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Sunlight Diffusing Tent for Lunar Worksite

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TABLE OF CONTENTS

I. Abstract

The purpose of this paper is to provide a solution to problems astronauts encounter with sunlight on the lunar surface. Due to the absence of an atmosphere the moon is subjected to intense sunlight creating problems with color and contrast. This problem can be overcome by providing a way to reduce intensity and diffuse the light in a working environment. The solution to the problem outlined in this paper utilizes an umbrella, tent-like structure covered with a diffusing material. The design takes into account structural materials, stresses, fabrics, and deployment.

II. Nomenclature

Upper Case

A = area

D = diameter

E = modulus of elasticity

F = force

I = moment of inertia

J = angular moment of inertia

L = length

M = moment

P = force

S = strength

T = torque

W = weight (lbs/in^3 except for the covering: lbs/in^2)

Lower case

b = base

c = outer radius

d = diameter

e = eccentricity

h = height

k = spring constant

s = cross bracing

x = horizontal direction

y = vertical direction

β = angle

σ = stress

θ = angle

Φ = angle

Subscripts

F = fabric

L = leg

P = center platform

R = rafter

S = structure

III. Introduction

Astronauts that travel to the moon do so in order to perform test or research. Because the moon does not have an atmosphere as the earth, sunlight is not diffused and therefore very intense on the lunar surface. The intensity of this sunlight is about 120,000 foot candles compared with the average lighting on earth being between 100 and 1000 foot candles. There is also a compounding problem in that the light is also unidirectional like light at the end of a long tunnel. This light causes objects on the moon to either be extremely bright or cast into a dark shadow. Because the light is so intense and so directional there is a distortion of color and contrast. Performing menial chores become frustrating if not impossible for the astronaut. This problem arises the need to provide an environment of diffused dispersed light. The objective of this paper is to present a possible solution for this problem.

IV. Constraints

There are many problems encountered when creating designs for lunar surface applications. One problem is that space is a vacuum. Many of the physical properties which hold true on earth are not so in space (i.e. gases do not rise, water would vaporize, etc.). Another difference is that the gravitational pull of the moon is one sixth that of the earth. The greatest problem created is that frictional forces are directly related to gravitational forces. There is extreme difficulty in mobility for man because it is like walking on ice. An important thing to take note of is that even though friction changes momentum does not; therefore, the ability to stop motion is greatly affected. Because the atmosphere is a vacuum there is no convective heating or cooling and no protection from ultraviolet radiation. Heating and cooling is done by radiation which provides for large shifts in temperature. A lunar day is fourteen earth days and the surface temperature at this time is about 250°F; furthermore, the surface during lunar nights is about -250°F. Each of these aspects is a large change from the earths environment and must be considered when determining possible solutions.

There are a number of desires which would be optimal to incorporate into a solution of the problem. One desire is that it would be lightweight. It costs approximately twenty thousand dollars per pound to carry payloadto the moon. Saving ounces of weight can be a big cost relief. It must not only be able to fit in a shuttle bay but it is desirable to take up as little room as possible. The shuttle bay dimensions are about 15 feet in diameter and 30 feet long. Because astronauts have very little dexterity in their suit, the final design must be self-assembling if assembly is required. It is also very desirable that an astronaut be able to have this diffused light wherever necessary. If the design solution is some sort of apparatus then it should be mobile.

V. Ideas

A. Alternatives

Many design considerations are listed in Appendix A. On the second page of Appendix A is a chart ranking the effectiveness of each idea in vital areas. A ranking scale of one to ten, with one being worst and ten best, was used to rank effectiveness of each idea in different categories. Weighting factors were given to each category to indicate its importance. The total column shows each idea's figure of merit where the larger the number shows the more effective idea. It should be understood that the larger number does not necessarily indicate the most feasible idea. This process emphasizes two ideas above the others. The first is the inflated tent made of a diffusing material. This is good because it is very lightweight and compact. Another advantage is its capability to provide both diffused light as well as blocking out intense reflections. Negatives to this idea include the succeptability of the tent to be ripped and loose its air. This design must also be reinflated each time an astronaut uses it. It is clear from this that a structural foundation is desirable. The second idea is a portable umbrella. This is a useful idea because it demonstrates how a structural framework can be made lightweight and compact for transportation. The largest problem with this idea is that it does not block reflections and it requires the astronaut to reposition it whenever necessary. Taking the good points from these ideas an optimal design is created.

B. Design Concept and Possibilities

Incorporating a compacting structure and translucent material yields an optimal design. A tent which operates like an umbrella yields the stability of a structure and the lightweight compactness of a fabric. Possibilities for the design include the following:

1) Use torsion springs in the framework so that the structure can fold in a compact fashion and also be self assembling.
2) Three legs for stability on an uneven surface.
3) Wheels on the legs for mobility.
4) Ceiling rafters connected to the legs as well as additional rafters used to hold up the fabric and give a larger work area.
5) Use compression springs and extensional legs so that the height of the tent can be reduced for shipment.
6) Fixing the material tightly to the frame for additional support, thereby lessening the amount of a heavier structure needed.

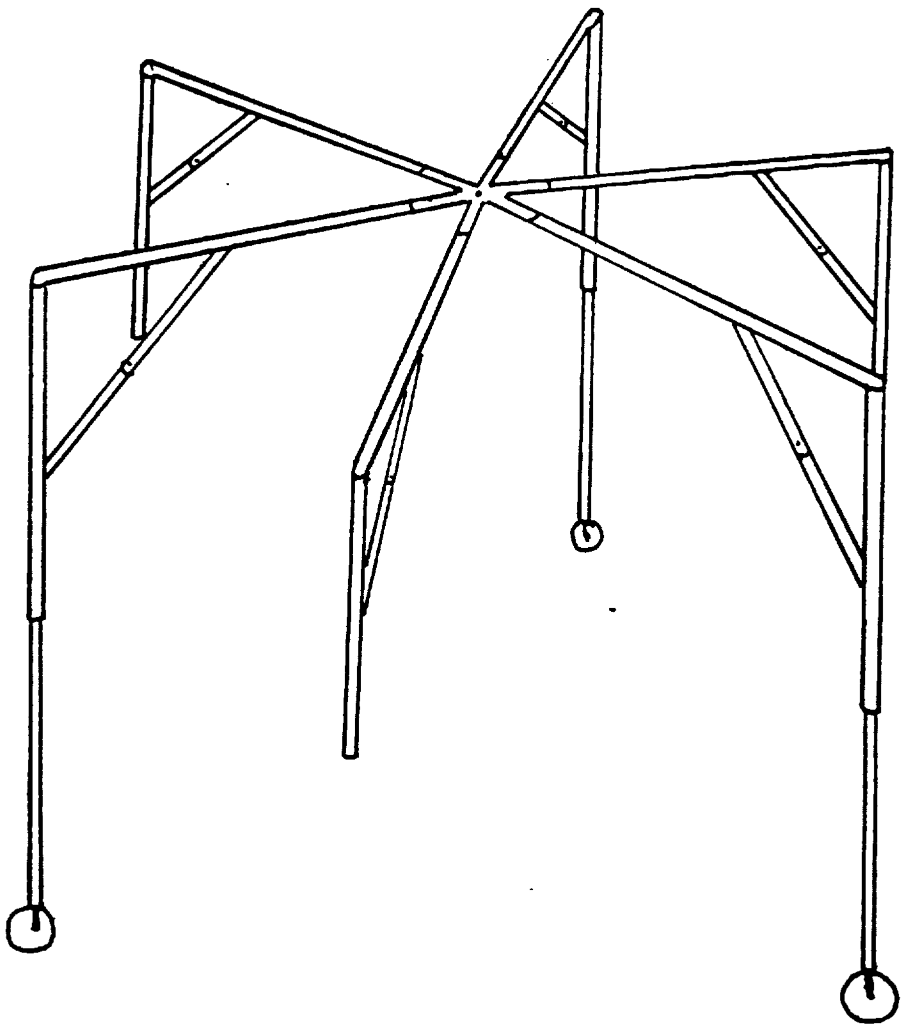
7) Locking mechanisms to relieve the need for springs after the initial assembly (also providing a more stable structure).

8) Material that not only reduces intensity but also diffuses light to reduce shadow problems.

