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BAGGING SYSTEM, SOIL STABILIZATION MAT, AND TENT FRAME FOR A LUNAR BASE

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Georgia Tech's School of Textile and Fiber Engineering and School of Mechanical Engineering participated in four cooperative design efforts this year. Each of two interdisciplinary teams designed a system consisting of a lunar regolith bag and an apparatus for filling this bag. The third group designed a mat for stabilization of lunar soil during takeoff and landing, and a method for packaging and deploying this mat. Finally, the fourth group designed a sunlight diffusing tent to be used as a lunar worksite. Following are summaries of these projects.

LUNAR REGOLITH BAGGING SYSTEM 1

This project encompasses the design of a two-part system consisting of a bag-filling apparatus and a bag. This system is designed to be used in construction applications on the Moon. The apparatus must not require more than 10 kW of power; it should fill bags for a given operating time and then recharge. The system should also be robotically controlled and must withstand harsh lunar environmental constraints. Some of these constraints include a temperature range of -250°F to 250°F, absence of a protective atmosphere, high levels of ultraviolet and gamma radiation, and abrasive regolith. These bags should provide adequate protection for a lunar habitat; they should also provide structural support. However, the bags must be small enough to be transported by an astronaut should a structural repair of the habitat be necessary.

The bag-filling machine is designed to be used in conjunction with the lunar SKITTER (which is currently in development). This bag-filling apparatus will operate 8 hours per day and fill 120 bags per day, with each bag having a capacity of 1 cu ft of regolith. The 5.5 ft × 12 ft, 1984-lb machine will be made of boron/epoxy and graphite/aluminum composites. The projected operating life is five years. Bags will be supplied to the machine on a prefabricated roll.

The bags will be constructed of Clark-Schwebel Fiber Glass Corporation's ECG 75-1/0 glass fiber in a plain weave fabric. Glass was selected on the basis of its high strength, elastic recovery (almost 100%), outstanding dimensional stability, excellent temperature use range, and excellent radiation resistance. Following is a list of bag/fabric specifications.

Ends per inch:	44
Picks per inch:	32
Fabric thickness:	0.0068 in
Fabric warp breaking strength:	250 lbf/in
Fabric fill breaking strength:	200 lbf/in.
Warp yarn:	ECG 75-1/0
Fill yarn:	ECG 75-1/0
Bag stitching yarn:	ECG 75-1/0
Stitch density:	40 stitches/in
Yarn diameter:	0.00036 in
Yarn linear density:	1 lbm/7500 yd

A schematic of the lunar regolith bagging system is shown in Fig. 1. Following is a list of bagging machine specifications.

Brush length:	5 ft
Brush diameter:	2 ft
Brush mass:	6.21 lb
Brush rpm:	150 rpm
Brush drive:	#40 chain and sprocket
Drive composition:	graphite/epoxy composite
Interior shroud coating:	Teflon
Machine length:	12 ft
Machine height:	6.56 ft
Machine width:	5.5 ft
Bag capacity:	1 cu ft
Funnel capacity:	10 bags of soil
Funnel height:	3.28 ft
Funnel top diameter:	3.67 ft
Funnel bottom diameter:	0.98 ft
Roll capacity:	975 bags
Full roll diameter:	3.18 ft
Roll shaft composition:	boron/aluminum composite

