THE LUNAR CART

By Glenn C. Miller*

ABSTRACT

A need was defined for expanded experiment-carrying capability for the lunar-surface crewmen, to be used between the Apollo 11 capability and the lunar roving vehicle capability. Methods used on earth to satisfy similar requirements were studied. A two-wheeled cart was built and tested to expected mission requirements and environments. The vehicle was used successfully on Apollo 14.

INTRODUCTION

After the first manned landing on the moon, the NASA Manned Spacecraft Center needed to expand the capability of the crewmen to carry experiments and associated tools a greater distance from the lunar-landing site. The lunar rover was to be used on later missions, but in the interim, a simple light device was desired to bridge the gap in mobility range for the Apollo experiments. The basic requirement was to carry a maximum of 163.30 kilograms (360 pounds) of equipment up to 3352.8 meters (11 000 feet) from the landing site. The weight limit for this capability was 13.61 kilograms (30 pounds). There were 30 items of potential payload, and they varied widely in size, shape, material, and weight; thus, no standardized mounting procedures could be used.

STUDY OF POTENTIAL CANDIDATES

Various devices used on earth to satisfy similar requirements were examined. This examination resulted in the following list: the travois, the suitcase, the pallet, and the single-, dual-, and four-wheeled vehicles. Each of these devices was an expression of the materials and resources available for the situation under which they had evolved on earth. Because each device was successful on earth, presumably, it would work on the moon.

The travois was conceived to carry heavy loads, but it disregarded efficient power utilization (fig. 1). Basically, the suitcase was designed to protect transported objects and to reduce many items to one item (fig. 2). A pallet, an excellent device for carrying many different things, accommodated a diverse and changeable payload (fig. 3). The wheelbarrow was a means of transporting heavy loads or diverse and

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changeable loads for short distances; it reduced the lifting load and minimized the rolling friction by utilizing the wheel (fig. 4). The two-wheeled cart, a more stable wheelbarrow, reduced the wheel-bearing pressure for each wheel (fig. 5). The four-wheeled wagon was a very stable vehicle having low surface-contact pressure/wheel (fig. 6). The wagon was inherently heavier and less maneuverable than were the one- or two-wheeled vehicles. The single-, dual-, and four-wheeled vehicles and a pallet were chosen for testing.

SELECTION OF CONCEPT

A test vehicle was constructed to observe the options. The payload of 163.30 kilograms (360 pounds) became the prime criterion in the final selection of a test vehicle. To keep the loaded wheelbarrow stable, the crewman had to grip the handles constantly; thus, he was fighting continually the desire of the pressurized glove to remain extended. Within several minutes, his forearms became so tired that he had to rest. Also, the decision was made that the crewman should pull rather than push the vehicle. If the wheel became lodged in a hole or deep soil when the crewman was pushing the vehicle, he could be catapulted over the vehicle; however, if the wheel hit an immovable object when the crewman was pulling the vehicle, it was pulled from the crewman's grasp. The two-wheeled cart was a solution to the stability problem of the wheelbarrow and considerably reduced the arm fatigue; therefore, the heavier four-wheeled vehicle was eliminated from further consideration. Thus, the two-wheeled cart, which contained a pallet as the body of the cart, became the final selection.

TYPE OF WHEEL

The rubber tire was selected because of its widespread use on earth. The rubber tire did not present a temperature problem. Previously, rubber tires were tested, under load, to 202.59° K (-95° F) before they failed; the predicted minimum operational temperature on the lunar surface was 238.70° K (-30° F). The principal problems with the rubber tire were the ability of the tire to hold air in a vacuum and the tear resistance of the tire on the lunar surface.

DEVELOPMENT AND QUALIFICATION

Vehicle/Crew Interface

To define the crew interface, 1/6g testing was conducted. The first configuration had two handles that caused problems: the rolling gait of the crewman imparted the same roll to the cart, and the fact that two handles required two hands disturbed the gait. By switching to one handle, both problems were eliminated (fig. 7).

The next interface problem, the tiring of the crewman's arm from gripping the handle, was solved by going to a triangular grip (fig. 8). The dimension of the triangle base was greater than the gloved hand; however, the altitude of the triangle was less than the gloved hand. This fact allowed the crewman to insert his hand on the grip; with a 90° rotation of his hand, the glove was wedged into the triangle. In this fashion, the crewman could pull the cart without gripping the handle.

In testing the vehicle, the fact was noted that the two legs, which provided the desired static stability, would hit the ground often. To solve this problem, a hinged joint was added, allowing the lower half of the leg to rotate when it hit a rock or the ground (fig. 9). A spring in the joint then forced the lower half of the leg to return to vertical. The joint had a slot to accept a pin in the lower leg when the leg was set on the ground; this action locked the joint for the desired static stability.