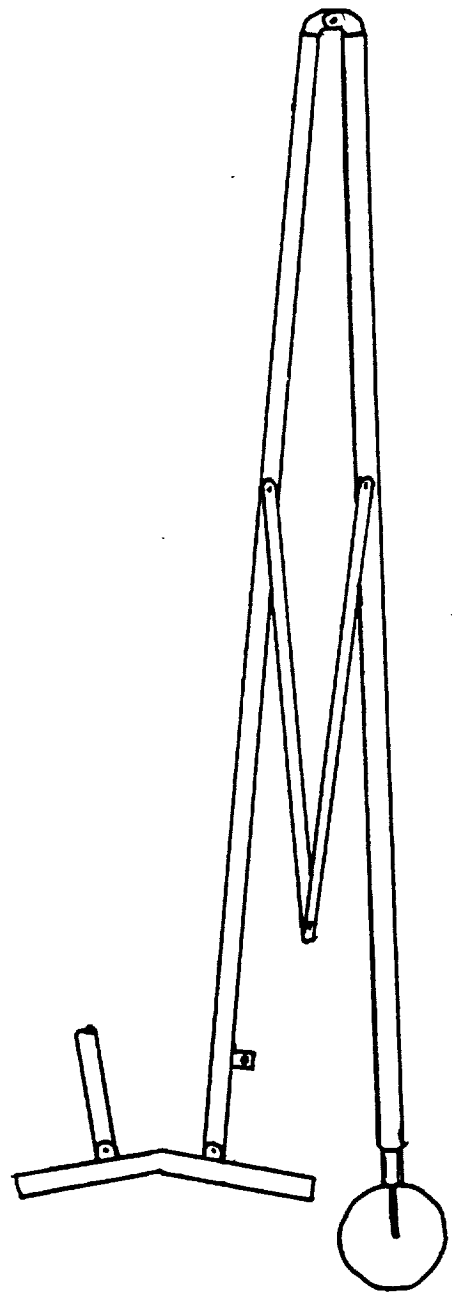
C. Benefits

One obvious benefit of such a design is that it not only diffuses light but it also prevents problems with reflections off the lunar surface. It provides a large working environment so that various tasks can be performed. It is mobile so that it can be moved to any area needed. Another plus is that it is compact and self deploying. Drawings for the general structure design can be seen on the following pages.