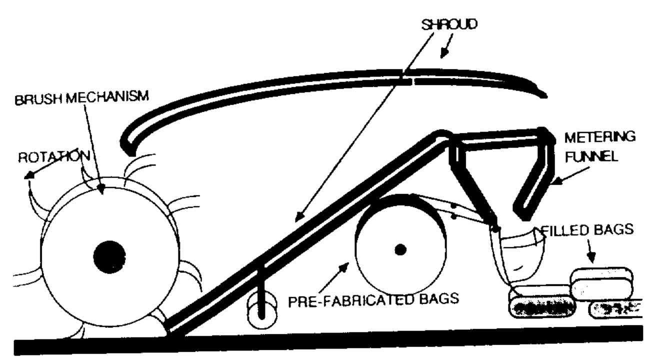

Fig. 1. Schematic of Lunar Regolith Bagging System 1

The bag-filling machine will operate by brushing small particles of regolith into the shroud. The shroud is designed to guide the flying debris through a calculated trajectory to the metering funnel. Prefabricated bags containing small metal strips in their mouths are opened electromagnetically. Shown in Fig. 2 is the bag opening method. A strain gauge is used to monitor bag volume. When a bag is full, the electromagnet is deenergized, thus allowing the bag to close. The closing mechanism consists of a continuous loop Kevlar drawstring

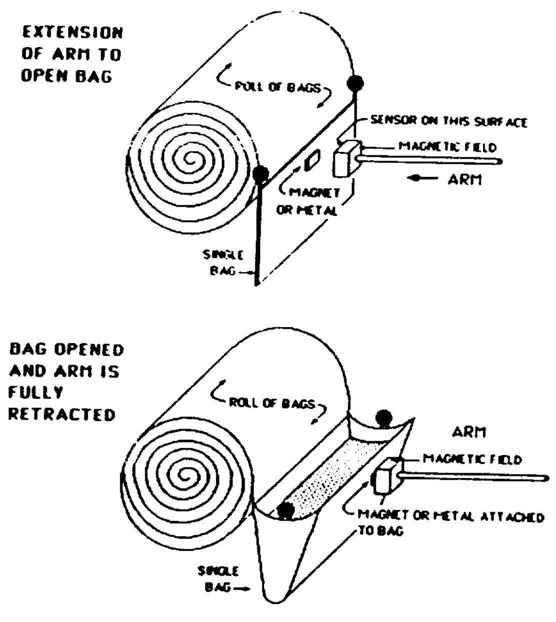

Fig. 2. Bag Opening Method for Bagging System 1

with raised barbs along its length, and two boron/aluminum composite balls mounted on the loop and adjacent to bag sides (as shown in Fig. 2). When a bag is full, it is cut away from the remainder of the roll with a diamond blade. As the bag drops from the machine, the composite balls slide into clutch slots. Meanwhile the barbed loop is pulled irreversibly through bag eyelets. The clutch then releases the balls, and the full, sealed bag drops to the lunar surface. The drawstring is a convenient feature that a recovery team might exploit in retrieving and transporting these lunar sandbags.

LUNAR REGOLITH BAGGING SYSTEM 2

As in the previous project, the goal of this design is to provide a satisfactory system for containing lunar regolith and for filling this container (bag). These bags are to be used in lunar construction applications. This system must operate under minimal power (less than 10 kW), and must withstand lunar environmental constraints such as severe temperature gradients, ultraviolet and gamma radiation, and abrasion by regolith. These bags also should provide protection and structural support for a lunar habitat. Additionally, the bag size should facilitate ease of transportation for either an astronaut or a transporting device.

The bag will be constructed of Kevlar 149 in a ripstop weave. Though a Dupont scientist indicated that this fiber is suitable for this application, its behavior under gamma radiation is questionable. This fiber does, however, have many advantages that suggest its suitability for this application; among these are low density, high strength, good cut resistance, good puncture resistance, and good ultraviolet and electron radiation resistance. The proposed bag configuration is analogous to the geometry of a pillowcase. This shape offers maximum packing potential (ratio of regolith volume to unfilled bag volume), good stackability, and low seam requirements. Following are bag specifications.

Bag fabric weight:	6 oz/yd^2
Fabric temperature range:	-300-800°F
Bag seams:	flat felled
Stitch density:	7-12 stitches/in
Bag width:	36 in
Bag length:	72 in
Bag fabric thickness:	0.0076 in
Bag fabric volume:	39 in^3
Maximum regolith volume:	29702 in^3
Bag mass/regolith mass:	0.001554

For Earth-to-Moon transportation and for bag-filling purposes, unfilled bags will be stacked one inside the other in "Dixie cup" fashion. This stacking configuration will facilitate accuracy in mechanical bag placement for filling. A magnetic thread to be used for bag opening will be woven into the mouth of the bag. Four 8.75-in long magnetic buttons to be used for fastening a full bag will be sewn into a lip in the mouth of each bag.