The proper height of the pallet above the ground was determined with a suited test subject. The wheel diameter and cross section were defined by measuring the pull-force capability of the crewman at 1/6g and by matching this capability with the calculated pull force of various wheel combinations. The required pull force compared with the load is shown in figure 10. The crewman's capability for sustained pulling was approximately 26.69 newtons (6 pounds), and his instantaneous pull force was approximately 111.2 to 155.68 newtons (25 to 35 pounds). From these data and the experience of the suited test subjects, the conclusion was reached that the crewman could pull as much as 163.30 kilograms (360 pounds) of vehicle, but that this action would have considerable effect on his oxygen and water usage and would reduce his total extravehicular-activity time on the moon. The vehicle payload was reduced by eliminating one experiment; the payload and the vehicle weight then became 61.24 kilograms (135 pounds). On the slopes of Cone Crater (a significant lunar-terrain goal for Apollo 14), the crewmen had to use the full 26.69-newton (6 pound) pull-force capability as opposed to the 3.34-newton (0.75 pound) capability on level surfaces. However, by trading the pulling job between crewmen and by remembering that the downhill portion of the traverse would be considerably easier, the decision was reached that the vehicle could be pulled without affecting the mission time on the lunar surface.

Vehicle/Environment Interface

The critical environments affecting the vehicle were heat, atmosphere, vibration, and the lunar surface. The environment-critical parts of the vehicle were the rubber tires, the wheel bearings, and the overall structure of the vehicle.

Wheel-bearing thermal drag. - The wheel-bearing test was accomplished by cold soaking the wheel assembly to 216.48° K (-70° F) in a vacuum chamber, heating the wheel hub to 366.48° K (200° F), and measuring the thermal gradients and the drag of the bearings. A simulated lunar soil (a mixture of red crushed volcanic scoria and air-floated clay) was poured on the bearing dust cover at the same time. The peak drag, 342.04 gram-centimeters (4.75 inch-ounces), was well within limits.

Launch and landing vibration. - This test was performed as part of a requalification test of the modular equipment stowage assembly (MESA) to which the lunar vehicle was to be attached for the ride to the moon.

Thermal vacuum. - This test was performed to simulate the entire thermal mission. The vehicle was placed in a vacuum chamber in thermal wrappings on a pallet simulating the MESA. The temperature of the walls and floor were lowered to simulate deep space and the lunar surface at the sun angle anticipated for the landing site during the time between landing and vehicle deployment. In this portion of the test, the vehicle-tire temperatures fell below the limit temperature of 216.48° K (-70° F); therefore, in the actual mission, the vehicle was deployed earlier and set aside in the sun until it was to be used. Later in this test, a suited subject deployed the vehicle inside the chamber. The maximum temperature of the vehicle structure and tires (≈366.48° K (≈200° F)) was recorded as anticipated; however, the temperature was not exceeded.

Thermal-vacuum endurance. - This test was devised to duplicate the travel ability of the vehicle on the lunar surface (fig. 11). A wooden cylinder 76.20 centimeters in diameter and 182.88 centimeters long (30 inches in diameter and 72 inches long) was coated with sand embedded in epoxy. A contour was cut in the drum so that one revolution of the drum represented 25.40 linear centimeters (10 linear feet) of an average lunar surface. Several rocks, varying from 2.54 to 10.16 centimeters (1 to 4 inches) in diameter, were bolted to the surface of the drum and were placed in groups by size along the length of the cylinder. The cylinder was mounted on an axle in the chamber, and the test vehicle was supported from the ceiling of the chamber at an angle of 8.3° from the vertical to provide the 1/6g force of the cart normal to the cylinder. The cylinder was run at a speed of 0.305 m/sec (1 ft/sec) for 2 minutes; the tire temperature was 216.48° K (-70° F) to simulate the condition at the beginning of a traverse. Then, the cylinder was run at a speed of 1.07 m/sec (3.5 ft/sec), and the tire temperature was 366.48° K (200° F). The second run was conducted on an area without rocks (150 revolutions), on an area with several 3.81-centimeter (1.5 inch) rocks (300 revolutions), on an area with 6.35-centimeter (2.5 inch) rocks (10 revolutions), and finally, on an area with 10.16-centimeter (4.0 inch) rocks (3 revolutions). This test was equivalent to 1411.22 meters (4630 feet) of horizontal travel. The last section of the run was done at 255.37° K (0° F), the predicted temperature of the tire in motion. This run was varied over the cylinder on the same basis and totaled 999 revolutions (3044.95 meters (9990 feet)) of travel.

Vehicle/Payload Interface

By mission time, 23 metal, cloth, and plastic equipment items were mounted on the pallet of the vehicle (fig. 12). Four cameras, the hand-tool carrier, lunar-soil-sample bags, lunar-atmosphere-sample containers, and a lunar-surface magnetometer were included. Springs, clips, bags, straps, and existing protrusions on the items to be mounted were used to hold down the items. All interfaces were compatible with restrictions imposed on the crewmen in a pressurized garment.