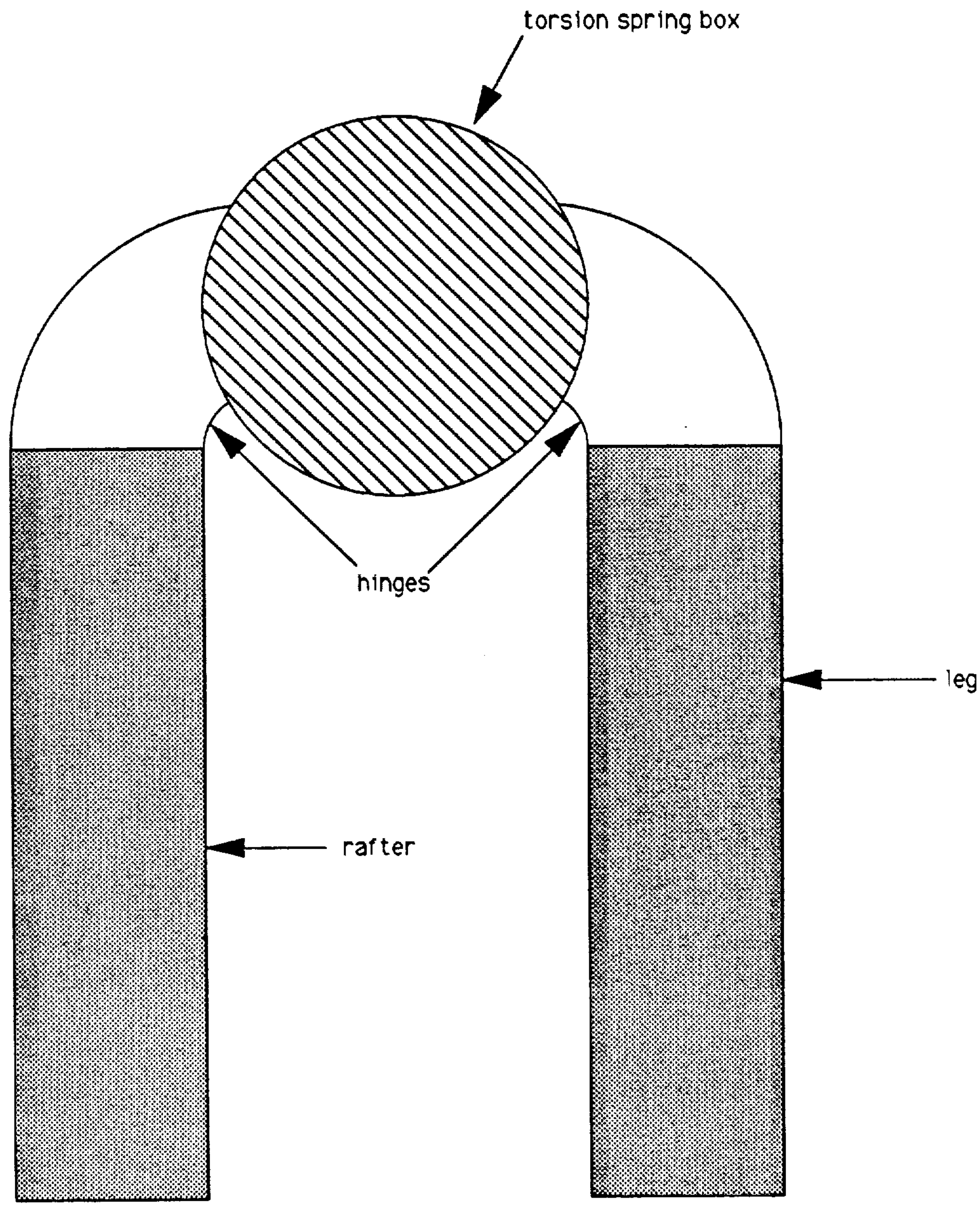
Structural Design Perspective



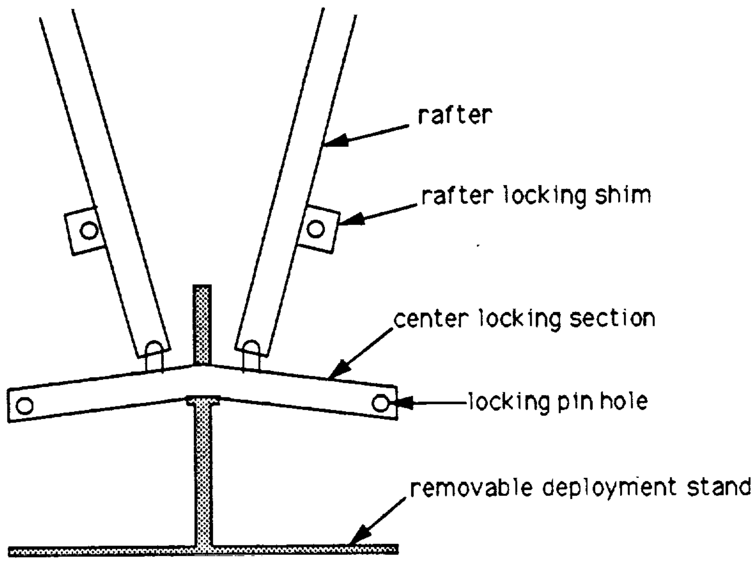
Sectional View of Extension Leg



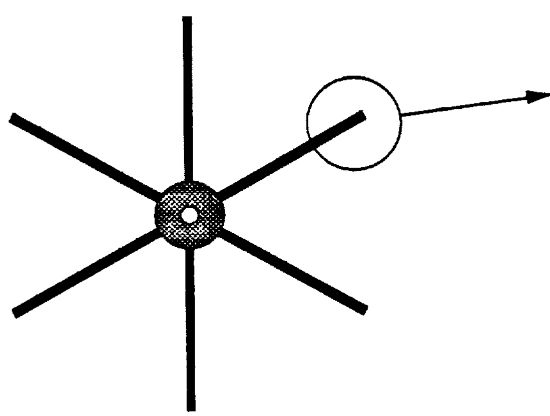
<u>Rafter to Leg Assembly</u>

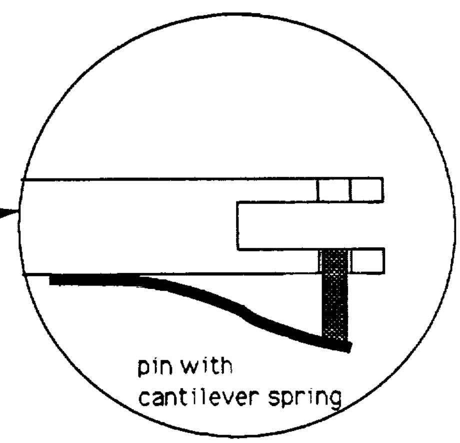


Center locking section



side view with stand

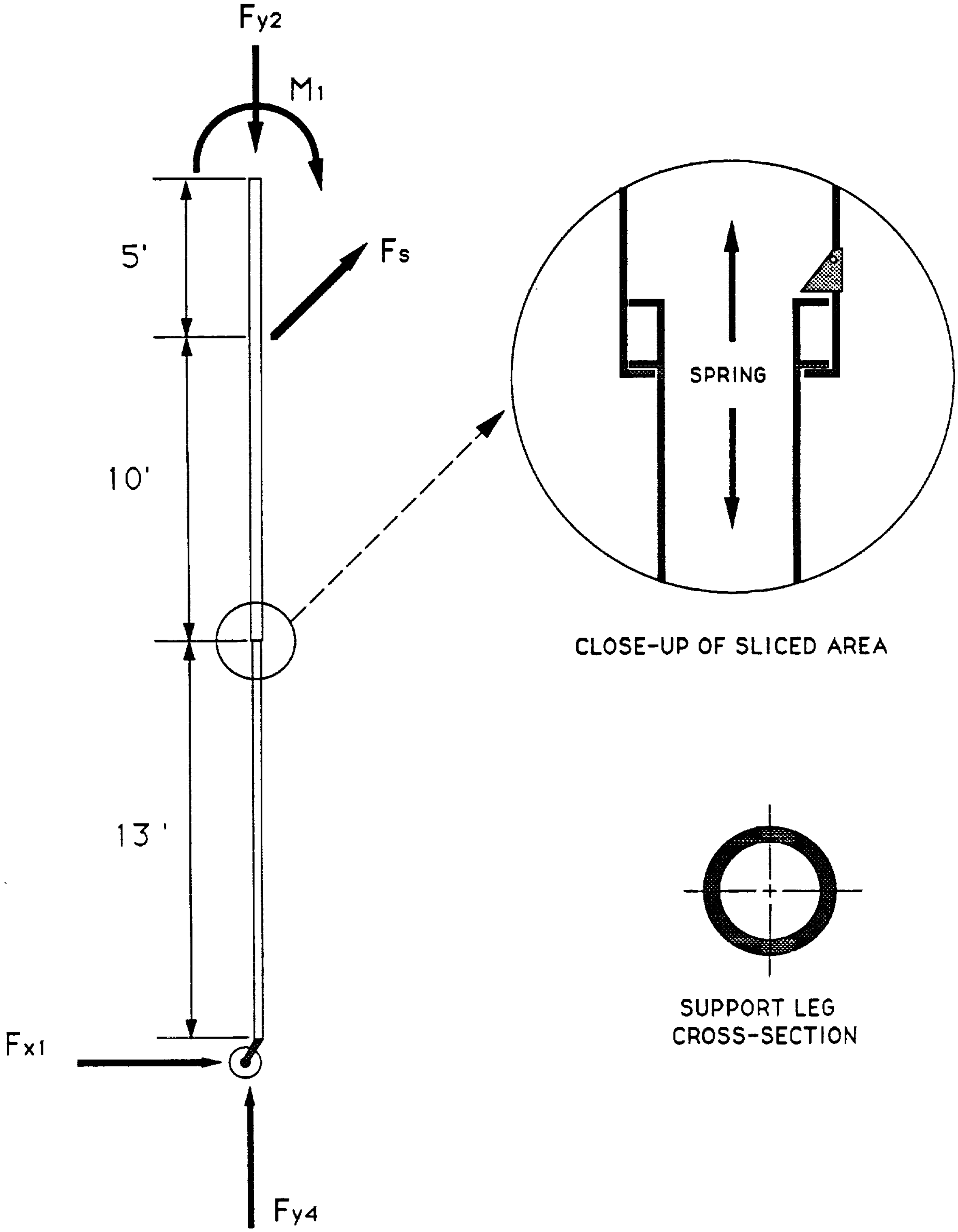




close-up of center
locking mechanism

top view of center locking section

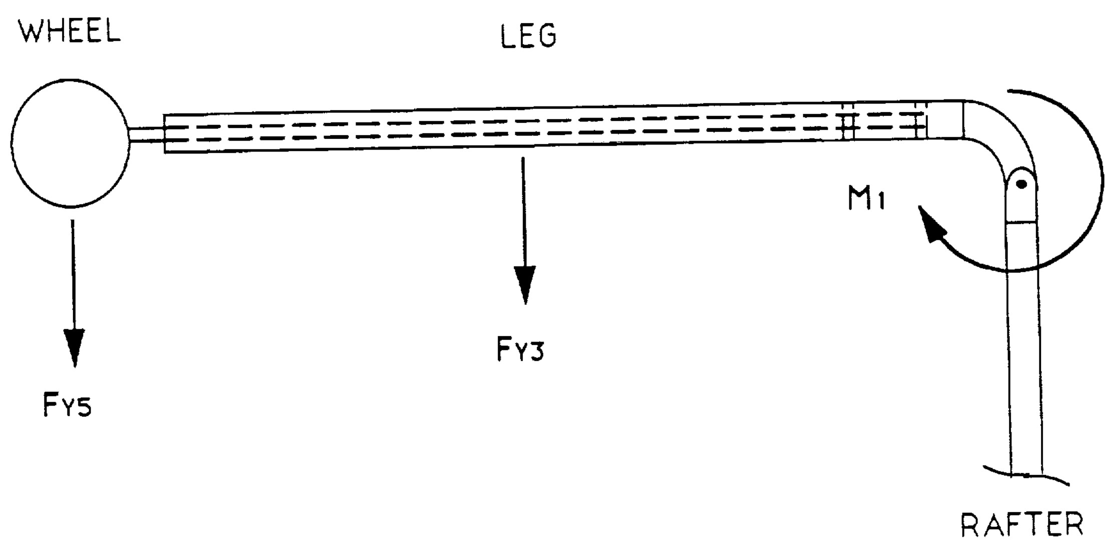
FORCE DIAGRAM OF THE SUPPORT LEG



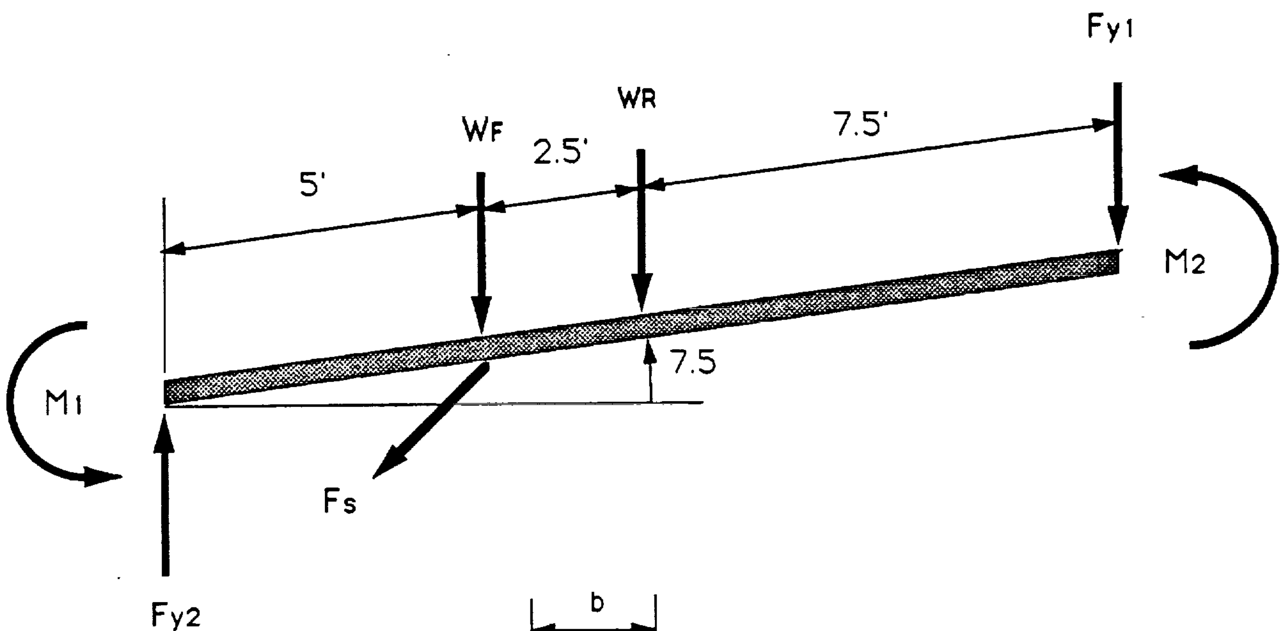
CLOSE-UP OF SLICED AREA

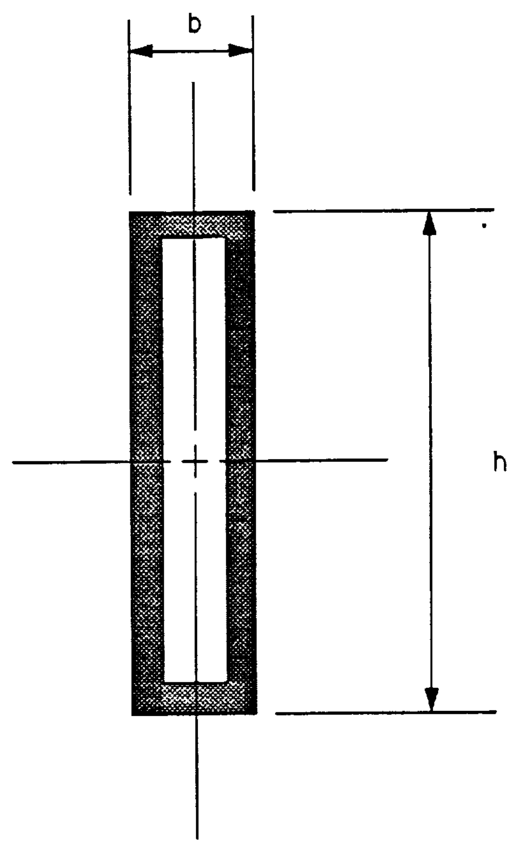
SUPPORT LEG
CROSS-SECTION

RAFTER TO LEG TORQUE REQUIREMENT DIAGRAM



FORCE DIAGRAM OF A RAFTER





RAFTER CROSS-SECTION

VI. Design

A. Structural

1. Materials

As is stated in the constraints, whatever material is used to build this structure must be able to withstand very harsh conditions. It is important that materials be able to maintain their strength and stiffness under all possible conditions. For this design there are two main materials that must be selected.