The proposed bag-filling mechanism is analogous to a "french fry scoop." The scoop will be attached to a lunar truck by an electronic arm whose motions are controlled by an electronic microprocessor. In filling, the scoop will be inserted into a bag opening. An electromagnet will activate the magnetic thread in the bag mouth, and will withdraw the bag from the bundle. As the lunar truck moves forward, it will drag the scoop and the bag through the regolith at a depth of 2 in. Electronic weight sensors will monitor the amount of dirt in the bag and eventually activate the magnetic closure system. The proposed closure system consists of hooks that will draw the inner bag lip out and cause the button magnets to snap together and thus seal the bag. Advantages of this bag-filling system are minimal disruption of regolith, minimal contact between moving parts and airborne regolith, and valid sealing mechanism for lunar temperature range.

This system is designed to operate for 8 hours per day and to fill approximately 16,000 cu ft of soil in 8 days.

SOIL STABILIZATION MAT FOR LUNAR LAUNCH/LANDING SITE

Presented in this project is a method for providing soil stabilization for a lunar launch/landing site. Flying debris (i.e., unrestrained soil) associated with lunar landers has the potential to damage equipment and to injure personnel associated with future lunar colonies. The proposed mat is large enough to compensate for landing errors; its expected life span is 10 years (assuming quarterly use). A schematic of this mat is shown in Fig. 3. Design constraints include light weight, adequate heat resistance for takeoff, sufficient impact resistance (for landing), ease of transportation and deployment, and low mat porosity.

The mat is to be constructed of Fiberite Corporation's PAN-based carbon fiber in a 2 × 2 basket weave. This structure will provide good tear strength, good crease resistance, and good

