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Design of a Radiator Shade for Testing in a Simulated Lunar Environment

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EXECUTIVE SUMMARY

Design of a Radiator Shade for Testing in a Simulated Lunar Environment

The National Aeronautics and Space Administration (NASA) and The Universities Space Research Association (USRA) have chosen the parabolic/catenary concept from their sponsored Fall 1991 lunar radiation shade project for further testing and development. NASA asked the design team to build a shading device and support structure for testing in a vacuum chamber. Besides the support structure for the catenary shading device, the design team was asked to develop a system for varying the shade shape so that the device can be tested at different focal lengths. The design team developed concept variants and combined the concept variants to form overall designs. Using a decision matrix, an overall design was selected by the team from several overall design alternatives.

Concept variants were developed for three primary functions. The three functions were structural support, shape adjustments, and end shielding. The shade adjustment function was divided into two sub-functions, arc length adjustment and width adjustment.

This report is divided into seven primary sections. First, the introduction presents background information about NASA and USRA. This section also provides project background, project problems, and tasks to be accomplished by the design team. Second, the function alternatives section includes design considerations, information about the vacuum chamber, and design alternatives for the three functions. Third, the Evaluation of Function Alternatives section describes the different methods the design team considered to evaluate these alternatives. Fourth, the Evaluation of Design Combinations section, presents the design combinations and their advantages and disadvantages. The fifth section, Design Selection, presents decision matrix results and the final design decision. The sixth section, Design Solution, presents the design solution and the embodiment for the test shade. Lastly, the seventh section gives the conclusions for the project, recommendations for the test shade, and ambient testing procedures for the test shade.

I. INTRODUCTION

This report presents the design of a radiator shade by a team from the UT Mechanical Engineering Design Program. The shade is a test model that will be used in a simulated lunar environment. The following document contains the project statement, the design methodology the team followed, the design alternatives developed by the team, and the overall design chosen by the team.

1.1 Sponsor Background

This project was co-sponsored by the National Aeronautics and Space Administration (NASA) and the University Space Research Association (USRA). NASA was established in 1958 to conduct and coordinate research of flight within and beyond earth's atmosphere. Since its establishment, NASA has launched numerous unmanned space flights such as artificial satellites and space probes, and manned space flights which include lunar bound spacecraft. Currently, plans are being made to establish outposts on the Moon and Mars. NASA is also involved in the development of Space Station Freedom, which is to be built around the year 1995.

The Universities Space Research Association was created by NASA. USRA administrates the Advanced Design Program. This program brings NASA engineers together with engineering students and faculty to coordinate design projects applicable to current aerospace problems. USRA design projects benefit NASA because they provide useful engineering solutions and maintain working ties between government and academic

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engineering institutions. The projects also provide students with interesting and educational real world design opportunities.

1.2 Project Background

NASA has studied the establishment of manned planetary bases periodically for several years. Recently, the primary focus has been to examine the feasibility of manned missions to the Moon and to Mars.

Extended manned missions to the Lunar and Martian surfaces pose new challenges for Active Thermal Control Systems (ATCS's). A thermal control system controls the heat transfer process that occurs between the living environment and the surroundings, making it possible to heat or cool the environment. An example of an ATCS is a home central heating and air conditioning system. In the vacuum of space, these systems must reject heat to the lunar environment through radiation. Heat rejection can be accomplished using a radiator, which carries a working fluid that absorbs waste heat produced in the living environment. As the fluid passes through the radiator, it radiates heat to the lunar environment.

Moderate temperature (275K to 295K) heat rejection becomes a problem during the Lunar day when the effective heat sink temperature exceeds the source temperature. The heat sink temperature is the temperature of the surroundings to which heat can is to be transferred by radiation. It must be less than the source (radiator) temperature.

The primary factors affecting the thermal environment of the moon are the 29.5 earth-day diurnal cycle, a relatively high solar flux, and the lack of a lunar atmosphere. The angle at which the sun's rays strike the lunar surface at noon varies by +/- 1.53 degrees due to the inclination of the lunar equator to the ecliptic plan.[1] Therefore, the

design case for an east-west aligned vertical radiator at the equator will include solar radiation at an angle of incidence of 1.53 degrees relative to the radiator plane. Using a radiator at the lunar equator may present problems when the radiator absorbs more heat than it rejects during the lunar midday.

The various components of radiant energy (shown in Figure 1.1) include solar radiation incident on the radiator, surface infrared radiation, albedo, and direct solar radiation. These components could strike a horizontal or vertical radiator and reduce its effectiveness, resulting in a net heat transfer into the radiator.
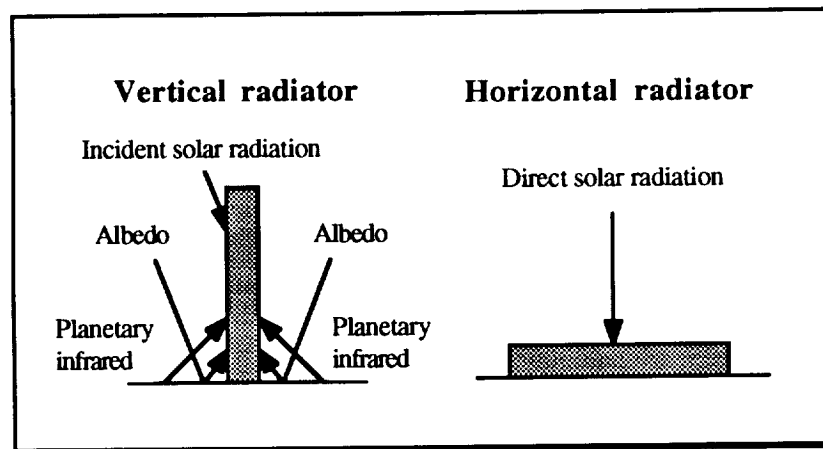
Figure 1.1: Various components of radiant energy within the lunar atmosphere.

This project focuses on rejecting heat during the lunar midday. Net heat rejection can be accomplished by decreasing the radiation incident on the radiator with a shading device. A reflective shade placed underneath the radiator will block radiation from the hot lunar surface and reflect radiator output into cold space.

This project is the second of two parts. Part 1 was conducted during the fall 1991 semester. The first part covered the conceptual design of the shading device. The second part of the project covers detailed design and construction of an engineering model for one of the preliminary designs selected from the Fall 91 project. NASA selected the Parabolic Reflector concept as the design to pursue this semester. Figure 1.2 illustrates the Parabolic Reflector concept. Because the radiator is oriented east-west at the equator, the sides are exposed to very little direct sunlight.
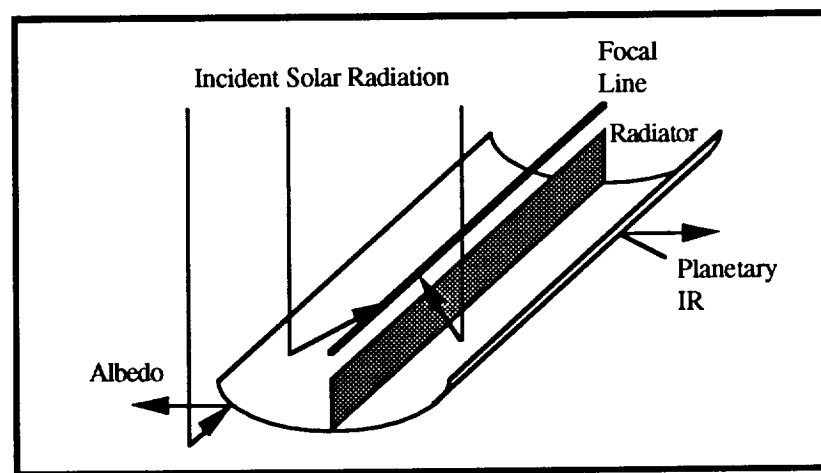
Figure 1.2: Parabolic Reflector shading device.

The model produced by this design team must be suitable for thermal vacuum chamber testing at NASA JSC. Preliminary ambient testing of the model will be performed to verify proper operation of various components.

1.3 Project Purpose

The purpose of this project was to design and construct a flexible parabolic or catenary shade test article, with the capability to shade an ATCS radiator. The test article is to be used for testing under a solar lamp array inside a vacuum chamber. The device is automated for focal length adjustment from outside the chamber. The test results will be used to confirm the feasibility and proper focal length setting of parabolic shading devices for future use in extraterrestrial ATCS's.

1.4 Project Requirements

The lunar radiator shade project had the following requirements:

1. Design and construction of a flexible hanging parabolic or catenary shaped shade test article to be tested inside a NASA-JSC vacuum chamber under a "solar" lamp array.
2. Detailed drawings of the test device.
3. System mass and volume calculations.

1.5 Project Criteria

Criteria for the test device include the following:

1. The device should support a radiator with a length to height ratio of at

least 10 (2.4" X 24" suggested).

2. The edges of the parabolic/catenary shade must rise to even with the top of the radiator.

3. The shade should have end shields.

4. The device must withstand a lunar environment (hard vacuum, low gravity, intense solar radiation, temperature cycling between 102K and 384K).

5. The device must be transportable by station wagon (to JSC from Austin).

6. The device must be constructed of pre-approved materials such as Al 6061 T6. Additional materials must be approved by sponsor.

7. The shade material will be aluminized polyimide film.

8. A factor of safety of at least 1.5 should be used in construction.

9. The focal line of the radiator must be adjustable to accommodate a range of focal line settings. Focal line settings must include 1.0, 1.5, and 2 times the radiator height as shown in Figure 1.3.
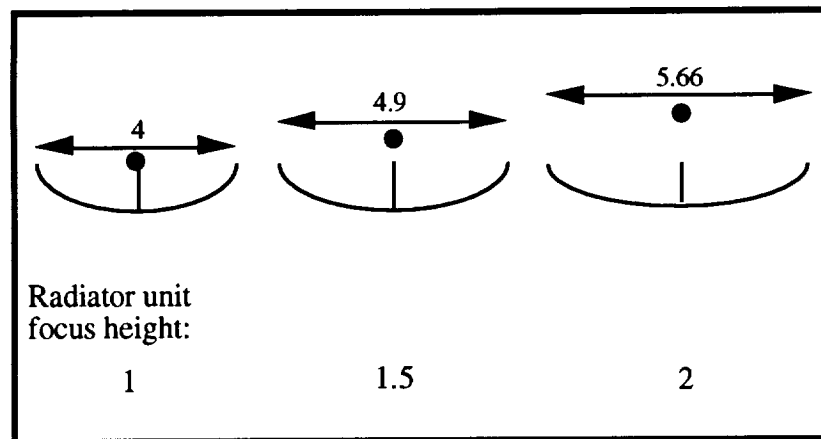
Figure 1.3: Shade with varying focal length setting.

