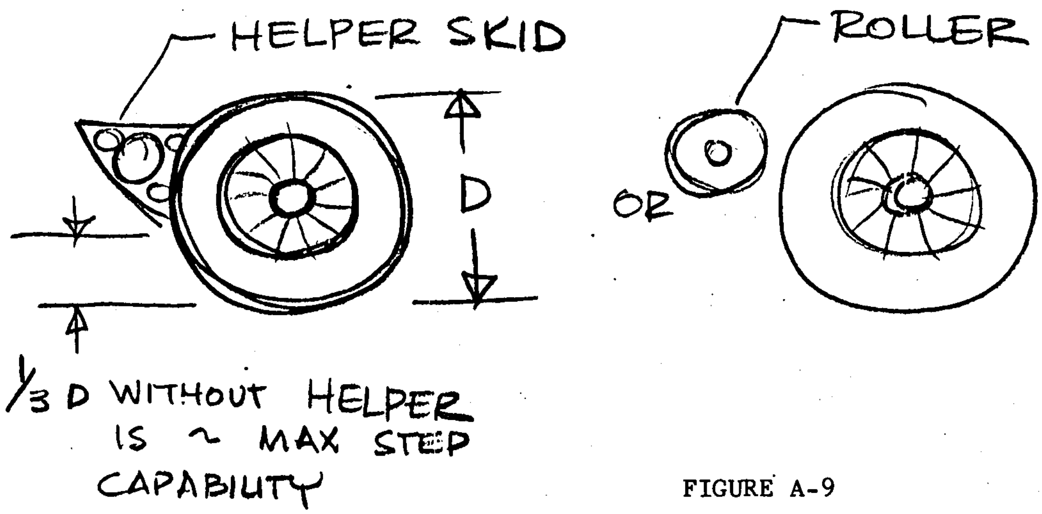


FIGURE A-9

PLEASE FORWARD ANY COMMENTS OR SUGGESTIONS TO: DICK LOVE R-P&VE-ABT
876-3566, -1526, OR 877-2135

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2. "Recommendations on Remaining Task Work", Lunar Surface - Special Purpose Equipment Memo, March 24, 1965.

3. Evans, Maj. T. C., "Extended Lunar Exploration", presented at 10th Annual Meeting of AAS, May 4-7, 1964.

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5. Mason, R. L., W. M. McCombs, D. C. Cramblit, Engineering Lunar Model Surface (ELMS), NASA - J. F. Kennedy, S. C. TR-83-D, Sept. 4, 1964.

6. Cramblit, D. C., W. Merritt, Preliminary Lunar Roving Vehicle Steering and Stability Considerations, TR-4-56-2-D, NASA - J. F. Kennedy Space Flight Center, March 31, 1964.

7. "Space Batteries", Technology Handbook, NASA SP-5004.

8. "Antenna (75' Portable Army Type)", Arde, Inc., 2115 Seminole Dr. S. W., Huntsville, Ala.

9. Doughtie, James, Elements of Mechanisms, "Linkages", Chapter 5, Wiley, 1954.

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