The first material considered is that used for the structure itself. Consideration is made for both metals and composites. Composites can be very lightweight and have good strength but there are too many potential problems. Composite strength tends to be uni-directional or bi-directional and can be brittle if cracked or bent in the wrong direction. Rosato and Schwarts explain, "The relatively high energy per quantum, high absorption coefficient of materials and the intensity of ultraviolet radiation in space can; therefore, produce a profound effect on certain materials." They go on to explain that non-metalic materials are much more susceptible to radiation damage than metals. Considering various metals, NASA's Space Materials Handbook lists a number of satisfactory metals. Both magnesium and titanium have desirable qualities but titanium proves best for this purpose because of its high strength and light weight.

Ti-Al-Mo-V alloy:

Sut = 200 kpsi

Sy = 172.5 kpsi

Density = 0.163 lb/in3

A second material important to this apparatus is a spring metal. Typically springs are made of music wire or oil tempered wire. These are good materials but they do not function properly at temperatures extremes. From Shigley it is found that chrome silicon is quite capable of operating at high temperatures. Without exact information on this material it is assumed to have much of the same properties as carbon steel.

2. Legs and Rafters

In order to assure that the structure will not fail, stresses at concentrated loads and required lifting forces must be solved for. The calculation procedure begins with separating the frame into free-body diagrams. Then a set of equations are developed based on the free-body diagrams and applied loading using the summation of forces and moments. Using these equations the frame members and spring requirements are found.

The free-body diagrams are shown in the preceding drawings section. For the static calculation $\Sigma F = ma = 0$ and $\Sigma M = J\alpha = 0$. Applying these equations to the free-body diagrams results in the following set of equations:

$R = 186 \cdot \cos\theta$

Fy_5 = estimation of wheel assembly weight

$Fy_3 = 180 \cdot (A5+A6) \cdot WS + Wcomp.spring + 180 \cdot (2\pi R)/6] \cdot WF$

$M_1 = 90 \cdot Fy_3 + 180 \cdot Fy_5$

$W_R = A_1 \cdot W_S$

$W_F = R \cdot W_F/6$

$Fy_1 = 180 \cdot W_S(A2+A4) + W_M + 48 \cdot A_3 \cdot WS + W_C$

$$F_S = (M_1 - 360 \cdot Fx_1)/(60 \cdot 2^{.5}/2)$$

$$Fy_2 = W_M + WR + F_S \cdot 2^{.5}/2$$

$$M_2 = 180 \cdot Fy_2 \cdot \cos\theta - M_1 - 120 \cdot W_M \cdot \cos\theta - 90 \cdot WR \cdot \cos\theta$$
$$- 120 \cdot Fs(2^{.5}/2)\cos\theta + 120 \cdot Fs(2^{.5}/2)\sin\theta$$

Moments M_1 and M_2 are important results since they correspond to the required spring torques. It is then possible to calculate the stresses in the beams at various points. The stress at the center of the structure is calculated by:

$$S_2 = M_2 c/I$$

where c is the distance form the neutral axis to the outer fiber. The stresses at various other locations are similarly calculated. A spreadsheet utilizing these equations is located in Appendix B. By varying the size of the beams numerous times and iterating between this spreadsheet and a spring design program (Appendix B) an appropriate design was obtained.

Buckling of the leg is checked at the time when the structure is fully erected. The analysis involves a larger column on the top of a smaller one; the end conditions are both pinned. Analysis is done utilizing a simplified member having the same cross sectional dimensions as the smaller column but with a length of both columns combined. If this model does not buckle, then the actual structure will not buckle under that same load. The secant formula (Shigley) is used in this analysis. There is an eccentricity involved. The relation is as follows:

$$A_L > P/Sy \left(1 + e \cdot c/k^2 \sec((P/A_L E)^{.5} L/2k) \right)$$

where $k = L \left(Sy/(2\pi^2 E) \right)^{.5}$

$$P = W_L + W_R + W_F + W_P$$

$e = (7.5\ W_R + 5\ W_F + 15\ W_P)/P$

$c = 1.375$

$L = 28$ ft

$I = 0.477\ in^4$

$A_L = 0.528\ in^2 > 0.469\ in^2$

Therefore buckling does not occur.

3. Compression Spring

The compression spring located inside the three legs is designed based on the following constraints:

- Solid height = 15 feet
- Total deflection = 13 feet
- F_{min} exerted by the spring = $W_S - (W_{wheel} + .5 \cdot W_{Leg})$

The spring design calculations are developed from equations given in Shigley. These equations and the applied Turbo Basic subroutine are located in Appendix C.

B. Fabric

1. Material Selection

Astronauts working on the moon are confronted with very intense light and glare from the sun due to the absence of an atmosphere. The astronauts need proper lighting to perform required tasks. The sunlight subjected to the lunar surface should be diffused 99.5 to nearly 100 percent to provide lighting at an acceptable level. The light can be diffused by using a dark face visor on the helmet of the astronaut's uniform. A darkly tinted visor may reduce the intensity of the light to a desirable level, but the contrast of the light from the surface will still pose a problem. The color perceived by the astronaut may be altered causing color coded equipment to be difficult to discern. A fabric skin surrounding a skeletal frame is essential in providing light acceptable for use on the lunar surface.

The fabric chosen must be able to withstand the hostile environment encountered on the surface of the moon as stated earlier in this report. Temperature ranges from -250 to 250°F along with radiation resulting from high ultraviolet (UV) radiation as well as gamma radiation resulting from cosmic galactic rays. However, factors such as wind and moisture are not present on the lunar surface.

The strength of the material is important since the fabric is used to give dimensional stability to the skeletal frame. The fabric must possess adequate elongation and elastic recovery properties. This allows the fabric to be compacted in transportation and unfolded as the structure erects. The fabric weight must be as low as possible to reduce transportation costs, allow the structure to erect properly, and reduce the load on the structure after installation.

Several fiber types were considered for use in the fabric selection. The main fibers considered were acrylic, carbon. glass, nylon, polyester, and Teflon. The fiber properties may be compared in Appendix D.

Acrylic

Acrylic fibers may be used in temperature ranging up to 320°F. Other advantages of acrylic include good elongation at low levels of extension, excellent resistance to UV radiation over long periods of time, and a low density as compared to other fibers considered. Light transmittance and color tests performed on samples from Glen Raven Mills using the Cary 219 Spectrophotometer revealed adequate results from only one layer of fabric. The disadvantages of acrylic fiber are a low strength relative to the other fibers and deterioration from gamma radiation.

Carbon

Carbon fibers are formed by converting a precursor fiber, usually acrylic or rayon, into 95 to 99 percent carbon. The carbon fiber is very heat resistant and is the strongest fiber available. Carbon fibers also have a low density in comparison to other high strength fibers such as fiber glass. Carbon fibers are used for nuclear protection and would withstand gamma radiation present on the lunar surface. Disadvantages of carbon are a low elongation (less than 1 percent), and a black color. There is concern that the black color may not provide an adequate spectrum of transmitted light.

Glass

Glass fibers possess excellent strength properties; approximately 250,000 psi. Although glass fibers have a low elongation of only 3 to 4 percent, the elastic recovery is 100 percent. Glass fibers resist creasing and wrinkling.

Temperatures up to 600°F may be used without damaging the fiber. Fiber glass possesses excellent resistance to UV radiation over long periods of time. The major problem of glass fibers is poor abrasion resistance. A representative from Clark-Schwebel Fiber Glass Corporation stated that glass fabrics are able to withstand the presence of gamma radiation. A fabric sample received from Clark-Schwebel tested on the spectrophotometer revealed a uniform reading of 0.29 percent light transmittance over the 400-700 nanometer range.

Nylon

The basic advantage of nylon is excellent elastic and elongation properties. The elastic recovery is usually 100 percent, but it is not instantaneous. High temperatures present on the surface of the moon would even aid in the elastic recovery. Nylon can withstand temperatures up to 300°F. Nylon is a relatively strong fiber for its density level. The abrasion resistance of nylon is excellent. The problem of nylon is its weakness to UV radiation. Nylon exposed to sunlight for just a short period of time may deteriorate, a factor not acceptable for use on the lunar surface.