1.6 Optional Desired Tasks (in order of priority)

1. Make shade focal length remotely adjustable, possibly using a motor.

2. Design and construction of a radiator with electric heater.

3. Design and construction of a lunar surface simulator.

4. Purchase and attach thermocouples to test shade, radiator and simulated lunar surface.

5. Make shade focal line continuously adjustable between 1.0 and 2.0 times the radiator height.

6. Construct a metal can to isolate the motor (used in a remotely adjustable design) from the vacuum environment.

1.8 Design Methodology

Steps in the design process include the following:

1. Consult with the project sponsor (Michael Ewert) and faculty advisor (Dr. Michael Bryant) with emphasis on clarifying the problem and recognizing feasible solution concepts.

2. Patent and literature search for existing applicable solution principles.

3. Development of alternative solution principles for the required device functions.

4. Evaluation of the various combinations of function solution principles.

5. Choosing one of these combinations as the system design.

6. Building the test shade from pre-approved materials.

7. Testing the device operations in ambient conditions.

8. Preparation of the written report which includes discussion of the design process and detailed drawings of the solution.

9. An oral presentation of the project results.

1.9 Confidentiality Concerns

All project documents are considered NASA/USRA property. These documents were presented to members of the UT Faculty for grading and advising purposes. No documents will be given to persons outside the NASA and UT communities without prior sponsor approval.

II. FUNCTION ALTERNATIVES

This section begins with a presentation of background information on the design problem, the desired catenary shape, and the vacuum chamber in which the test shade will be used. This section also discusses three critical functions (support, adjustment, and end shielding) and several design team solution alternatives for each. Each function's subsection contains background information on the function, problems involved in finding solutions, and criteria used to compare the various solution alternatives. For each solution concept, a brief description precedes a listing of its advantages and disadvantages.

2.1 Background

The following three subsections present background that is useful for discussing the alternate designs.

2.1.1 Design Problems. The primary goal of the design team was to develop a catenary shaped radiator shade with an adjustable focal length. The focal length is increased by widening the catenary shape which is formed when the flexible shade material hangs between two edges. Adjustment requires both moving the two edges together or apart, and providing the appropriate length of material between the edges. Focal length adjustment should be automated and remotely controllable so that a full series of tests may be conducted without the expense and time necessary to depressurize the chamber after each adjustment. See Appendix A for a complete list of specifications.

The shade and the mechanisms for adjusting its width must be supported by a frame. Strategic frame design may integrate the necessary motion enablement and control into the frame itself. The frame should not add significantly to the system mass or volume and may allow the device to be collapsed for easier transportation and storage.

The actual shade designed for the lunar base may be very long so as to minimize end effects but there is a practical limit to how long the test model should be. End shields will be used in order to limit end effects on a test model of reasonable length. One of the major problems in optimizing end shield design is the fact that the shape of the end being shielded changes with shade adjustment. An end shield large enough to cover the entire shade end at its widest setting will stick out at narrow settings causing some external shading of the catenary shade. External shading will cause the test article to differ from the optimal lunar system being modeled. An end shield which doesn't completely cover the shade end allows radiation to strike the radiator. In addition to how completely the end shield blocks solar and surface radiation from hitting the radiator, its effectiveness may also be influence by where it reflects the energy striking the shield on the radiator side. The end shield should not reflect a considerable amount of radiation into the radiator.

2.1.2 Catenary Shape. When a heavy uniform cable with no resistance to bending hangs freely from two points it forms a catenary shape ($y=a[Cosh(x/a)]$).[2] The larger the parameter "a" the flatter the curve.[3] Very flat catenary curves are often approximated by the parabolic curve ($y=x^2/[4p]$) where p is the focal length.[4] Catenary curves do not appear to have a true focus. However, graphical comparison of parabolic curves having the three required focal lengths with catenary curves that pass through the same origin and end points demonstrates that even the lowest focal length setting is flat enough so that the corresponding catenary and parabolic curves are virtually identical (see Figure 2.1 and Appendix C : Catenary/Parabolic Analysis, for more detail).

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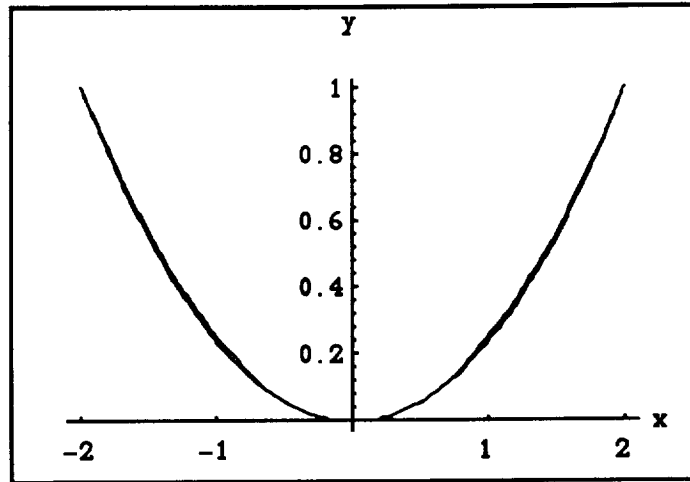
Figure 2.1: Parabolic and catenary plots overlaid for the one unit focal setting,

the parabolic curve is slightly narrower than the catenary.

The aluminized polyimide shade material is uniform and hangs freely between two points but its resistance to bending may be too large compared to its weight per unit length for the shade to hang in a perfect catenary shape. The material's non zero stiffness to weight ratio will become even larger in the moon's reduced gravity. How will the non ideal properties of the shade material affect its assumed catenary hanging shape?

An extreme example of a high stiffness to weight ratio is a weightless beam. If such a beam is subject to equal but opposing moment couples at its two ends it deflects into the shape $y=c(x^2-Lx)$.[5] When this equation is transformed so that the vertex is at the origin, it assumes the familiar parabolic form ($y=c\ x^2$) (see Appendix C). Therefore, whether modeled as either of the two extremes, stiff and weightless or heavy with no resistance to bending, the shape of the shade is parabolic or very close to parabolic (flat catenary), respectively. Furthermore, the purpose of the test article is not to test a perfect

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catenary shape but to test a real hanging shade, like one that might be reproduced on the moon, in order to assess how it behaves compared to computer models.

Table 2.1 presents critical dimensions for the three focal length settings with a 2.4 inch tall radiator (see Appendix C for calculations).

Table 2.1: Critical Parabolic Dimensions

Focal Length (radiator heights/inches)	Width (inches)	Arc Length (inches)	End Angle (degrees to horizontal)
1/2.4	9.6	11.0	45.0
1.5/3.6	11.8	13.0	39.2
2/4.8	13.6	14.6	35.3

2.1.3 Vacuum Chamber. The test articles will be subjected to a simulation of a Lunar thermal environment including hard vacuum, intense radiation, and high temperatures. The thermal vacuum chamber that will be used in the testing of the shading device is one of the larger chambers used by NASA (See Figure 2.2). The combination of its size and control features allow it to accommodate a variety of tests economically, with a fast response time.[6] The chamber is currently configured in the man-rated mode for shuttle EVA (extra-vehicular activity) Testing/Training, i.e. the astronauts may use the chamber to simulate "the vacuum of space" and their activity outside of the spacecraft.

The major structural elements of the chamber include: a removable top head, the fixed chamber floor (non-rotating), and a dual manlock at the floor level. The removable top head allows a test article to be inserted into the chamber by cranes and solar modules to be mounted on the top to simulate the sunlight-to-darkness cycle. Infrared (solar)

simulators can also be designed to fit each specific test, to simulate variable albedo and planetary radiation heat fluxes. The dual manlock provides easy access to the test articles as well as a means of transporting test crewmen from ambient air pressure to the thermal-vacuum environment and back during manned tests.
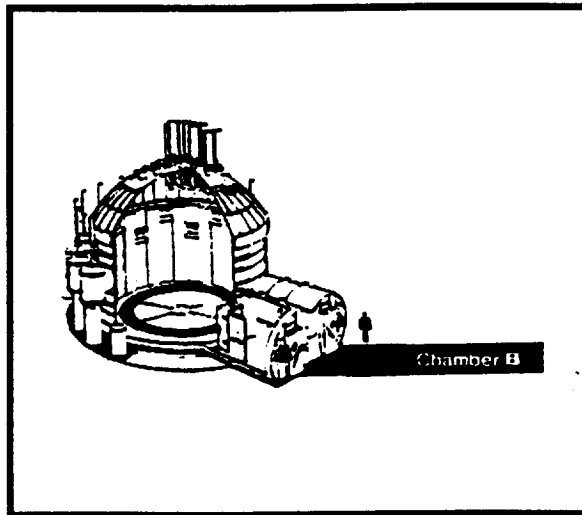
Figure 2.2 A cross-section of a typical vacuum chamber.[6]

The chamber has a 10.7 meter diameter, a 13.1 meter height, and a weight of 34,000 kg. The total heat absorption capacity of the chamber is 130,000 W and its maximum heat flux is 1393 W/m^2.

2.2 Alternates for Providing Support for the Radiator and Shade

The test article allows for support of the device consisting of a radiator, a shade, (see Appendix A), certain criteria were selected to apply to the support structure (frame).

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This frame should provide minimal shading of the radiator and maintain at least a 1 inch clearance between the shade and the ground level. The frame must be structurally stable and be made of a pre-approved material such as, stainless steel or any aluminum material. When loaded, the structure should be able to support at least 5 kg, allowing for a factor of safety of 1.5. Collapsibility for the frame is desired, so that the test article will be easily transported and stored. To allow possible testing in a smaller, alternative vacuum chamber, the horizontal diagonal of the device should be 40 inches or less with a maximum height of approximately 12 inches. If possible, the frame should not utilize the total maximum dimensions at all times, i.e. the frame should be foldable. The frame must be easily machined therefore it must not have intricate geometry.