The Rubber Tire

The tire specifications are shown in table I. The first tire that was delivered met these specifications except for pressure loss. The primary problem was the permeability of the synthetic natural rubber tubes. Standard tubes are made of butyl rubber and are good to 233.15° K (-40° F); thus, the synthetic material was used. An increase in thickness from 2.54×10^{-2} to 15.24×10^{-2} centimeters (0.01 to 0.06 inch) and a 10.16×10^{-3}-centimeter (4 mil) layer of polyurethane solved this problem. Six weeks before launch, when the cart was stowed on the launch vehicle, the tires were inflated in a vacuum bell jar to 10.34×10^3 N/m^2 (1.5 psia). Just before inflation, the tires were baked at 366.48° K (200° F) for 24 hours to reduce the outgassing.

CONCLUDING REMARKS

Used on the Apollo 14 mission, the MET (fig. 13) successfully met all requirements. The slopes of Cone Crater, the fully loaded MET (foreground), and the lunar module (background) are illustrated in figure 14.

DISCUSSION

J. Schmuecker:

What design changes were made as a result of the testing, particularly structural changes as a result of environmental tests? If there were no changes or if the changes were minor, in retrospect was the extent of the test program justified?

Miller:

The wheel-support hinge was thickened after hinge failure in tests. This could have been discovered without the vacuum or temperature environment that were part of the structural tests. Tire-tube thickness was changed as a result of environmental testing. The tire-inflation procedure was changed also. The mission time line changed as a result of environmental testing. I feel that the tests were justified.

R. J. Peterson:

What type of bearings are used for the wheels and how are they lubricated? Did you use seals to exclude contaminants?

Miller:

Bearings were standard BEMOL roller bearings with a Feuralon retainer ring that provided dry-film lubrication. We designed a dust cover to exclude contaminants.

TABLE I. - TIRE SPECIFICATIONS

Color	Black
Size, width by height, cm (in.)	10.16 by 40.64 (4 by 16)
Inflation pressure, N/m^2 (psia)	10.34×10^3 to 20.68×10^3 (1.5 to 3)
Deflection under load, percent	30
Allowable pressure loss:	
6 weeks in 101.34×10^3 N/m^2 (14.7 psi) ambient and 2 weeks in vacuum, N/m^2 (psia)	0.69 (0.1)
Abrasion and wear, meters (feet) of travel over simulated lunar surface	6096 (20 000)
Outgassing, percent weight loss after baking in a vacuum chamber for 72 hr at 394.26° K (250° F)	>4.3
Operating temperature environment, °K (°F)	208.15 to 394.26 (-85 to 250)

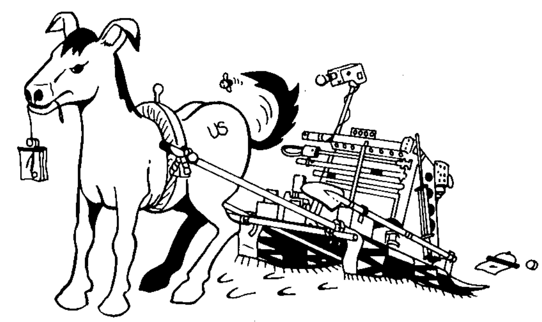

Figure 1. - The travois.

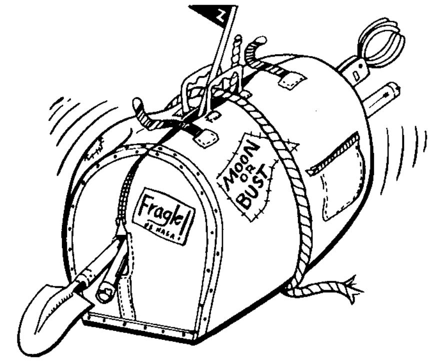

Figure 2. - The suitcase.

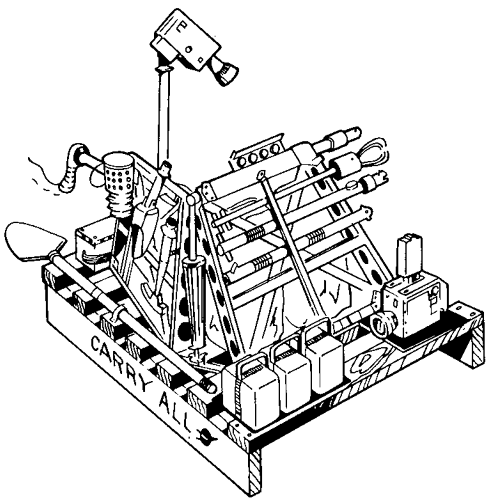

Figure 3. - The pallet.