Polyester

Polyester possesses a range of good strength properties, but the elongation and strength decreases as the strength is increased. Polyester may tolerate temperatures up to 300°F, but only 70 to 80 percent of the initial strength is retained. Although not as severe as nylon, polyester weakens in the sunlight. Polyester may, however, be used if shielded by another fabric such as glass or Teflon. Polyester is an organic fiber and the presence of gamma radiation will eventually deteriorate the fiber.

Teflon

The temperature range of Teflon is up to 400°F on a continuous basis without any loss of strength. The flex-abrasion resistance of Teflon is the best of all fibers. Teflon exhibits an excellent resistance to sunlight and UV radiation. Teflon is naturally brown, but may be bleached white. Bleached samples received from Stern and Stern Industries provided excellent light and color transmittance results if used in multiple layers. The problem of Teflon is that it is organic and requires replacement within 10 years due to deterioration from gamma radiation.

2. Test Data

The majority of the data relating to the fiber and fabric properties is available in textbooks, technical manuals, company brochures, professionals, etc. There is little to no information available on the light transmittance characteristics. All fabric samples considered for use were tested on a Cary 219 Spectrophotometer. The Cary 219 is able to plot the transmittance of light passing through the fabric over the range of human vision (400-700 nm). A relatively flat line is needed to assure a white light. The light may pass through the fabric by either the porosity of the fabric resulting from a loose weave, or the translucency of the fibers. The Teflon coated fiber glass possesses a loose fiber glass weave allowing light to pass through, whereas the other samples are translucent.

According to Faber Birren in Light, Color, and Environment, light intensity levels acceptable for working conditions should range from 100 to 500 ft-candles. The intensity of light present on the surface of the moon is approximately 120,000 ft-candles. The intensity of light should be diffused 99.5 to nearly 100 percent to provide proper lighting requirements. Transmittance results may be seen in Appendix E. The results of transmittance of fibers and weight relations may be compared in the following table.

Comparison of Weight to Diffusion

Fabric	# Layers	% Transmitted Light 400nm	700nm	Weight Oz./Yd.^{2}
Fiber Glass Style 7781	1	0.28	0.29	8.95
Teflon T-162	2	0.20	0.35	20.34*
Teflon Coated Glass 18 mil	1	0.01	0.70	17.00
Silicon Coated Glass 11 mil	1	0.01	0.25	17.00
Acrylic	1	0.20	0.42	9.25

* Total weight of two layers

3. Specifications

In light of the overall fiber properties and results from the light transmittance test, a fabric composed of fiberglass is the material chosen for use on the lunar workstation. The fabric chosen is Style 7781 manufactured by Clark-Schwebel Fiber Glass Corporation. This fabric allows uniform light intensity of approximately 350 ft.candles which is within the range suggested by Birren.

The internal structure of glass can be described as a continuous chemical network whose dimension are determined by the length and diameter of the filaments. Because the internal structure is rigid and continuous, flexibility is obtained by drawing the individual filaments to extremely small diameters. This high-speed attenuation of molten glass results in an extremely rapid cooling of the glass filament.

Raw materials for glass fibers are primarily silica, sand, and limestone with small amounts of other compounds such as aluminum hydroxide, sodium carbonate, and boron. The formulation of the glass depends on the desired use. The fabric chosen, Style 7781, is E glass composed of the following:

Silicon dioxide	52-56%
Calcium oxide	16-25%
Aluminum oxide	12-16%
Boron Oxide	8-13%
Sodium and potassium oxide	0-1%
Magnesium oxide	0-6%

These selected raw materials are melted in a furnace at temperature of approximately 3000°F. The compounds combine to form a clear melt, which is shaped into marble form approximately 5/8 inch in diameter. The marbles are fed into a small furnace and remelted; the molten glass falls through a platinum bushing with 400 to 1600 orifices. The fibers are pulled together, lubricated for ease in handling, and wound on tubes for use in fabric manufacturing. The filament diameter used is 2.5×10^{-4} inches; 816 filaments provide a strand of glass with a TEX of 66.

The glass fibers may be woven on virtually any loom used for traditional textile fibers. Style 7781 is a eight harness satin weave with thread densities of 57 X 54. The eight harness satin weave is the most pliable weave available providing a fabric composed of fiber glass to drape over the structure. The fabric thickness and weight is 0.009 inches and 8.95 oz./yd.^{2} respectively. The breaking strength of the fabric is 350 X 340 lbf/in. The fabric is manufactured in 8 feet widths. The fabric is cut in lengths of 43 feet. Two fabric pieces are seemed together providing a width of 15 feet to be used on each side of the structure.

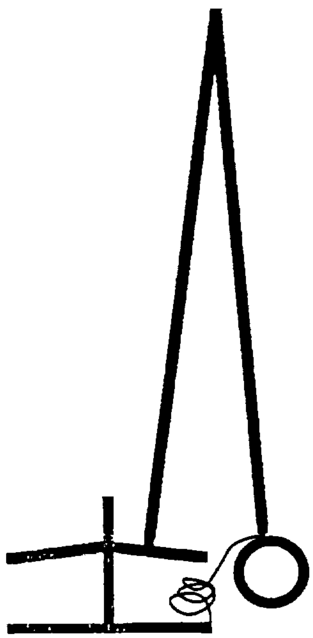
The fabric is attached to the frame by using loops wrapped around each leg of the frame. The loops are made of Teflon coated fiber glass. The Teflon coat is added on the loops to overcome the problem of poor abrasion resistance inherit in fiber glass. The Teflon will aid in the erection of the structure from its packaged position. Once the structure is erected in position, the abrasion resistance of the Teflon is no longer required. When the Teflon degrades due to gamma radiation, the fiber glass is all that is needed to hold the fabric to the structure.

VIII. Deployment and Use

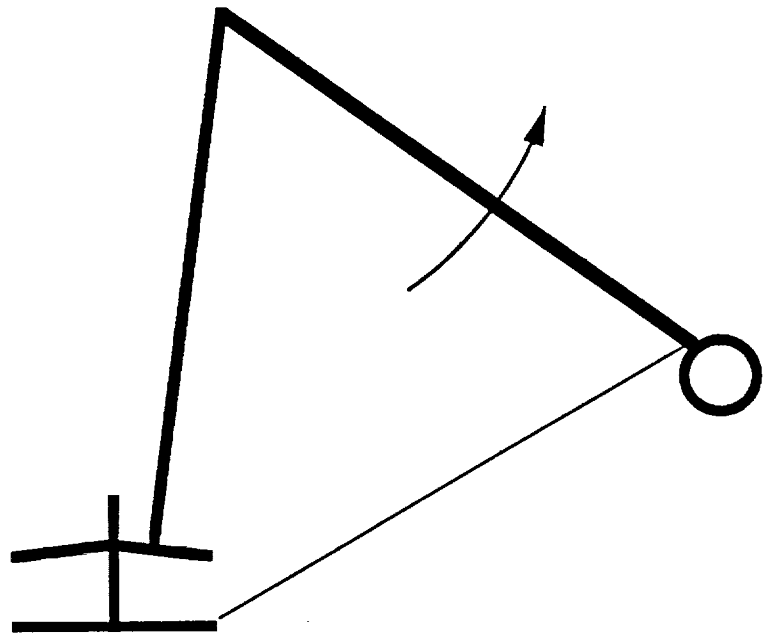
Deployment of the tent will require some control devices not specified in the report. For successful tent erection, these control devices release the tent in stages. A diagram of each stage for a leg can be followed on pp. 28,29. Stage 1 shows the structure in a fully compact state. Restraining chords are attached from the stand to the base of the legs so that the wheels will be forced to land in the correct spot (15.4 ft from center). At stage 2 the legs are released while the rafters are held in place. Stage 3 allows the rafters to spring down, thereby placing each wheel in the correct spot. Stage 4 utilizes both center-to-rafter and rafter-to-leg torsion springs to push the center section upwards. Stage 5 releases the extensional leg latches, moving the entire structure upward, and the material drapes down over the legs. At this time all locks and supports are fully engaged and there is no more need for the springs.

Astronauts will be able to enter and leave the tent through slits in the material. The slits are fifteen feet high and can be opened an additional thirteen feet by a zipper if necessary. The large openings allow the tent to be rolled over most any object desired. The tent can be moved any number of ways but it would typically be wenched.