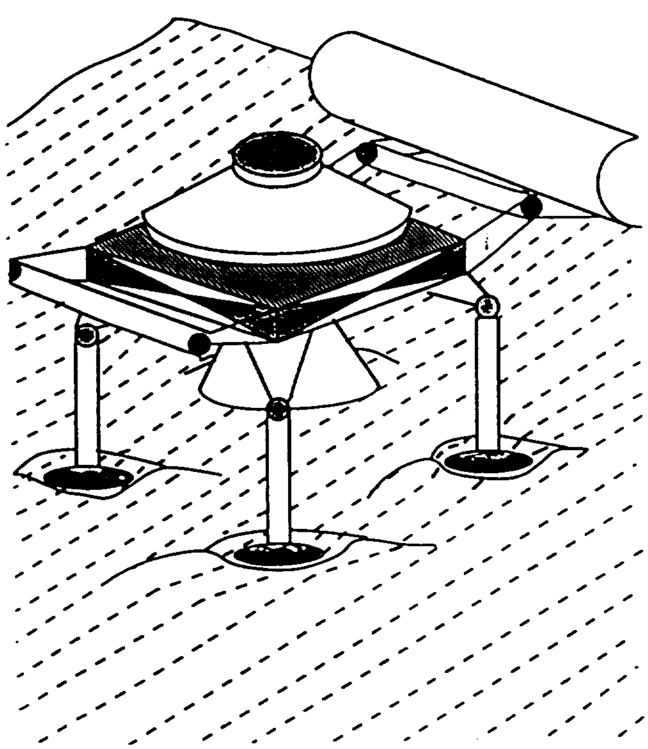

Fig. 3. Schematic of Soil Stabilization Mat for Lunar Launch/Landing Site

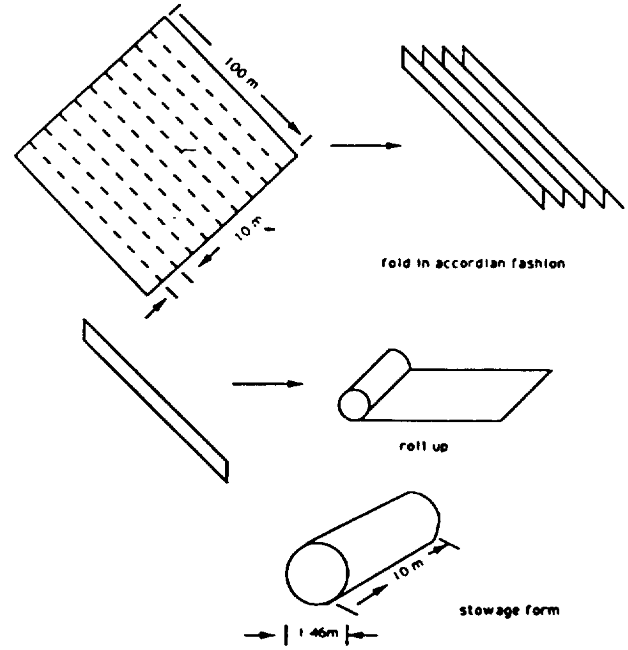

Fig. 4. Stowage of Soil Stabilization Mat

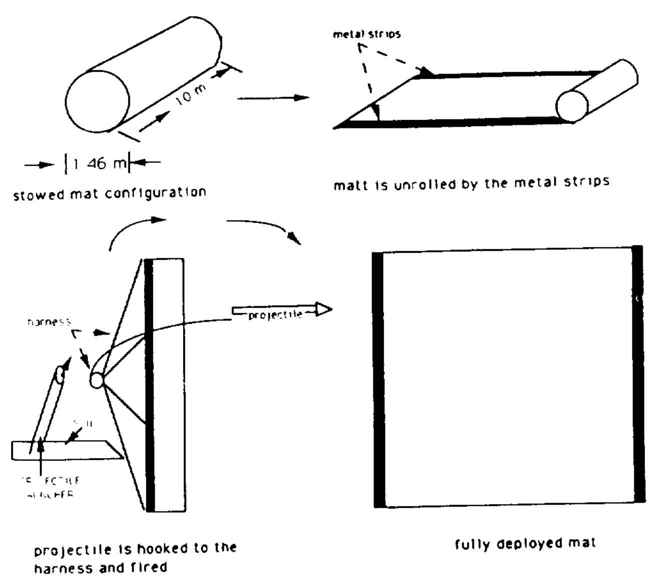

Fig. 5. Deployment of Soil Stabilization Mat

abrasion resistance. The mat will be double layered and 0.066 in thick. Forty panels measuring 100 m by 2.5 m each will be double stitched together using carbon thread and flat felled seams to form a square mat covering an area 100 m by 100 m. This mat will weigh 30,500 lb, including seams.

Heat resistance for takeoff is a key requirement for this mat. Exhaust gases associated with takeoff reach a maximum temperature of 1500°C. Exposure time is, however, only a few seconds. With a maximum usage temperature of 2000°C, carbon is appropriately heat resistant.

The mobility of yarns with respect to one another within a basket weave imparts good tear resistance to the mat. It is not feasible to clear a landing site of sharp rocks. It is, however, feasible to employ a fabric whose structure retards tear propagation.

Carbon fibers also resist ultraviolet and gamma radiation that cause organic fibers to degrade.

The stowage form of the stabilization mat is shown in Fig. 4. The 100 m by 100 m mat is folded in accordion style over 10-m widths. The resulting form is then 10 m wide and 100 m long. This form is then rolled along the lengthwise direction to form a cylinder measuring 1.46 m in diameter and 10 m in length. Thus the mat will fit into the shuttle's cargo bay (12 m × 6 m × 6 m). The mat's weight (30,500 lb) will also be within the shuttle's 60,000-lb capacity. The mat deployment method is shown in Fig. 5. Metal strips in the mat will serve as coil springs that will unroll the mat. A harpoon-like device will be attached to the edge of the accordion fold and fired. This harpoon, when fired, will complete mat deployment.