In consideration of these constraints, the team established several criteria upon which the evaluation of the alternatives for shade support was based. *Collapsibility,* which will allow the frame to be transported easily. The frame will require non-fixed connections such as, pin joints or sliders, and a locking mechanism to ensure stability. *Structural stability* is crucial to the operation of the test article. The frame must be able to support the shade, the radiator, and any devices used for automation, including low horsepower motors. *Machinabilty* and *manufacturing* considerations are important criteria to consider when examining the budget and time constraints of the project. Given the time constraints faced by the design team, machining should be limited to basic operations. Other criteria for evaluation are listed in the advantages and disadvantages section of each alternative.

The team developed four alternates for support of the radiator shade and analyzed these based on some of the above explained criteria. The alternate designs are described in the following order:

1. Rectangular Frame.
2. Truss.

3. I-Beam.

4. V-Frame.

2.2.1 Rectangular Frame. The rectangular frame, shown in Figure 2.3, consists of twelve members connected by rigid dowels or slots. This structure is geometrically simple and will provide three dimensional support for the test article. Ideally, the shade would be supported or attached to the top edges of the structure and hang parabolically in its center.
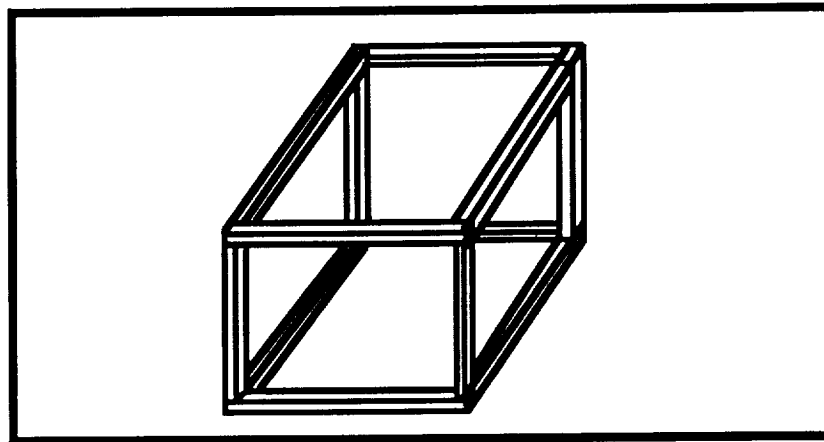
Figure 2.3: Rectangular Frame Structure

The advantages of the rectangular frame are as follows:

1. Easily manufactured or machined.

2. Simple design and geometry.

3. Could be easily disassembled.

The disadvantages of the rectangular frame are as follows:

1. Not structurally stable with simple pin connections.

2. Not easily collapsible for transportation.

3. May provide too much shading by the frame.

4. Difficult to add in adjustment capabilities for the shade.

5. Occupies a large volume.

2.2.2 Truss. A truss structure consists of ten joint connectors, nine skeletal bars connected at their ends by the joint connectors, and four diagonal bars (see Figure 2.4). The shade would theoretically hang from, or be attached to, the top corners of the structure. In a truss, joint connectors can be simple pins as they are not required to support moments. Trusses are widely used in bridges because of their structural dependability due to primarily axial loading.
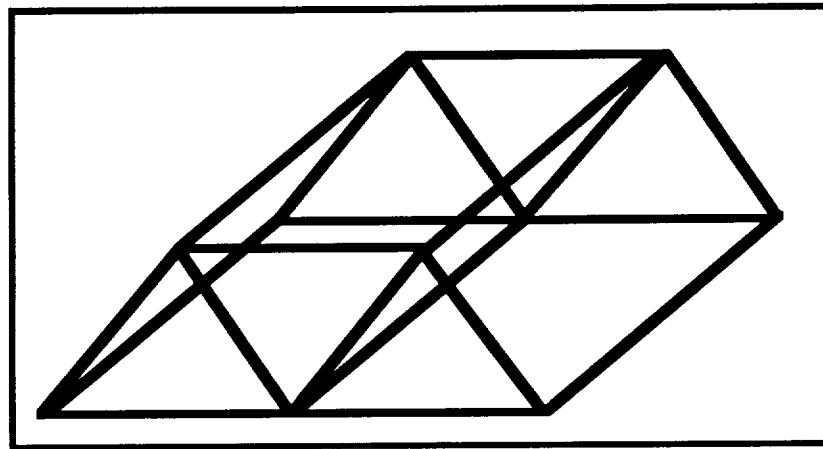
Figure 2.4: Truss Structure

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The advantages of the truss structure are as follows:

1. Statically determinant and structurally sound.

2. Easily manufactured.

The disadvantages of the truss structure are as follows:

1. Will be hard to transport unless collapsible.

2. May provide too much shading by the frame.

3. Occupies large volume and surface area.

4. Difficult to provide movement of the shade (adjustability).

2.2.3 I-Frame. The I-Frame is similar to the rectangular frame structure in that it has ten members connected by dowels or slots (see Figure 2.5). The shade would connect at the top of the structure and hang freely with the center members being parallel to the radiator.
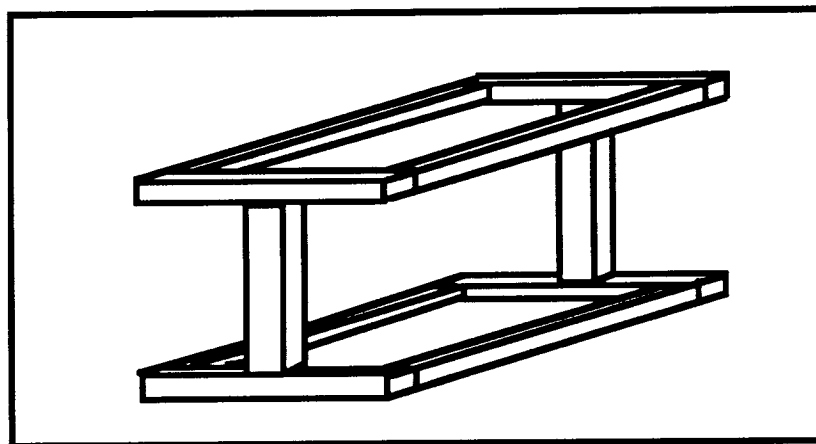
Figure 2.5: I-Frame Structure

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The advantages of the I-Beam are as follows:

1. It is easily manufactured.

2. Simple geometry.

The disadvantages of the I-Beam are as follows:

1. Not stable with simple pin connectors.

2. May provide excessive shading.

3. Occupies too much volume.

4. May excessively torque center member connections if load is unbalanced.

2.2.4 V-Frame. The V-frame consists of six bar members connected by pin joints and four link members to allow for widening motion of the frame (see Figure 2.6). The V-Frame differs from the previous frames in that it adds the capability of movement and adjustability. This structure provides horizontal movement of the shade to increase shade width. The pin joints located at the center of each end, lift the radiator vertically.
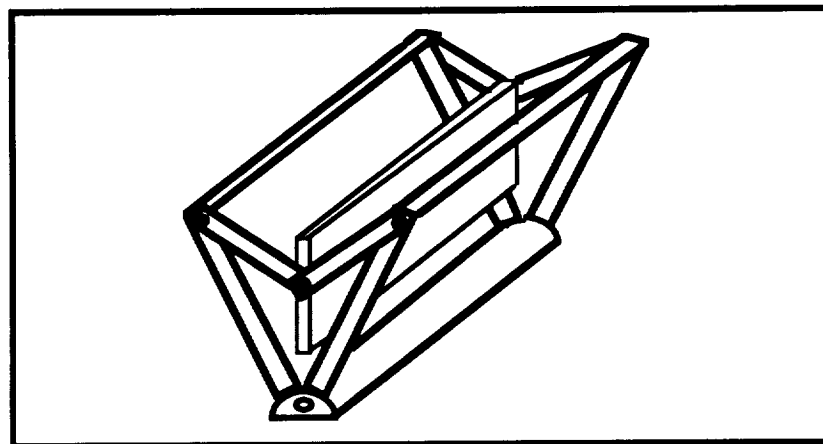
Figure 2.6: V-Frame Configuration

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The advantages of the V-Frame are as follows:

1. Offers adjustability.

2. Offers vertical movement of the radiator, if needed.

3. Collapsible for transportability.

4. Simple for continuous and discrete operation.

The disadvantages of the V-Frame are as follows:

1. Does not allow for radiator height to be equal to shade height at all times.

2. Does not eliminate excess material when it is not needed.

2.3 Shade Adjustment

The shade width and arc length must be adjusted to obtain the three required focal length settings for testing in NASA's vacuum chamber (refer back to Figure 1.3 for focal settings). Because of the time and expense involved in depressurizing the vacuum chamber, it is necessary that the adjustments be made without re-pressurizing. Furthermore, it is desired that, if possible, the focal length be continuously adjustable so that tests may be conducted using additional focal lengths within the required range. Continuous focal length adjustment requires continuous width and arc length adjustment.

The arc length, which corresponds to the length of shade material used in the catenary shape, must change with the width because of the requirement that the height of the catenary shape remain constant (at the radiator height). As the shade is adjusted to a narrower width, extra shade length in the width direction must be taken up or the shade will

hang down below the radiator (see Figure 2.7). The design task is further complicated by the fact that the arc length does not vary linearly with the width of the catenary shape (the relationship involves the hyperbolic sine).
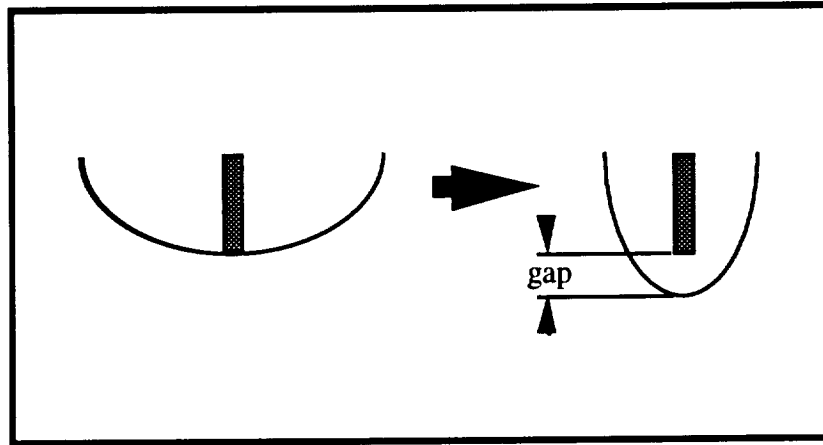
Figure 2.7: Undesirable gap caused by extra shade length.