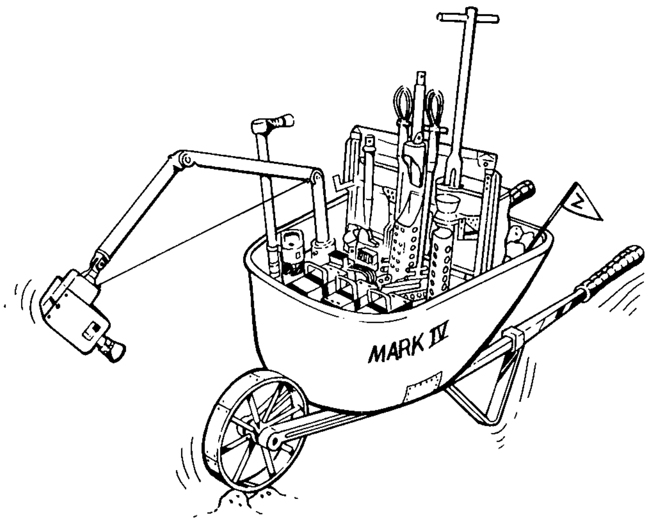

Figure 4. - The wheelbarrow.

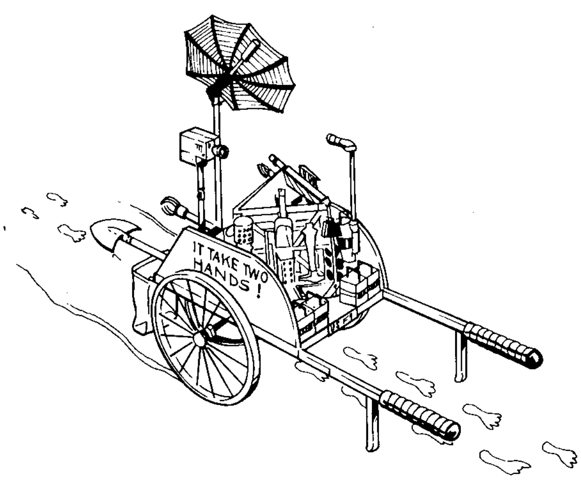

Figure 5. - The cart.

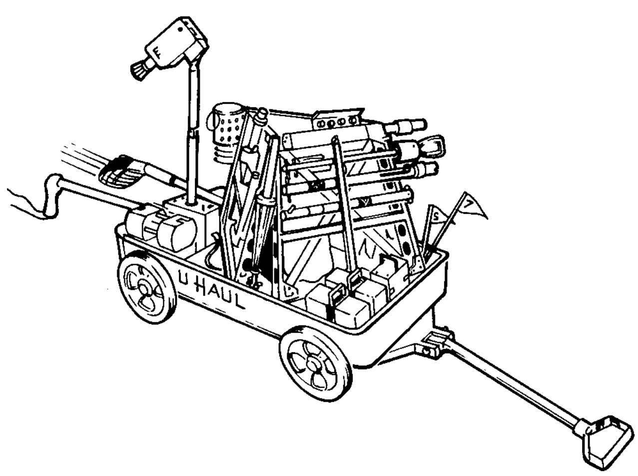

Figure 6. - The wagon.

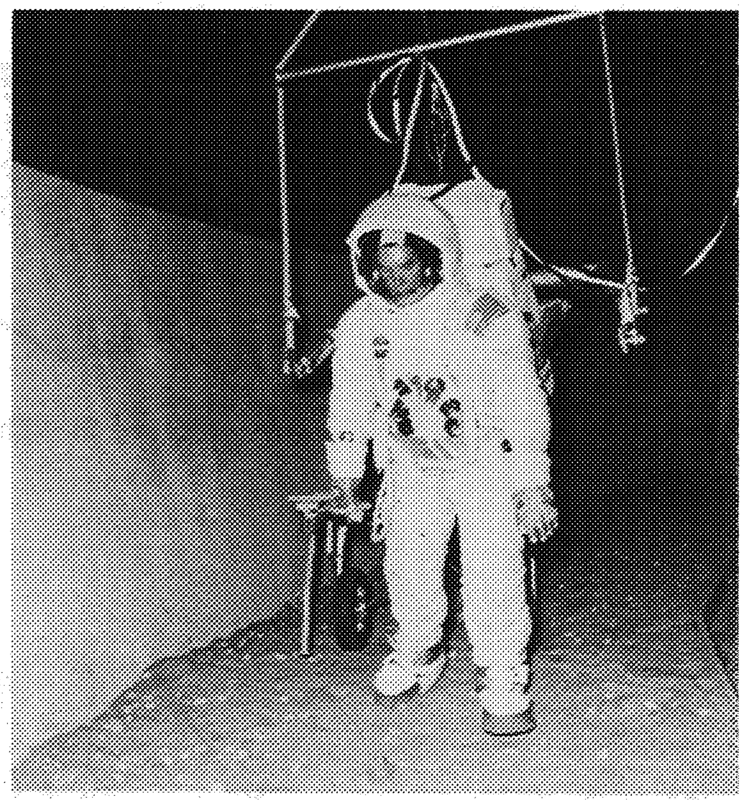

Figure 7. - Cart with one handle.