This mat is designed to accommodate landings and launches of space vehicles measuring up to 18.9 m (62 ft) in length, 6.1 m (20 ft) in diameter, 27,216 kg (60,000 lb) in vehicle weight, and 15,876 kg (35,000 lb) in cargo weight. Following is a cost breakdown for the lunar mat.

Carbon fibers, $1000/lb	31,000,000
Weaving cost	100,000,000
Transportation to Moon, $25000/lb	775,000,000
Deployment	2,000,000
Total	908,000,000

Total estimated cost of production, transportation, and deployment of the lunar soil stabilization mat is $908 million, with transportation comprising the bulk of the cost.

SUNLIGHT DIFFUSING TENT FOR LUNAR WORKSITE

Sunlight on the Earth has an intensity range of 100-1000 footcandles. Because the Moon lacks an Earth-like protective atmosphere, sunlight on the Moon is not diffused. Lunar sunlight has an intensity of 120,000 footcandles. Also, lunar sunlight is unidirectional. This unidirectionality causes objects on the Moon to be either extremely bright or extremely shadowed. These characteristics of lunar sunlight may cause severe distortion of an object's color and contrast on the Moon. Because many tools are color coded, light distortion may be a problem in the astronauts' working environment. Presented in this project is a means of overcoming this difficulty. The proposed solution to this problem is a structure with an umbrella-like frame and tent cover.

A schematic of the tent frame is shown in Fig. 6. The proposed hexagonal structure consists of a tripod frame with three rafters. The three legs will provide stability on uneven surfaces, and attached wheels will provide mobility. Rafters connected to the three legs plus the three additional rafters will form a hexagonal frame for the fabric cover and provide a large work area. Torsion springs incorporated in the frame will enable the structure to be folded compactly and to be self-assembled.

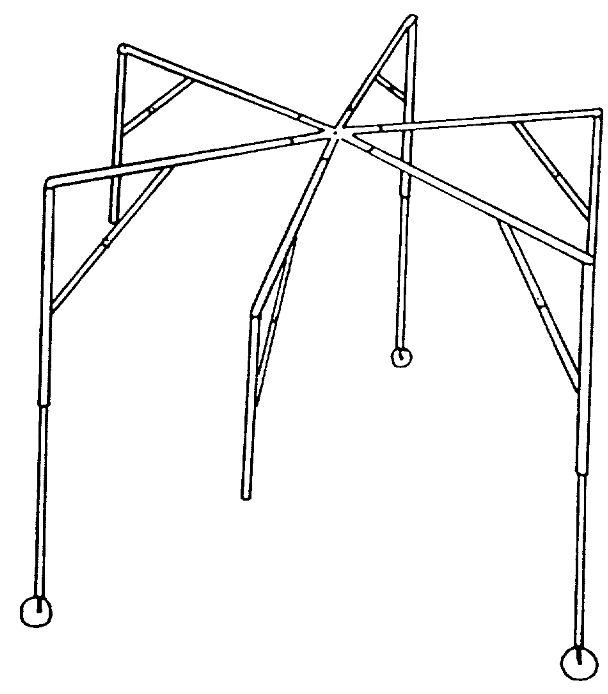

Fig. 6. Sunlight Diffusing tent Frame

Compression springs and extensional legs will reduce tent height for transportation requirements. The fabric cover, fixed tightly to the frame, will provide additional structural support.

Construction materials for this tent must withstand previously described harsh lunar conditions. Specific requirements of the apparatus are low weight to minimize transportation cost, minimal cargo space occupancy, ability to self-assemble, ability to both reduce light intensity and diffuse light, mobility, and structural integrity.

The primary frame will be constructed of titanium and the springs of chrome silicon. The tent and cover will be constructed of Clark-Schwebel Fiber Glass Corporation's eight-harness satin weave Style 7781 glass fabric. Fabric specifications are as follows.