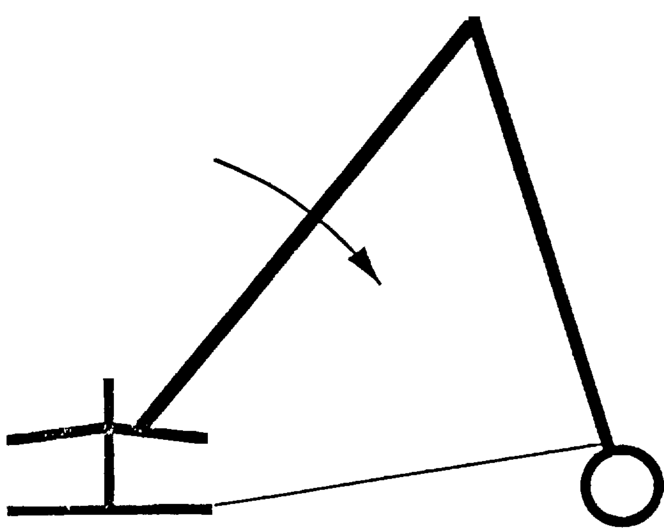
Stages of Deployment for a Leg



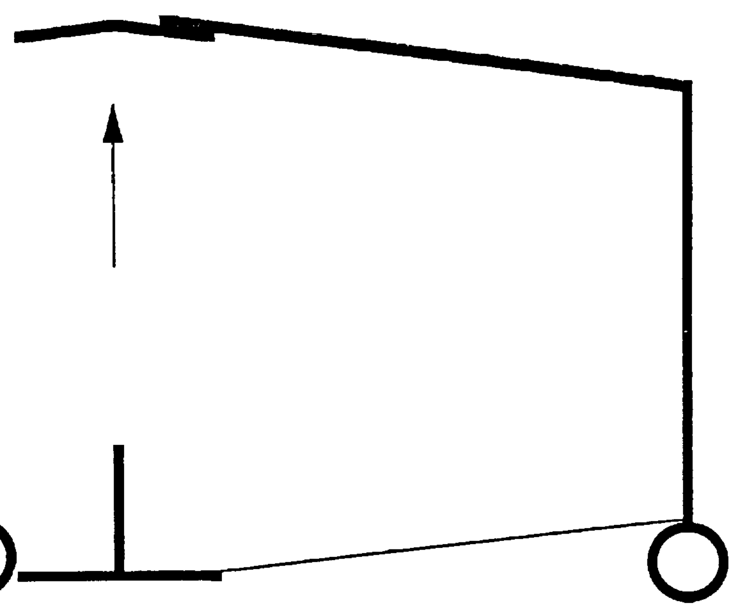
Stage 1



Stage 2



Stage 3



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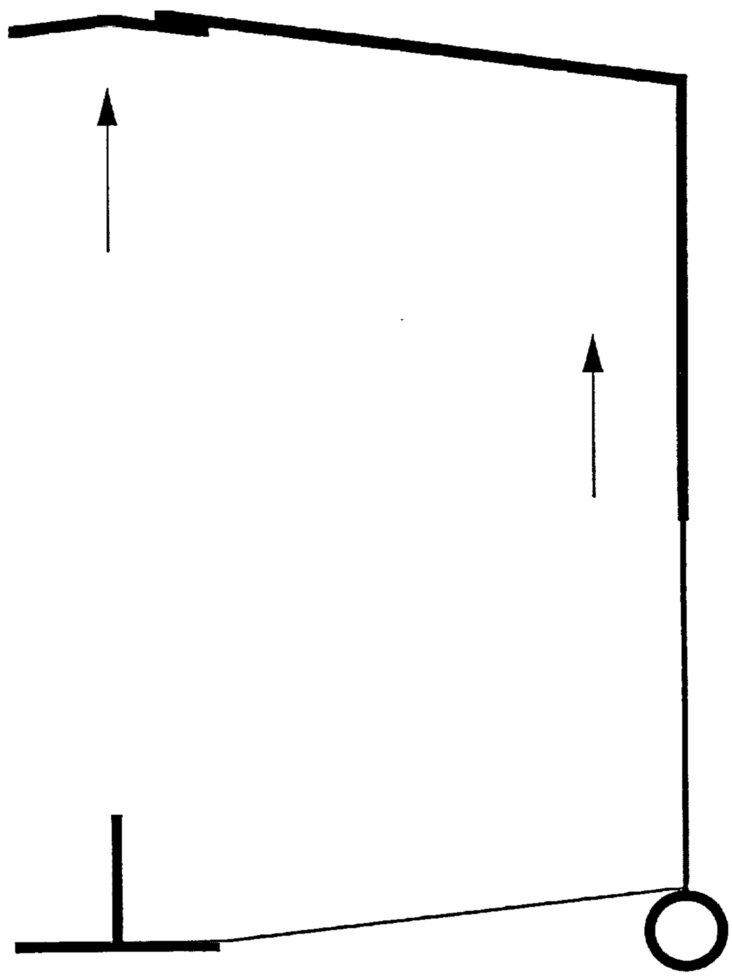


Stage 5

IX. Summary

Based on the analysis and research conducted, a recommendation is made for this lunar tent as a solution to the proposal problem. This design is successful in both meeting the criteria and incorporating many desirable features. Much of the final specifications can be seen in Appendix B. Listed below are a few important facts.

Total weight: 630 lb

Working space: 787 yd^2

Height: 30 ft

Height of largest object tent can move over: 28 ft

Shipment size: 6 ft diameter
15 ft length

Surface area: 387 yd^2

APPENDICES

Appendix A

Listing for Brain Storming Ideas

1. A shield which can be moved to directly block out the sun.

2. Vertical conducting wires with changing polarity and with polarized dust oscillating between them.

3. A dark building with solar powered light.

4. A sealed tent blown up by CO_2 cartridges and sustained by additional cartridges as needed.

5. A building made of adjustable blinds so that the astronaut can adjust the exact amount of light that he wants.

6. Use etched glass as a shield between the working area and the sun.

7. A tent which is not translucent but is white on the inside and brightened by a reflected sun light on the inside using mirrors.

8. A tent which is layered by woven steel to take advantage of refraction between the small space of the weave.

9. A pack that is worn by the astronaut which blows out a dark gas above the astronaut's head.

10. A motor with large circular disk overhead and grooves cut in the disk so that when spun light is evenly spread over the area.

11. An arched wall that is mobile and will rotate with the sun using a light sensor.

12. A dark disk that is maneuvered by a robotic arm that can reach any position to cast a shadow where necessary.

13. An umbrella with translucent material which can be hand carried and placed in such a way to diffuse light on a particular spot.

14. A vacuum system which can draw up moon dust and disperse it to form a cloud some distance from the work area to avoid getting the lunar equipment dusty.

15. A super conductive strip which repels variously doped magnets which would levitate at different levels creating a wall or cloud.

Appendix A: Comparison of Various Ideas

Idea #	Weight	Size	Quality of Light	Simplicity	Durability	Mobility	Asrtronaut Compatibility	Blocks Reflection	Energy Consumption	Total
Importance Factor	1	1	1	0.5	0.7	0.7	0.9	1	0.6	
1	10	5	1	10	8	9	5	1	10	44.4
2	8	8	3	1	2	6	2	3	1	30.5
3	3	3	10	4	2	7	5	10	8	43.6
4	9	10	9	8	1	5	1	9	10	52.1
5	1	2	7	4	7	3	5	10	10	39.5
6	1	1	4	8	3	4	4	5	10	29.5
7	3	3	8	4	4	7	8	9	10	45.9
8	1	1	8	7	9	3	7	8	10	42.2
9	8	10	4	8	5	10	1	6	8	48.2
10	1	1	8	5	2	1	9	1	1	24.3
11	6	4	3	3	6	2	9	1	5	32.2
12	5	5	1	4	2	5	6	1	3	26.1
13	10	10	8	9	9	10	3	1	10	55.5
14	1	3	3	2	2	9	3	3	1	22.0
15	1	4	2	1	9	3	3	2	1	21.2

APPENDIX B

Structural Calculations

Note: Weights are listed in pounds as measured on the Moon.

Fabric Weight	=	1.61E-04 lb/in^2
Steel Weight	=	2.76E-02 lb/in^3
LOWER LEG SECTION:		
Outer diameter	=	2.75 in
Thickness	=	0.063 in
I	=	0.477 in^4
Area	=	0.528 in^2
UPPER LEG SECTION:		
Outer diameter	=	3.25 in
Thickness	=	0.063 in
I	=	0.795 in^4
Area	=	0.626 in^2
RAFTER SECTION (LEGS):		
Height	=	4.00 in
Width	=	1.00 in
Thickness	=	0.063 in
I	=	1.09 in^4
Area	=	0.609 in^2
RAFTER SECTION (EXTENSIONS):		
Height	=	3.00 in
Width	=	1.00 in
Thickness	=	0.031 in
I	=	0.270 in^4
Area	=	0.246 in^2
HANGING EXTENSIONS:		
Outer diameter	=	1.50 in
Thichness	=	0.031 in
I	=	0.039 in^4
Area	=	0.144 in^2
CENTER LOCKING DEVICE SECTION:		
Height	=	2.00 in
Width	=	1.00 in
Thickness	=	0.063 in
I	=	0.186 in^4
Area	=	0.359 in^2

Misc. weight at center (springs & 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
Roof Angle	=	7.5 deg
*Refer to Drawings (pp. 13-15)		
Radius	=	184 in
Fy3	=	15.5 lb
M1	=	2.29E+03 in-lb
Wr	=	3.03 lb
Wf	=	2.86 lb
Fy1	=	8.61 lb
Fs	=	903 lb
Fy2	=	653 lb
M2	=	4.76E+04 in-lb
Stress on upper leg at hinge	=	4.69E+03 psi
Stress on upper leg at lateral support	=	-6.13E+04 psi
Stress on rafter at lateral support	=	-6.70E+04 psi
Stress on main rafter at center	=	8.74E+04 psi
Minimum Compression Spring Force	=	22.2 lb
Minimum Rafter to Leg Torque	=	2.29E+03 in-lb
Minimum Center to Rafter Torque	=	4.76E+04 in-lb
Total Weight	=	105 lb
Surface Area	=	387 yd^2
Volume	=	787 yd^3

APPENDIX C

Compression Spring Design

The following calculations and computer subroutine were used to design the compression spring imbedded in the upper and lower leg supports. This spring raises the tent-like structure to full height at the end of the unfolding process.