This section is divided into two subsections. The first discusses changing shade arc length. The second addresses methods of adjusting shade width and how to couple this adjustment with the arc length adjustment. A linkage between these two adjustments is desirable so that they can be performed simultaneously with a common power input. Multiple power inputs would increase cost and complexity and separate adjustments with a common input would require a gearing shift to change modes.

2.3.1 Arc Length Adjustment. The arc length of the catenary shade is changed by increasing or decreasing the length of material hanging between the two supporting edges. This can be accomplished in one of two basic ways, rolling up excess material or allowing the excess to hang outside the supported section. If a length of

material is allowed to hang outside the catenary section (see Figure 2.8), it might cause external shading, introducing unacceptable divergence from the desired radiative heat transfer model.
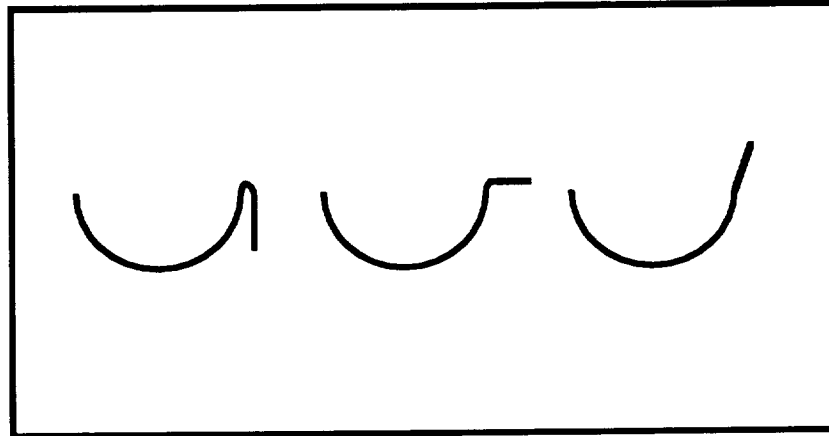
Figure 2.8: Three possible hanging positions for extra shade length.

Even if the shade is rolled, the roll itself will cause some shading which, depending on its position, may significantly effect results (see Figure 2.9). Rolling the material may also introduce a torque in the material which might effect its hanging shape. Even a small torque may be significant because the shade material is so light and the catenary shape is based on a "heavy" cable with negligible resistance to bending. A large rolling radius would reduce bending induced torque. A large rolling radius would also reduce the relative increase in diameter as more material is added to the roll. However, a small radius would decrease shading.
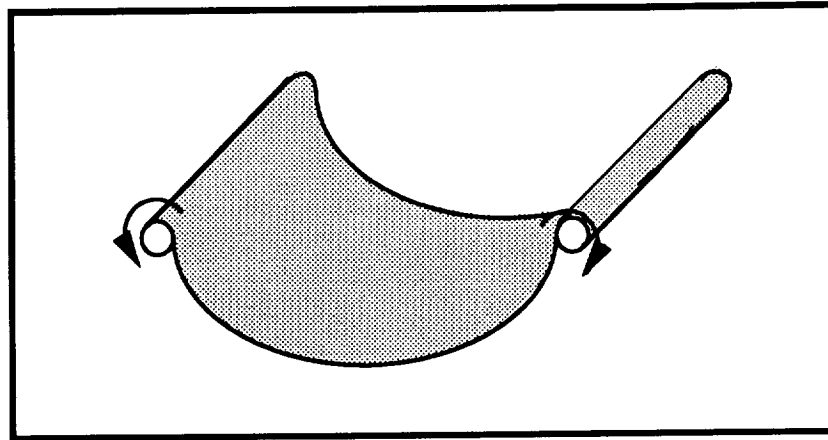
Figure 2.9: Rolling arc length adjustment.

2.3.2 Width Adjustment. Width adjustment is accomplished by increasing the horizontal distance between the two edges by which the catenary shade hangs. Because the radiator must remain centered between the two edges, the design team decided to move both edges symmetrically relative to the stationary radiator. Five mechanisms for changing the shade width are discussed in the following sub-subsections. Criteria for comparing width adjustment mechanisms include the following:

1. Continuous adjustment.
2. Symmetric adjustment.
3. Simplicity.
4. Weight.
5. Positioning accuracy.
6. Reliability.
7. Ease of manufacturing.
8. Required maintenance.

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2.3.2.1 Scissor Mechanism. In this arrangement (see Figure 2.10) a stationary rotating pinion gear (A) drives a pair of toothed racks (B) in opposite directions. These racks are attached to the horizontally fixed center joints (C) of a scissor mechanism. As the racks move the joints together or apart the scissor mechanism either extends or retracts (respectively), moving the edges of the catenary shade.
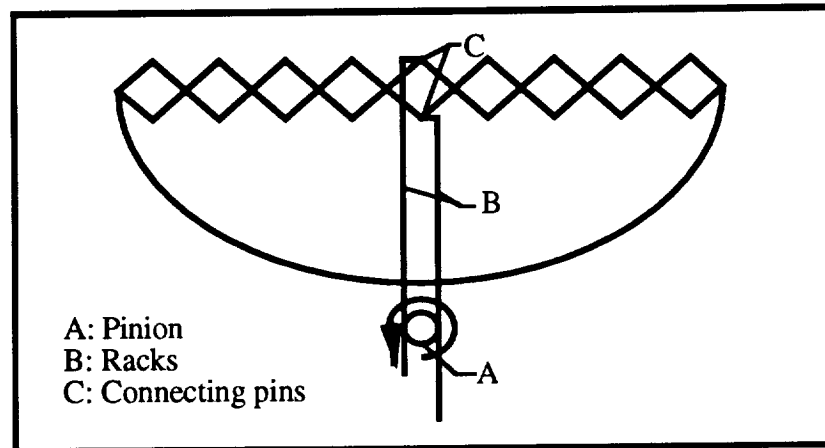
Figure 2.10: Scissor Mechanism for shade width adjustment.

Advantages of the Scissors Mechanism are as follows:

1. Simple.

2. Continuously adjustable.

3. Symmetric movement of both ends.

Disadvantages of the Scissors Mechanism are as follows:

1. Multiple links and long racks add considerable mass to design.

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2. Long toothed racks' precisely pinned scissors joints difficult to manufacture.

3. Extension will not be linear with gear input throughout scissors range.

4. Multiple pinned joints in scissors mechanism may require lubrication under vacuum conditions.

5. The high ratio of overall extension to overall rack motion may make exact positioning difficult.

2.3.2.2 Power Screw. For this alternative, the ends of the catenary shade are moved by a power screw (see Figure 2.11). The screw is driven by a worm gear at its middle. The threaded "nuts" at the moving shade ends might use a single ball bearing to contact each thread. This would minimize the need for vacuum condition lubrication and would allow use of a non-linear varying pitch thread that might create the hyperbolic sine linkage necessary to power both arc length and width adjustment simultaneously with one motor .
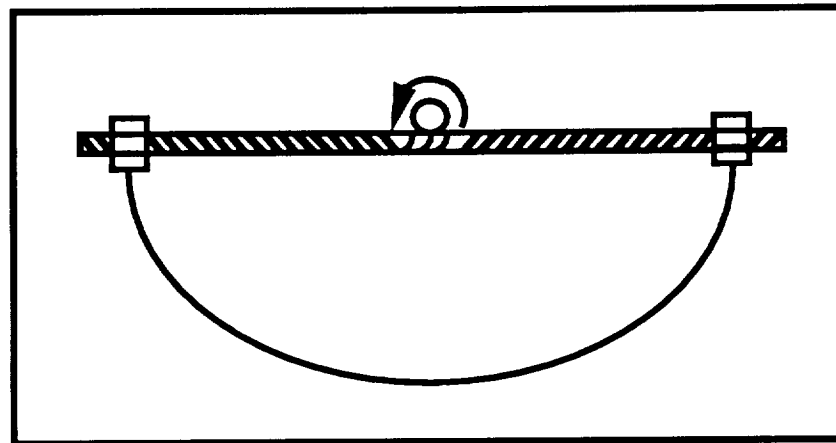
Figure 2.11: Power Screw for shade width adjustment.

Advantages of the Power Screw are as follows:

1. Variable thread pitch could provide correct nonlinear linkage.

2. Fine threads provide excellent positioning accuracy.

Disadvantages of the Power Screw are as follows:

1. Variable pitch threads difficult to machine.

2. Standard thread contact would require lubrication.

3. Power screw may add considerable bulk to design.

4. Ball bearing "nuts" difficult to manufacture.

2.3.2.3 Trolley. For this alternative, width adjustment is made using a loop of cable which turns around a pulley at one end and is powered at the other end by a rotating cone which it is wrapped around (see Figure 2.12). One side of the shade is attached to a point on the bottom of the cable loop and the other side is attached to a point on the top. Depending on which way the cable is running around its loop, the two ends of the shade are either getting closer together or further apart.

The cone can have a variable cross section and be threaded so that the loop of cable that wraps around it must move up or down the cone to a different cone diameter as the cone rotates.[7] For a constant rate of cone rotation, the rate at which the cable moves around the loop will depend on the diameter of the cone at the level where the cable wraps around it. Thus, a correctly shaped cone could provide the desired hyperbolic sine linkage.
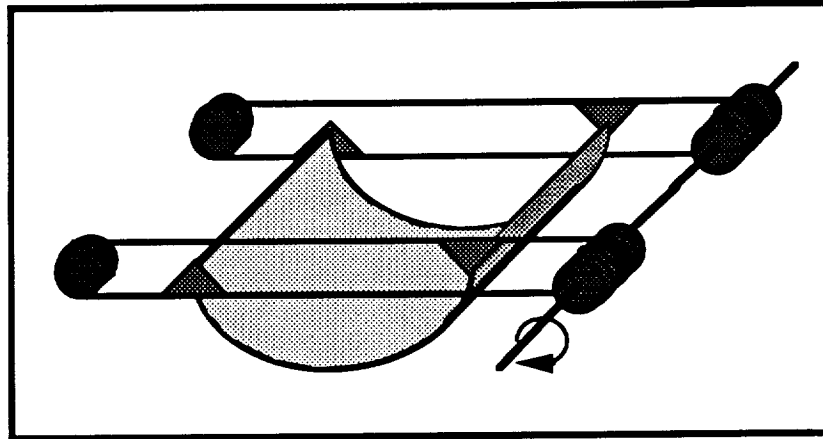
Figure 2.12: Trolley cable mechanism for adjusting shade width.