Ends per in:	57
Picks per in:	54
Fabric weight:	8.95 oz/yd^2
Fabric thickness:	0.0090 in
Ends breaking strength:	350 lbf/in
Picks breaking strength:	340 lbf/in

This fabric will allow uniform light intensity of approximately 350 footcandles. Manufactured in 8-ft widths, panels of fabric measuring 43 ft in length will be sewn together in pairs. Measuring 15 ft in width, these double panels will form the sides of the structure. Panels will be attached to the frame by means of Teflon-coated fiber glass loops.

A diagram of tent deployment is shown in Fig. 7. In stage one, the structure will be fully compact. Restraining cords connecting the stand and the leg base will ensure that the wheels land precisely 15.4 ft from the tent center. In stage two, legs will be released while rafters are held stationary. In stage three, rafters will spring down and correctly position wheels. In stage four, both center-to-rafter and rafter-to-leg torsion springs will push the center sections upwards. In stage five, extensional leg latches will be released. The entire structure will "pop up" and fabric will drop over the legs. All locks and supports will be fully engaged at this stage.

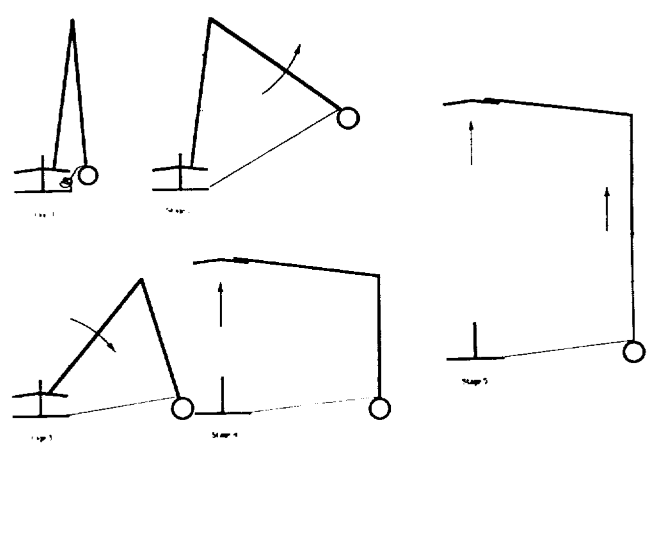

Fig. 7. Tent Deployment

Astronauts may enter and exit the work tent via slits in the fabric. Slits will measure 15 ft in length. Zippers will allow the slits to be opened an additional 13 ft. Large openings will allow the tent to be moved over large objects.

Listed below are structural specifications for the tent frame.

Lower leg section outer diameter	2.75 in
Lower leg section wall thickness	0.063 in
Upper leg section outer diameter	3.25 in
Upper leg section wall thickness	0.063 in
Rafter section (legs) height	4.00 in
Rafter section (legs) width	1.00 in
Rafter section (legs) thickness	0.063 in
Rafter section (extensions) height	3.00 in
Rafter section (extensions) width	1.00 in
Rafter section (extensions) thickness	0.031 in
Hanging extensions outer diameter	1.50 in
Hanging extensions thickness	0.031 in
Center locking device section height	2.00 in
Center locking device section width	1.00 in
Center locking device section thickness	0.063 in
Weight at center (springs and plate)	10.0 lb
Estimated weight of wheel assembly	5.0 lb
Estimated horizontal force at wheels	100.0 lb
Estimated compression spring weight	4.2 lb
Stress on upper leg at hinge	4.69×10^3 psi
Stress on upper leg at lateral support	-6.13×10^4 psi
Stress on rafter at lateral support	-6.70×10^4 psi
Stress on main rafter at center	8.4×10^4 psi
Minimum compression spring force	22.2 lbf
Minimum rafter to leg torque	2.29×10^3 in lb
Minimum center to rafter torque	4.76×10^3 in lb
Total weight	105 lb
Volume	787 yd^3