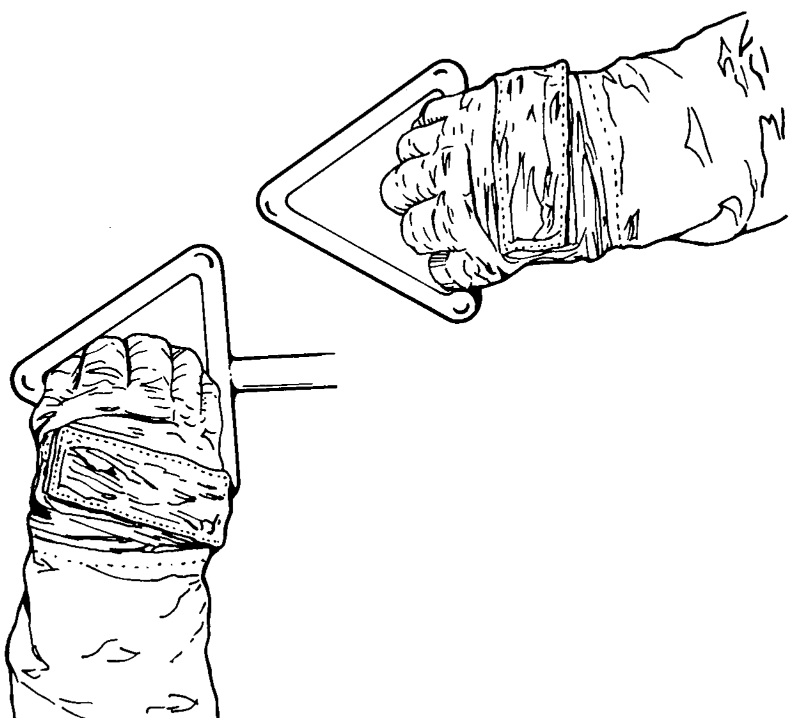

Figure 8. - Handgrip.

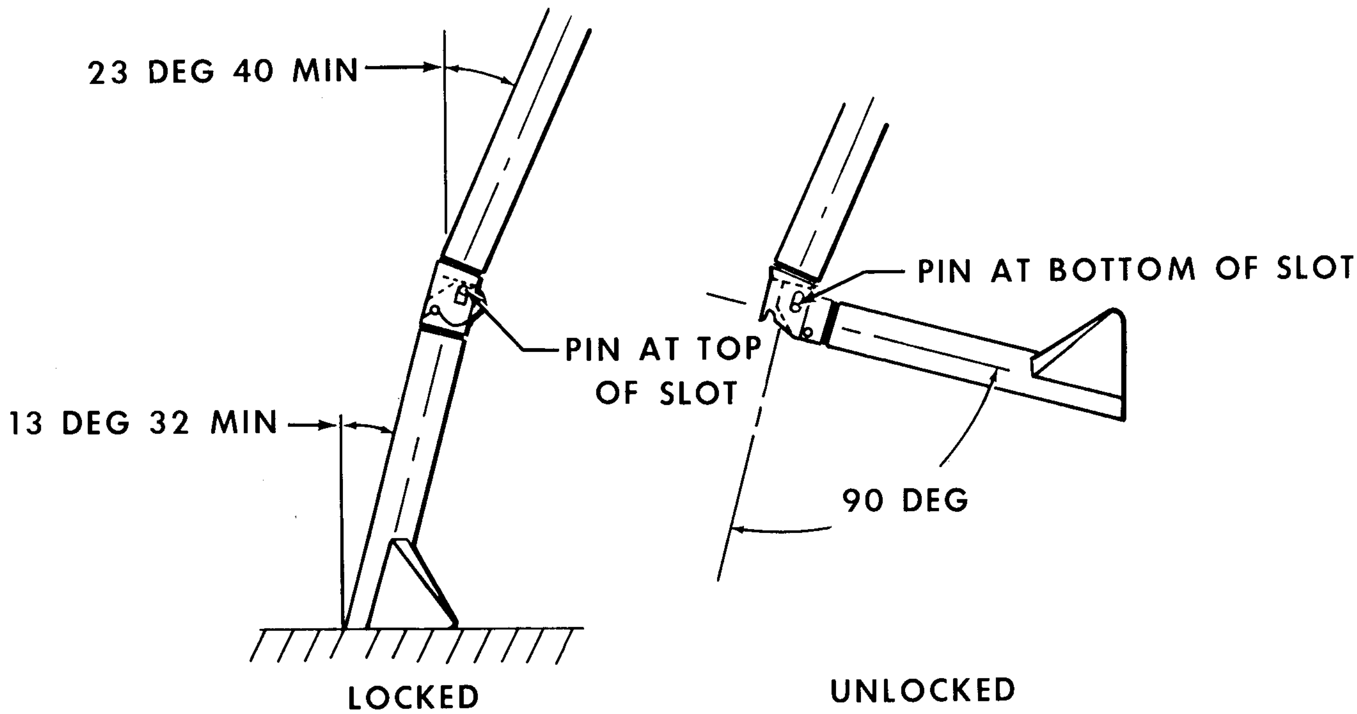

Figure 9. - Articulate leg.