This routine iterates between specified values of coil diameter D and wire diameter d. The output can be printed or displayed to a terminal screen. The attachment shows a preliminary output for our spring design.

Calculations:

WS = unit weight of steel

Ls = Solid height

dx = Amount of deflection

Fmin = minimum force

Fmax = maximum force

A = spring material constant: pg. 422 of Shigley

m = spring material constant: pg. 422 of Shigley

x = factor for shear stress: pg. 423 of Shigley

n = factor of safety

G = Modulus of Rigidity

D = mean diameter of the coil

d = diameter of the wire

k = spring stiffness

Smax = maximum induced shear stress in the spring

APPENDIX C

Sall = allowable shear stress

$c = D/d$

$6 <= c >= 12$

$Nt = Ls/d - 1$

$Na = Nt - 2$

$$Fmax = \frac{d^4 \; G \; dx}{8 \; D^3 \; Na} + Fmin$$

$$Smax = \frac{2c+1}{2c} * \frac{8 \; Fmax \; D}{\pi d^3}$$

$Sall = x * A/d^m$

$Smax <= 1/n * Sall$

$weight = WS \; Nt \; (\pi d)^2 \; D \; / \; 4$

Subroutine:

```
        FOR D=Dmin to Dmax STEP Dinc
          FOR d=dmin to dmax STEP dinc
            c = D/d
            IF c<6 or c>12 THEN GOTO JUMP
            Nt = Ls/d - 1
            Na = Nt - 2
            Fmax = d^4*G*dx/(8*D^3*Na) + Fmin
            shearmax = (2*c+1)/(2*c) * 8*Fmax*D/(PI*d^3)
            shearall = x * A/d^m
            IF shearmax>shearall THEN GOTO JUMP
            weight = WS*Nt*(PI*d)^2*D/4
            k = (Fmax-Fmin)/dx
            PRINT """"ANY VALUES THAT ARE DESIRED""""
JUMP:     NEXT d
        NEXT D
        RETURN
```

APPENDIX C

Results of the Subroutine

Input:

Unit weight of steel = 0.282 lbs/in^3

Solid Height = 180 in

Total deflection = 156 in

Minimum force exerted = 23 lbs

'A' (material property pg. 422 of Shigley) = 218 kpsi

'm' (material property pg. 422 of Shigley) = 0.091

Factor of safety = 2

Modulus of rigidity G = 11.5 Mpsi

Results:

D = 1.4 in

d = .14 in

Fmax = 47.5 lbs

Weight = 24.5 lb on Earth

= 4.1 lb on the Moon

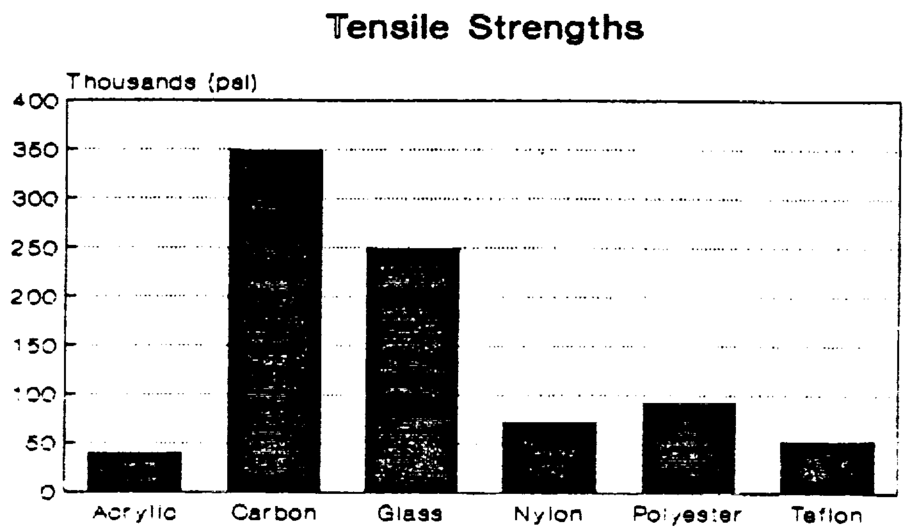
k = .16

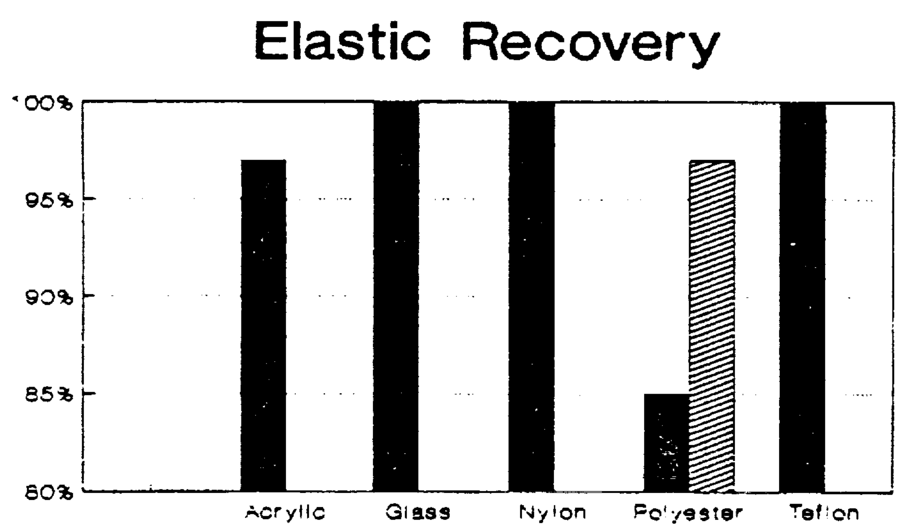
Number of coils = 1280

Maximum shear stress = 64800 psi

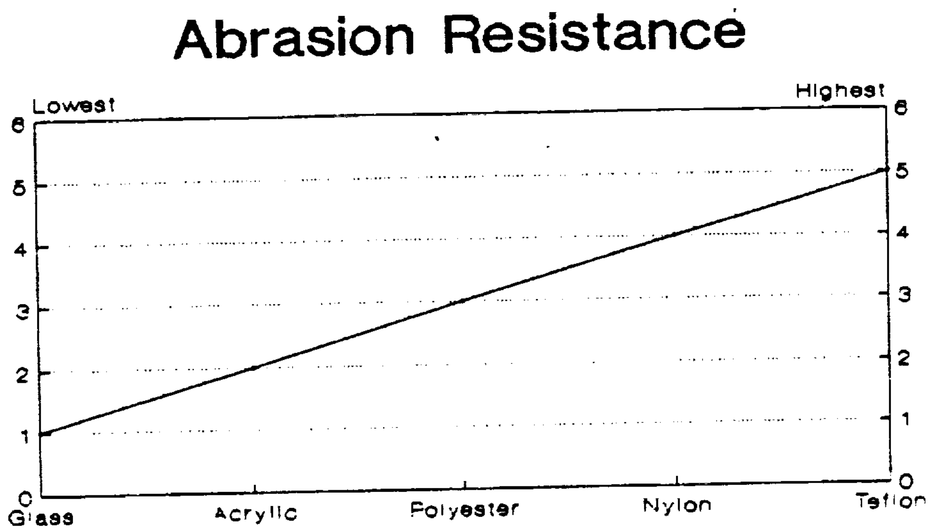
Allowable shear stress = 130000 psi

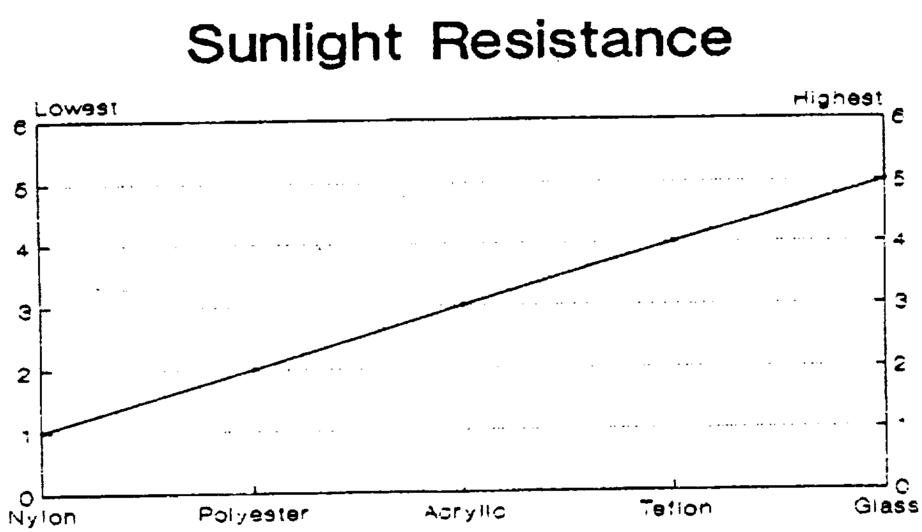
APPENDIX D
Comparison of Fiber Strengths and Elastic Recovery