Advantages of the Trolley cable are as follows:

1. Could provide hyperbolic sine linkage.

2. Relatively light mechanism.

Disadvantages of the Trolley cable are as follows:

1. Cables could become tangled.

2. Cables could slip on cone.

3. Cables might stretch due to prolonged tension or high temperature.

4. If the cable moves axially relative to the cone, the cone must move rather than
   the cable, so that the shade only moves in the width direction.

2.3.2.4 Rack and Pinion. This alternative utilizes a rack and pinion
arrangement to widen the catenary shade (see Figure 2.13). As the stationary pinion

rotates, the racks move in opposite directions. The shade edges are attached to the ends of the rack members.
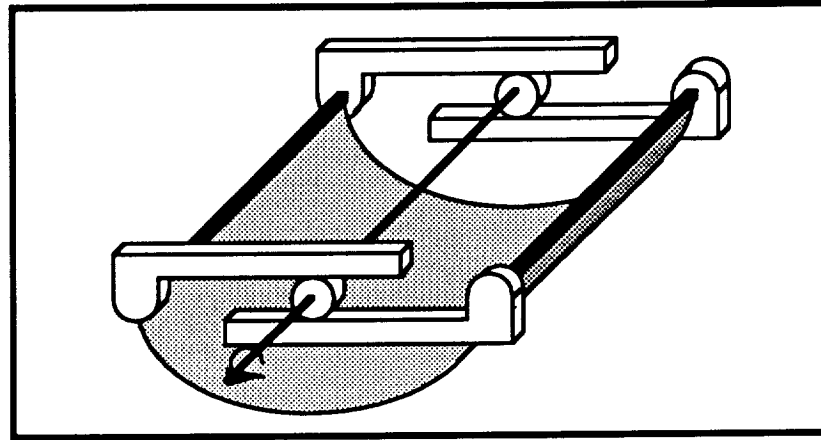
Figure 2.13: Rack and Pinion mechanism for width adjustment.

Advantages of the Rack and Pinion are as follows:

1. Provides continuous symmetric widening.

2. Accurate positioning.

Disadvantages of the Rack and Pinion are as follows:

1. Massive rack links.

2. Difficult to manufacture toothed rack.

3. Racks require support over a long range of motion.

2.3.2.5 Shaped Track. One promising method of providing the correct nonlinear width extension to arc length linkage was to store the information in the frame

mechanically. A mechanism using this principle is illustrated in Figure 2.14. Gears at the edge of the shade climb a shaped track. As the gears turn, the bars unroll additional shade material. The slope of the track determines how much material is unrolled per unit increase in shade width.
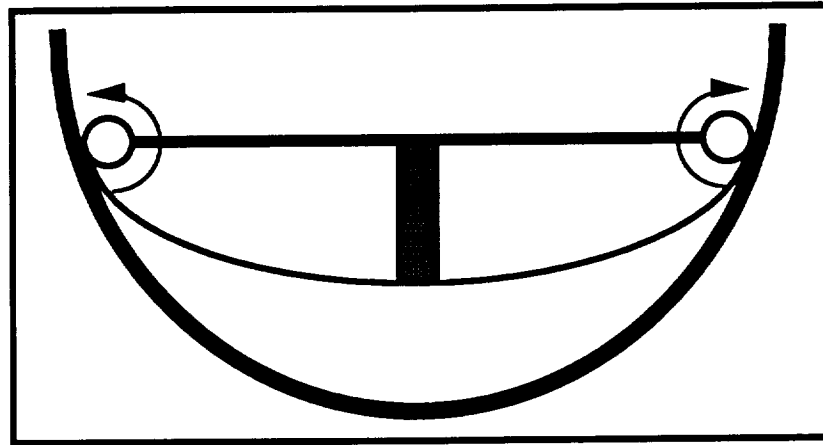
Figure 2.14: Roller shade climbing curved track.

Advantages of the Shaped Track are as follows:

1. Nonlinear linkage is built in.

2. Precise continuous positioning.

Disadvantages of the Shaped Track are as follows:

1. Massive track.

2. Difficult to shape track.

3. Difficult to machine teeth into curved track.

4. Either the entire shade and radiator moves vertically, increasing the gap between it and the simulated lunar surface, or a way must be found to move the track down.

5. Difficult to provide matching power to both gears while they move apart.

2.4 Alternates for Shielding Radiation Incident on the Ends of the Radiator

At noon, the sun only views the narrow top edge of the radiator directly and a small portion of the side at a very steep angle (at least 88.47° from perpendicular). However, during sun rise and sun set, sunlight enters the ends of the shade (see figure 2.15). Again, only the narrow edge at the end of the radiator recieves direct sunlight. However, because of the relatively great length (10 times greater than the height), the side area viewed by the sun may be significent, even at the steep viewing angle. In the vacuum chamber, radiation may leave the walls diffusely and an even more significant amount of the radiation entering through open shade ends may strike the radiator. Therefore, end shields are necessary to shade the ends of the radiator from thermal radiation. The relevant design considerations for the end shield are solar radiation, planetary infrared and albedo, volume occupied, and ease of manufacturing.

2.4.1 Spherical End Shield. The shape is a quarter of a hollow sphere (see Figure 2.16). Its curved shape surrounds the end of the radiator and shields the IR radiation and albedo from the lunar surface. This end shade has a single focal point where the incident solar radiation is directed.
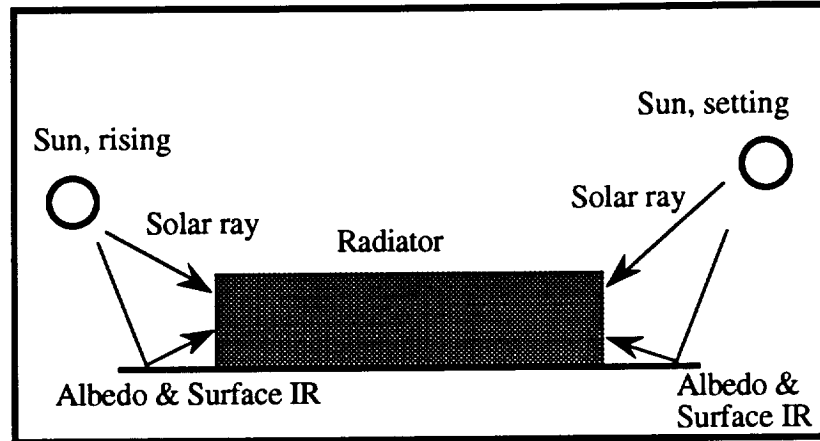
Figure 2.15: Components of radiation at sun rise and sun set.
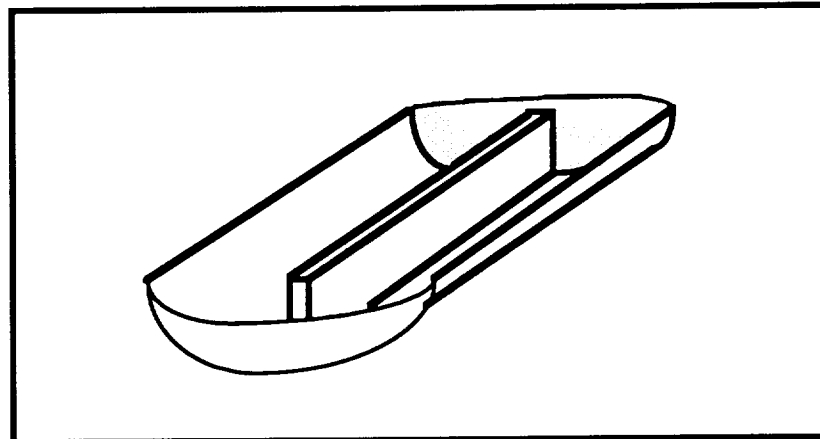
Figure 2.16: Spherical End Shield.

Advantages of the Spherical End Shield are:

1. Sunlight striking the radiator side of the end shield is directed upward, away

   from the radiator.

2. Focused solar radiation can be converted into useful energy (solar collector).

3. Blocks all IR radiation and albedo.

Disadvantages of the Spherical End Shield are:

1. Difficult to make the shield curved in two planes.

2. Difficult to connect to parabolic shading device.

3. The end of the radiator is exposed to solar radiation.(note view of end in figure 2.16).

4. Occupies large volume.

2.4.2. Parabolic End Shield. The shape of this end shield is the same as the hanging shade (see Figure 2.17). The outer surface blocks most of the IR radiation and albedo, and the inner surface focuses the solar radiation to a focal line above the radiator.
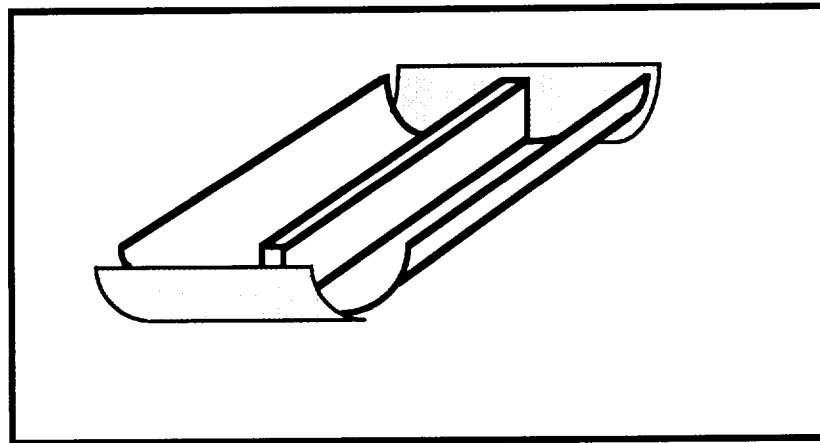
Figure 2.17: Parabolic End Shield.