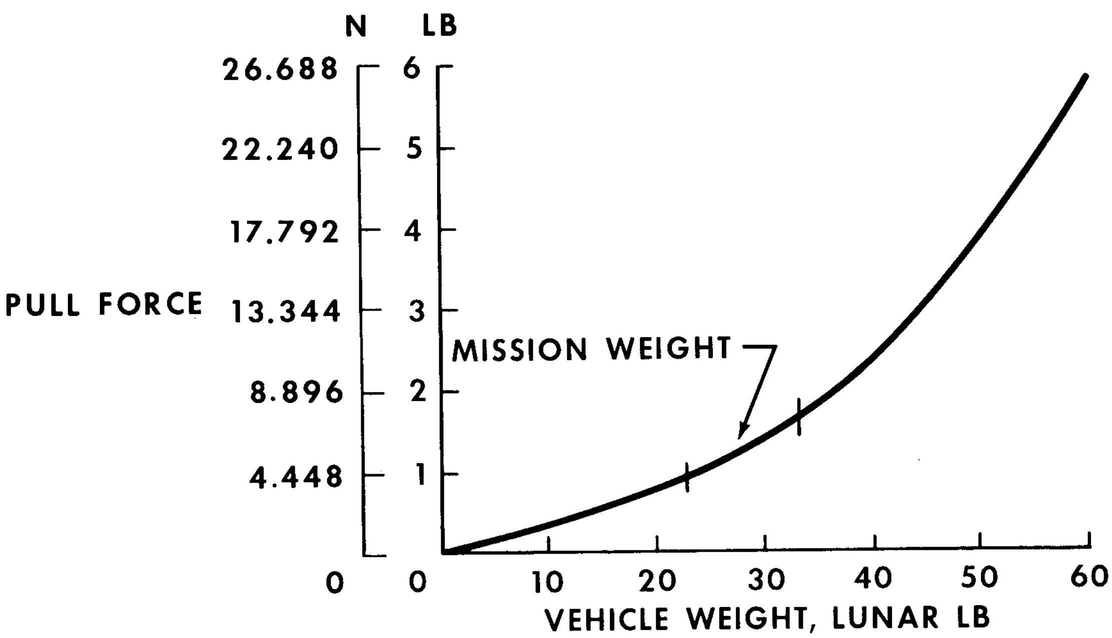

Figure 10. - Pull force compared with weight.

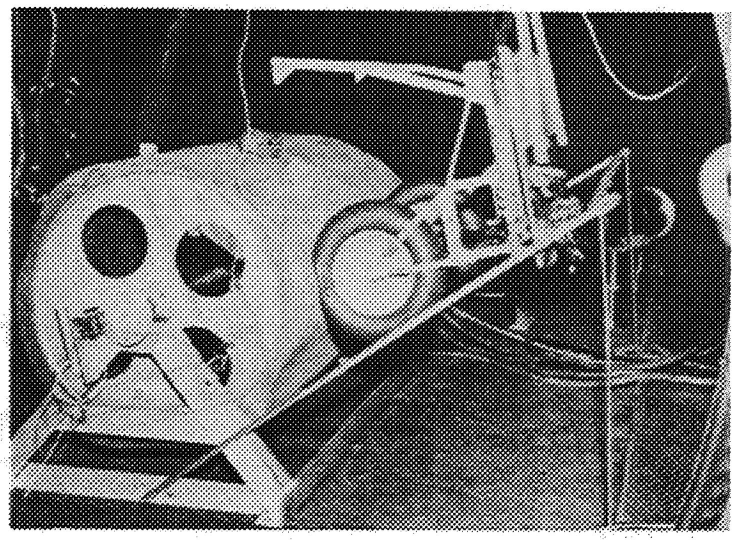

Figure 11. - Thermal-vacuum endurance test.