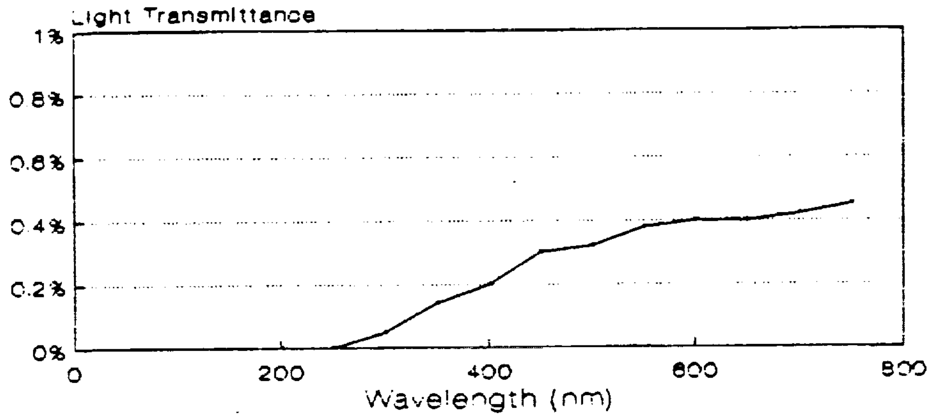
APPENDIX D
Comparison of Fiber Abrasion and Sunlight Resistance



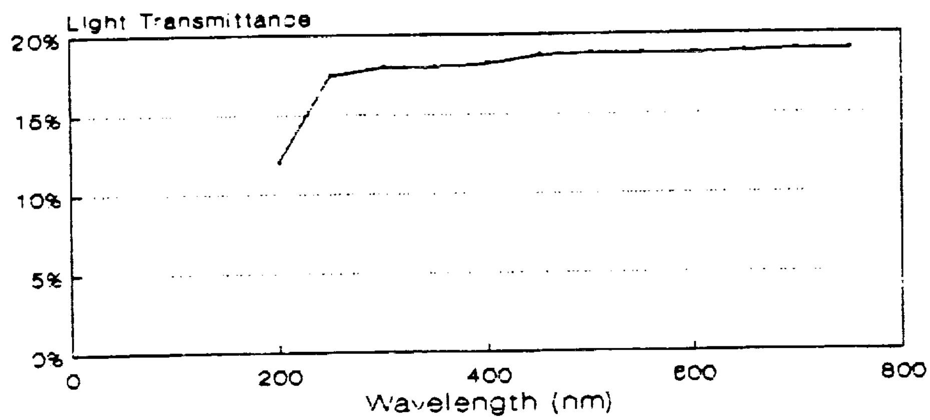


APPENDIX E
Spectrophotometer Test Results

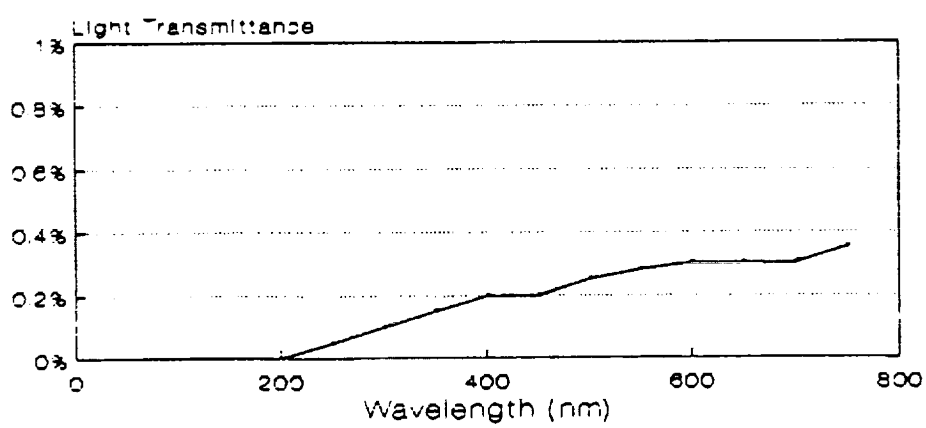
Acrylic
Sunbrella Oyster



Teflon (One Layer)
Stern and Stern T-162

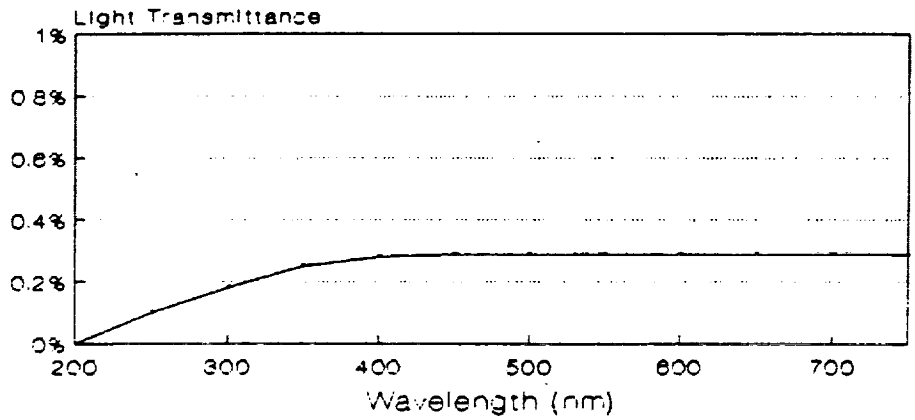


Teflon (two layers)
Stern and Stern T-162

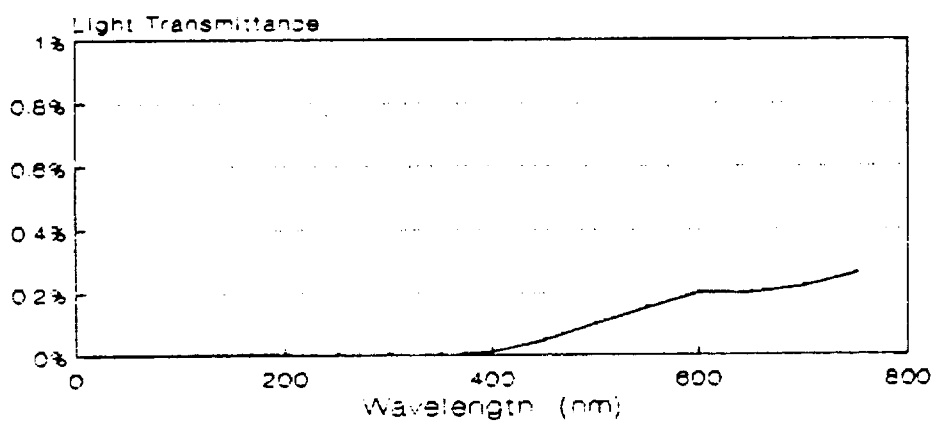


APPENDIX E
Spectrophotometer Test Results

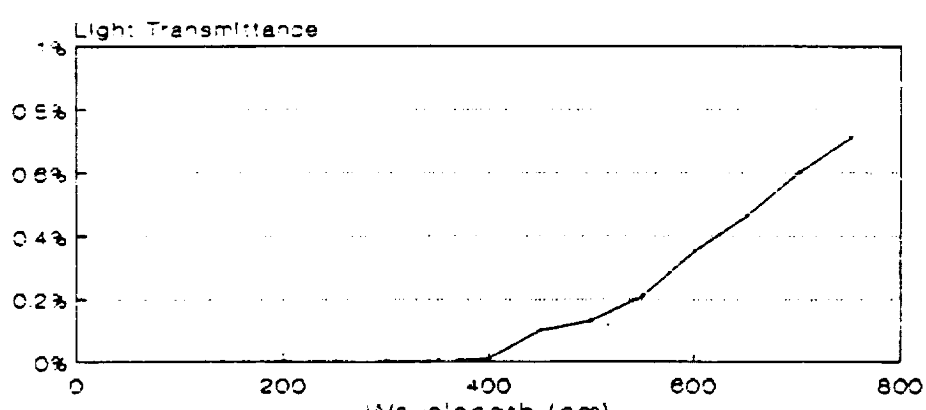
Fiberglass
Clark-Schwebel 7781



Silicon Coated Fiberglass
Chemglas 18 mil



Teflon Coated Fiberglass
Chemglas 18 mil



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