Advantages of the Parabolic End Shield are:

1. Easy to cut shape.

2. Easy to connect to frame.

3. Focused solar radiation can be converted into useful energy (with a solar collector).

4. Shape is adjustable.

Disadvantages of the Parabolic End Shield are:

1. Gaps expose the radiator to some IR radiation and albedo.

2. The ends of the radiator view some morning and evening sunlight.

3. Occupies large volume.

4. Needs extra frame support.

5. End shields extend beyond the parabolic shading device when it changes to a smaller shape.

2.4.3 Parabolic Shield Plate. The shape of this alternate is a flat parabolic plate (see Figure 2.18). The shield is cut to fit the curve of the parabolic shading device at its widest setting. The Parabolic Plate shields all the incident IR radiation, albedo, and solar radiation by covering the end of the radiator.

Advantages of the Parabolic Shield Plate are:

1. Shields all radiation from lunar surface and the sun.

2. Easy to cut shape.

3. Small space requirements.

4. Easy to install.
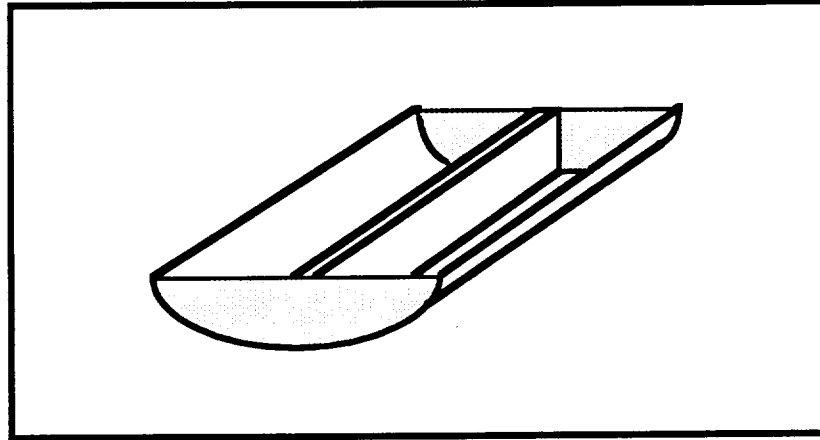
Figure 2.18: Parabolic Shield Plate.

Disadvantages of the Parabolic Shield Plate are:

1. Radiator end may absorbs heat trough contact with hot shade material.

2. End shield extends past the parabolic shading device when it changes to a smaller shape.

3. Difficult to support curved edge.

2.4.4 Rectangular Shield Plate. This alternate is a rectangular plate covering the end of the radiator (see Figure 2.19). The rectangular plate is aligned with the radiator at the top and at the bottom. The plate shields all the solar radiation incident on the end of the radiator, but exposes the sides of the radiator to the IR radiation and albedo. The side exposure will be particularly damaging with a narrow shield and the full 1.53° solar angle.
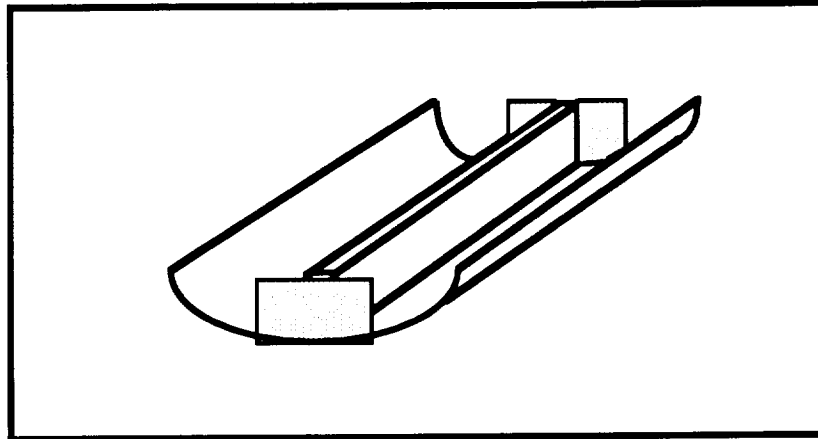
Figure 2.19: Rectangular Shield Plate.

Advantages of the Rectangular Shield Plate are:

1. Easy to cut shape.

2. Easy to install.

3. Blocks all incoming solar radiation from the radiator ends.

Disadvantages of the Rectangular Shield Plate are:

1. Depending on the width of the shield, the radiator sides may be exposed

   to some morning and evening sunlight.

1. Gaps expose the radiator to IR radiation and albedo.

2. Radiator end may absorb heat from the hot shade material.

2.4.5 Curved End Shield. This alternate is a rectangular plate being bent to touch the top and bottom of the end of the radiator (see Figure 2.20). The bending shape leaves a gap between the radiator and the shading material so that the radiator ends may not

absorb heat from contact with the hot shade material. This end shield blocks all the solar radiation and most of the IR radiation and albedo incident on the radiator.
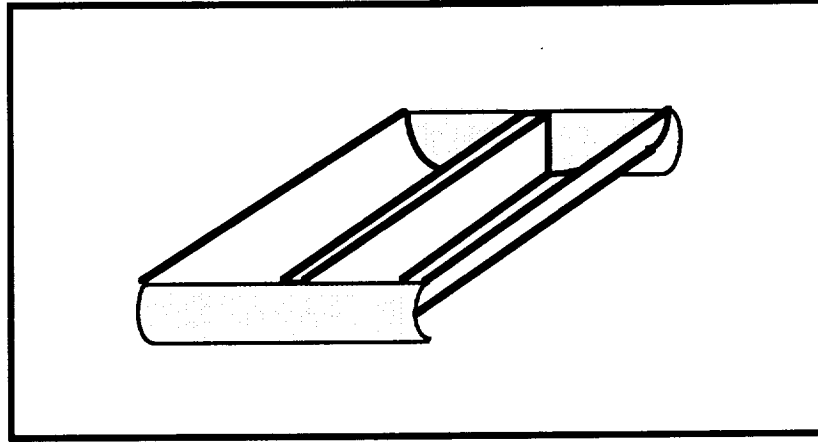
Figure 2.20: Curved End Shield.

Advantages of the Curved End Shield are:

1. Blocks all the solar radiation incident on the end of the radiator.

2. Blocks most of the IR radiation and albedo.

3. Minimal conductive heat transfer from the shade material to the radiator.

Disadvantages of the Curved End Shield are:

1. Over extended when the parabolic shading device changes to a smaller shape.

2. Small gap allows some IR radiation and albedo to pass through.

III. EVALUATION OF FUNCTION ALTERNATIVES

The *function alternatives* were evaluated on the bases of their compatibility with one another. A Morphological Matrix (shown in Appendix B) was used to produce several *design combinations* that satisfied the three critical functions. A set of criteria was developed for each function to evaluate the function alternatives. The alternatives were narrowed down by choosing the most feasible, economical, and logical method for accomplishing the function.

The alternates for each function were evaluated on separate criteria with respect to the function. The criteria used for evaluating the shade frame were structural dependability, machinability, ease of manufacturing, and collapsibility. The criteria used to evaluate the shape changing mechanism were adjustability, number of moving parts, ease of machining, mass and volume, symmetry of motion, and simplicity. The criteria used to evaluate the end shielding alternatives were shielding capabilities, volume, ability to connect to frame or shade, and ease of manufacturing.

The design team considered three possible methods of combining the function alternatives from the three functions to yield the design combinations. In the first method, all possible combinations are generated by a BASIC program which is then altered to sort off incompatible combinations yielding the most feasible combinations. In the second method, designs from each function are objectively combined and then judged as separate alternatives. The best alternative combinations are selected as the design combinations for further consideration. The third method involves the ranking of each function separately. The highest ranking design for each function are selected and then combined to become the design combinations. If compatibility problems arise, other function designs are re-examined and their ability to be integrated into the final design is determined.

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The sort program was used to identify all possible combinations of the alternatives for the three functions and then categorically sort the combinations (see Appendix J: Sort Program, for more details and a code listing). Two of the functions each had five solution principles and the third function four generating a total of one hundred possible combinations. The number of design combinations was then reduced by rejecting groups of incompatible or undesirable combinations such as all solutions with both shade attached end shields and shade rolling. By preceding in this manner, the number of solutions was reduced but there were still to many (72) for individual consideration.

The design team next used objectively selected combination of function alternatives to generate a manageable number of design combinations. Each designer used their own judgment to select several groups of compatible function alternatives and integrate them into design combinations. Drawings of the most promising design combinations are compared in the following sections. *Objective Selection* proved to be most beneficial in the decision process.

Table 3.1 shows the function alternatives picked through the objective selection process for all three functions: shade support, end shield shading, and arc length and width adjustment.

Table 3.1

Objective Selection Results

Shade Support	Shape Adjustment	End Shielding
Rectangular Frame	Trolley Cable	Rectangular Shield Plate
I-Frame	Rack and Pinion	
	Climbing Track	

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As the table shows, the most feasible designs for each function are as follows:

- Rectangular frame and I-frame for support
- Rectangular shield plate for end shielding
- Trolley cable, rack and pinion, and climbing track for shape adjustment

The rectangular frame is compatible with most of the alternatives for shape adjustment. However, the climbing track would require slight modifications in its frame design. The rectangular frame and the rectangular shield plate are compatible because the shield can be directly attached to the frame.

IV. EVALUATION OF DESIGN COMBINATIONS

After developing the function alternatives for the shade frame, end shields, and shape changing mechanisms, a set of criteria was established to evaluate and select the most feasible design combination. The previous section presented briefly, the criteria for each function alternative. The ability of the function alternative to satisfy the criteria determined the feasibility of the design.

The design team developed several design combinations from the list of most feasible designs for each function (given in section III.). Each design combination was evaluated separately and ranked according to its feasibility and compliance with the design criteria. The following section includes a brief description of each design combination and a listing of its advantages and disadvantages.

4.1 Design Combinations

This section discusses the combination of several functions into a design solution. Some of the criteria to be considered are simplicity of the design and number of moving parts. Limiting the number of moving parts should reduce the probability of positioning error and keep the design simple, safe, and easy to operate. Other criteria include stability of the device, availability of material such as belts that can withstand the high temperature vacuum, and ease of manufacturing.