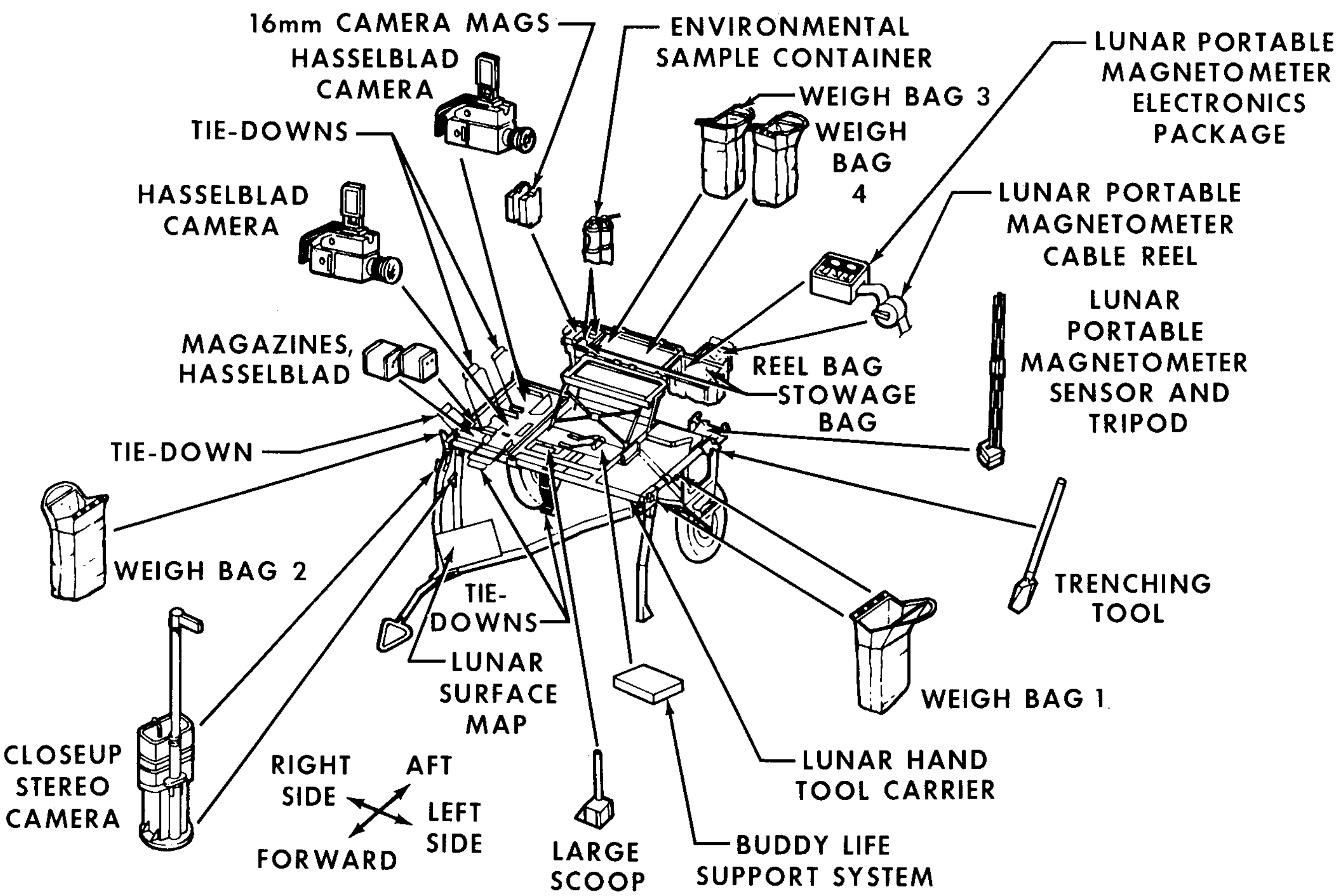

Figure 12. - Modular equipment transporter and equipment.

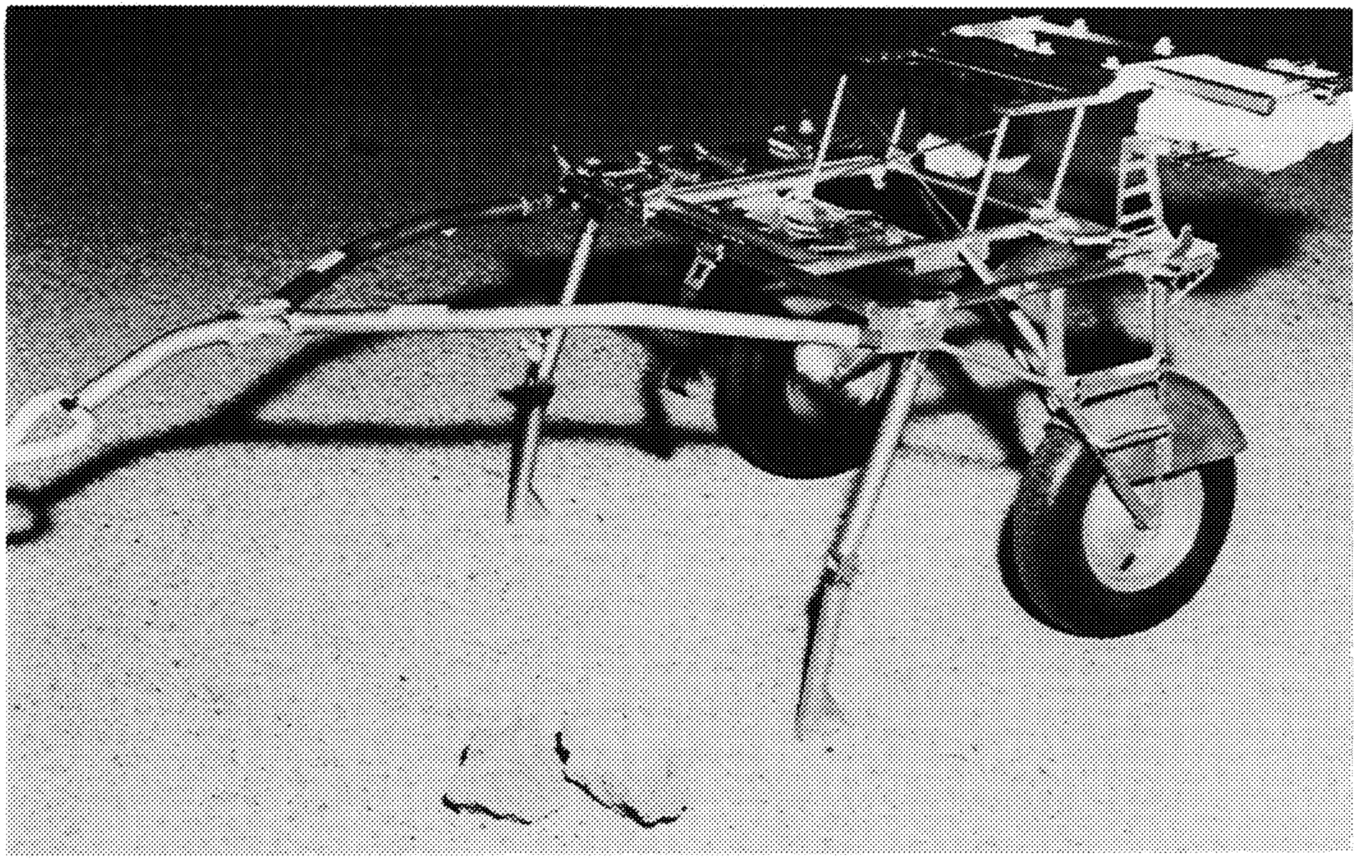

Figure 13. - Modular equipment transporter.

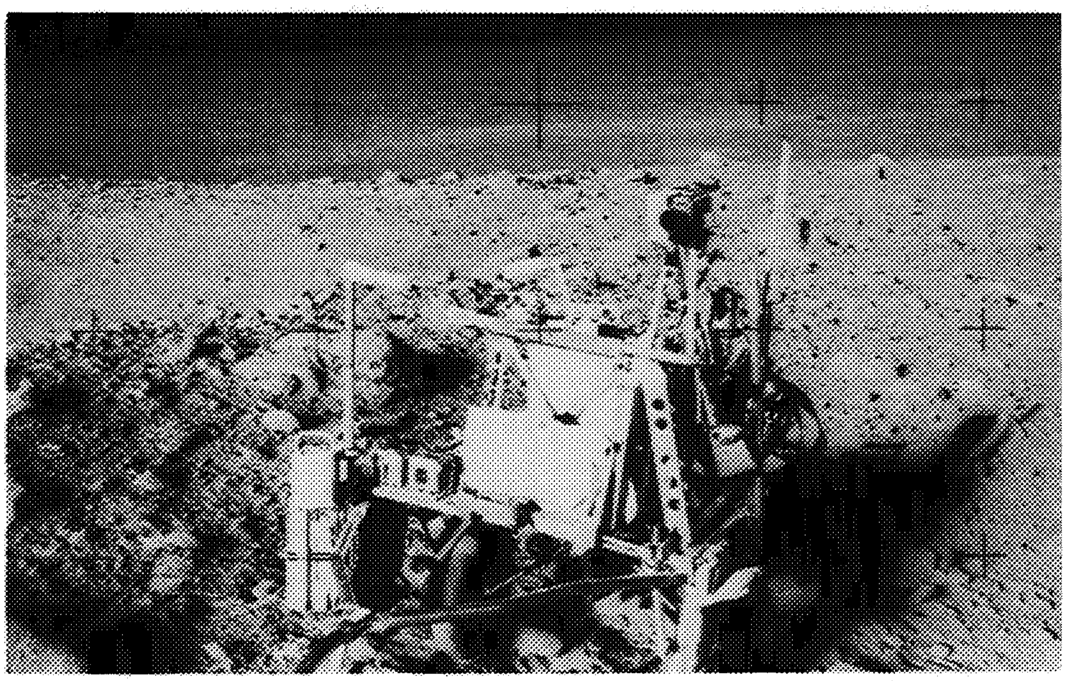

Figure 14. - Fully loaded modular equipment transporter at Cone Crater.