4.1.1 Two Belt Rack and Pinion. This alternative utilizes two belts at each end of the radiator driven by a motor (see Figure 4.1). The belts move the rack and pinion

mechanism which adjust the shade width. The edges of the shade material are held stationary so the amount of material in the catenary shape (between the ends of the two rack members) is linearly related to the width. The motor runs a shaft that is the length of the shading device and drives the belts at both ends of the radiator. The shaft is placed beneath the radiator and is supported by a V-Frame structure. Since the racks either move toward or away from each other, one side uses a reverse gear to enable the racks to travel in opposite directions direction. An alternative to this reverse gear is the use of a twisted belt (see Figure 4.2). The advantages of the twisted belt over the reverse gear is that it reduces the number of moving parts.
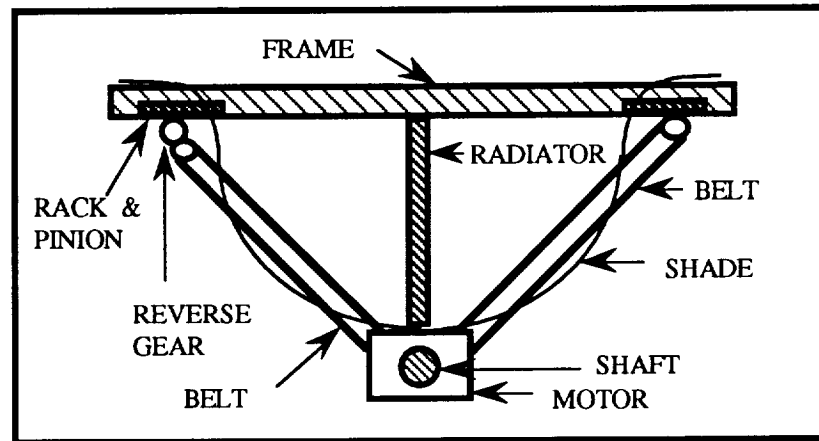

Figure 4.1: Two Belt Rack and Pinion with reverse gear.

Advantages of the Two Belt Rack and Pinion are as follows:

1. Only one motor is required

2. V- frame provides stable support

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Disadvantages of the Two Belt Rack and Pinion are as follows:

1. Too many moving parts.

2. Racks may protrude from the frame.

3. Too many belts used that may not withstand the heat and vacuum.

4. May not retain catenary shape after adjustment due to linear relation between arc length and width.
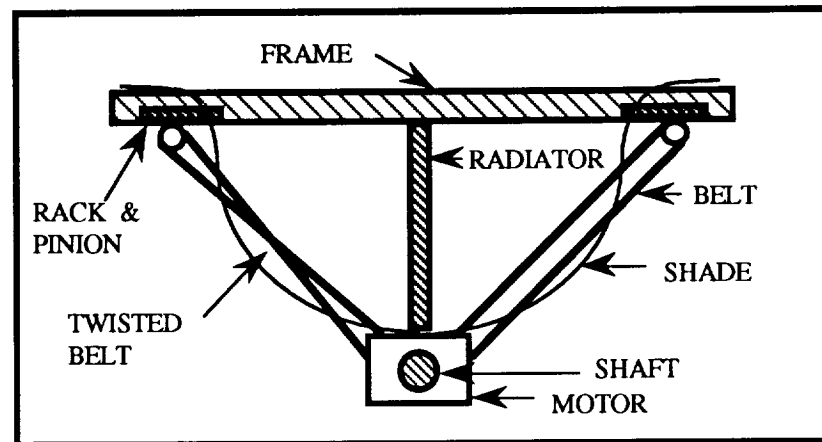
Figure 4.2: Two Belt Rack and Pinion with twisted belts.

4.1.2 I-Frame Rack and Pinion. This alternative combines an I-Frame structure and rack and pinion mechanism driven by a motor (see Figure 4.3). The belts connect the motor to the pinion which drives the racks in opposite directions. At each end of the radiator there is a belt that links the gear to a long motor shaft. The shaft, which has the same length as the radiator, is placed beneath the radiator.

Advantages of the I-Frame Rack and Pinion are as follows:

1. Fewer number of moving parts.

2. Shield shades drive mechanism from solar radiation.

Figure 4.3: I-Frame rack and pinion.

Disadvantages of the I-Frame rack and Pinion are as follows:

1. I-Frame structure is unstable

2. Belt may not withstand the heat and vacuum conditions.

3. May not retain catenary shape after adjustment due to linear adjustment coupling.

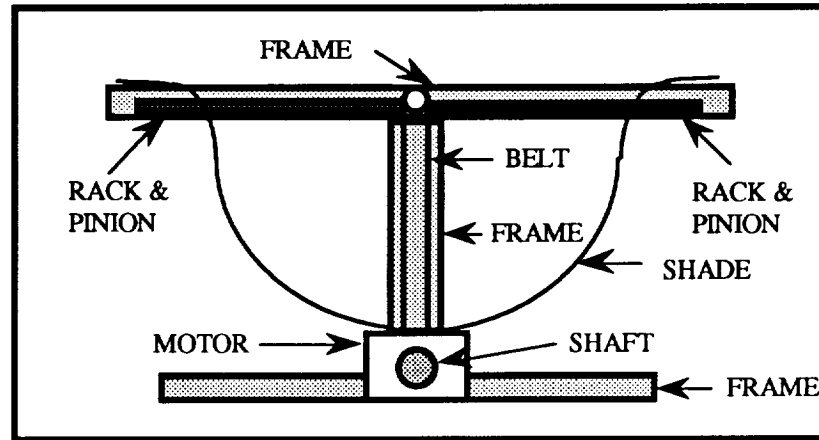**4.1.3 Rolling and Translating.** This alternative is operated by two motors. One motor is for rolling the extra shade length, and the other motor is for changing the width of the shade (see Figure 4.4). With this device, the catenary shape is retained by hanging one side from a non-rotating bar and rolling the other edge around a shaft. The rolling and translating motions are done separately to make shade adjustment easier. Shade

adjustment done by simultaneously rolling and translating is difficult because the rolling and translating relationship is not linear.
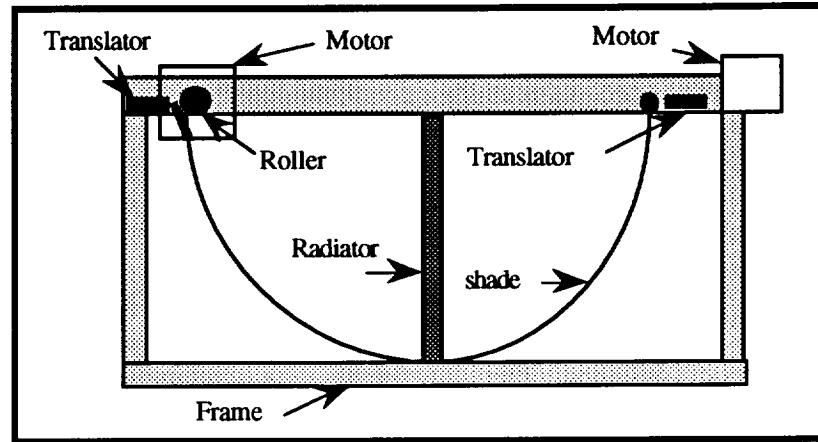
Figure 4.4: Rolling and Translating device.

Advantages of the Rolling and Translating alternative are as follows:

1. Able to retain catenary shape after shade adjustment.

Disadvantages of the Rolling and Translating alternative are as follows:

1. Hard to translate the rolling motor.

2. Two motors required.

3. Support for two motors needed.

4. Extra control needed.

4.1.4 Translation Mechanism. This alternative uses translation mechanisms to adjust the width and the arc length of the shading device (see Figure 4.5). The adjustments are done by having both sides move a certain distance with one side reducing

the arc length as it translate. The catenary shape is retained at the edge by bending the shade to the proper angle and keeping it bent with a support beam hanging across the translating edge. Two motors are required for operation, and a rack and pinion or a cable can be used to reduce the shade width.
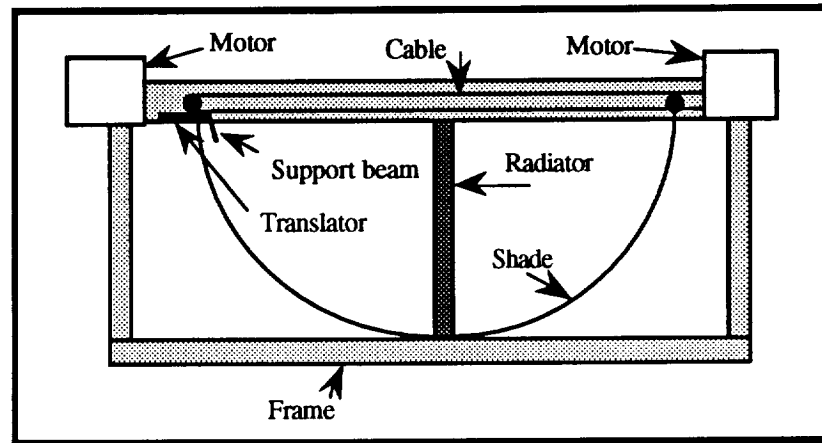

Figure 4.5: Translating Mechanism.

Advantages of the Translation Mechanism are as follows:

1. Able to retain catenary shape.

2. Easy to adjust with each function done separately.

Disadvantages of the Translation Mechanism are as follows:

1. Support beam may provide shading instead of the shade.

2. Extra support for the two motors required.

3. Extra control required.

4.1.5 Rack and Pinion. For this device, one motor widens the shade and another increases the arc length (see Figure 4.6). A tubular frame supports each rack member at three roller bearing points. The frame also supports the widening motor, the pinion and the radiator. Care must be taken so that the supports do not interfere with the necessary range of rack motion. The arc length motor is supported by one of the rack members.
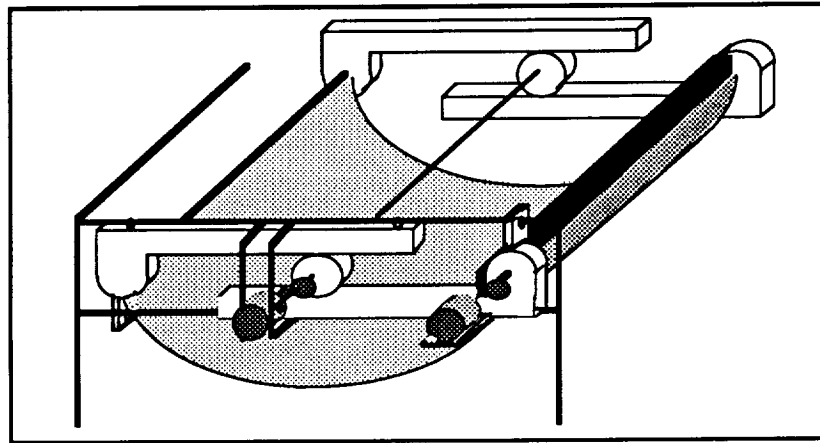

Figure 4.6 Rack and Pinion

Advantages of the Rack and Pinion alternative are as follows:

1. Correct arc length to width ratio may be attained through separate adjustments.

Disadvantages of the Rack and Pinion alternative are as follows:

1. Difficulty in machining racks.

2. At least 14 bearings required.

3. Two motors required.

4. If motors are massive, heavy supports required.

5. Two controls for adjustment.

6. Radiator placement is difficult.

4.1.6 Climbing Track. The climbing track alternatives allows each end of the shade to roll up around a shaft that has pinions at its ends. The pinions are powered and as they turn, they climb a curved rack (labeled Toothed track in Figure 4.7). The shape of the rack is such that the correct amount of shade material is unrolled for each increment in shade width.

The pinions are powered by a central motor using pulleys and cables. One cable is twisted so that the pinions rotate in opposite directions. The motor hangs from two bars which are connected to the roller shaft by a bearing. These bars maintain a constant distance for the cable "belts" to act through.

The pinions are held in contact with the curved rack using the apparatus shown in Figure 4.8. The bearings are necessary to allow the shaft to rotate and translate with minimal resistance.

The hanging bars for the motor are connected to the radiator hanging bar by sliding joints that also allow rotation. As the shade raises and widens the motor hanging bars slide farther out on the radiator hanging bar and the angle at which they intersect becomes less. A means must be found to insure that the radiator remains centered. Perhaps the radiator's travel can be guided by the frame.

Advantages of the Climbing Track are as follows:

1. Only requires one motor.

2. Provides desired nonlinear linkage between the width and the arc length.

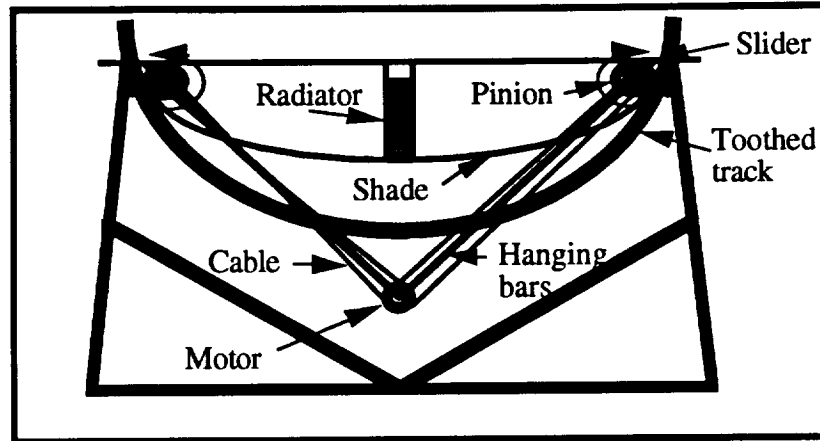3. Only one input to control for adjustment.

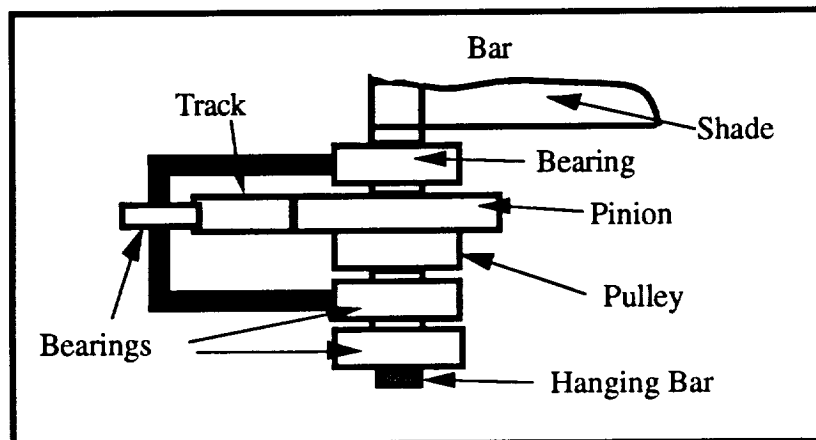Figure 4.7: Climbing Track

Figure 4.8: Top view of end of Roller Shaft

Disadvantages of the climbing track are as follows:

1. The motor, radiator, and shade all translate vertically. This requires additional power and may adversely affect the quality of the thermal model.

2. Difficulty in manufacturing the curved rack.

3. Large number of bearings.

4. The cables may slack during thermal cycling and slip. Perhaps the motor hanging bars could be spring loaded to extend.

4.1.7 Hanging Shade. The hanging shade alternative consists of a rectangular frame, two horizontal bars or shafts to support the shade, and a roller at each end of each of the shafts to permit horizontal motion of the bars. The shafts, driven by motors, increase or decrease the shade width and two tracks located at the ends of the frame allow motion of the rollers. See Figure 4.9 for a schematic of the design.
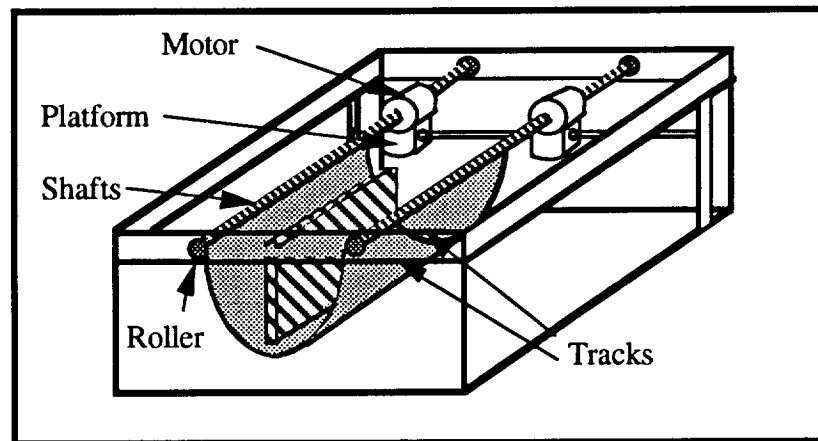

Figure 4.9: Hanging shade

The motion of the motors cause the shafts to roll apart or together, which increases or decreases the shade width. A reversible motor is desired for two way adjustment. As the shafts rotate, the rollers at each end roll on the track within the frame structure. The motors are located at one end of the frame with rollers at each end, to ensure equal motion

on both ends of the shade and frame. The roller and track mechanism may be toothed to prevent wheel slippage.

The shade itself is attached to the shafts so that the shade rolls up when the shafts are in motion. This reduces the extra shade material at the bottom of the radiator. With no vertical motion of the shafts or shade, the radiator and the top of the shade maintain the same height.

The motors are mounted on a platform so that they may move horizontally along their support shaft. The platform is a hollow cylindrical section, that is perpendicular to the rotating shaft, with the horizontal support shaft running through it. This allows the motors to slide as needed, and prevents them from rotating about the drive shafts. The support shaft mounts directly on the frame as needed.

The advantages of the Hanging Shade concept are as follows:

1. Simplicity.

2. Ease of manufacturing.

3. Limited number of moving parts.

4. Allows elimination of extra material at the bottom.

The disadvantages of the Hanging Shade concept are as follows:

1. Linear relationship between shade length and width.

2. Exact distances are difficult to gage.

3. Friction may present a problem with the platform sliding on the shaft.

V. DESIGN SELECTION

The final design combination was selected by employing weighting factors and decision matrices, all shown in Appendix F. First, weighting factors were determined to rate the relative importance of each design criteria. This was done by taking the average of each team member's desired weighting factor for each design criteria. The team then assigned a rating, a number between 0 (unacceptable) and 10 (ideal), for each design combination with respect to each design criteria. The ratings were based primarily on qualitative judgement. To complete the decision matrix, the sum of the products of the weighting factors and the ratings resulted in a single value for each alternative (see Table 5.1 for the decision matrix results). Ranking these values provided an organized and logical method to select the final design.

Table 5.1

Decision Matrix Results

Design Combination	Score
1. Translating Mechanism	6.57
2. HangingShade and Frame	6.53
3. Rolling and Translating	6.41
4. Rack and Pinion	5.27
5. I-Frame Rack and Pinion	4.97
6. Two Belt Rack and Pinion	4.70
7. Climbing Track	4.27

According to the decision matrix, the most feasible design combination is the Translating Mechanism. This device requires that one side of the shade be translated while the other side is lifted by a rack driven bar. Translation may be accomplished by several means, however, the design team has chosen to translate using a trolley mechanism. The trolley is compatible with the rectangular frame with minor modifications. However, the translator design is flawed in that the arc length is linear with the width so a cushion of extra material must hang below the shade in some focal settings to insure that enough material is available throughout the test range.

After further consideration, the design team chose to use the Rolling and Translating mechanism. Rolling and translating allows the extra material to be eliminated after the shade ends are translated the desired distance. In any case, the end shielding is compatible with the entire design as long as it can be modified to avoid interference with the pulley or trolley cable mechanism. Each component refinement and design consideration is considered in detail in the prototype embodiment, Section 6.1.2.

VI. DESIGN SOLUTION

The following sections present the embodiment design of the prototype and the design of an experimental test procedure. Each section will discuss an individual component of the design. The components of the design are as follows: shade frame, shape adjustment mechanism, and the end shield. The frame section will discuss materials, dimensions, methods of connection for frame components and structural calculations. The shape adjustment section is divided into two sub-sections. The first section describes the pinch and roller assembly used for arc length adjustment. The second section describes the trolley powered track and guide wheel arrangement used for width adjustment. Lastly, the end shield section will include mounting information, dimensions, and material information.

6.1 Design of the Prototype

6.1.1 Introduction

The prototype design solution is the combination of the most feasible design functions which were selected on the evaluation criteria presented in Sections IV and V. The embodiment design of the test shade is shown in Figure 6.1 The device consists of a trolley chain empowering translators which support the shade ends, two motors, and a pinch roller. The device uses translation to increase or decrease shade width symmetrically on both sides. The left side of the shade is rolled up or unrolled to eliminate space between the shade and the bottom of the radiator or to provide enough material "slack" to accommodate shade widening. The trolley chain pulls the translator bars, which are

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connected to the chain. The translator bars move horizontally as the translator motor rotates the shaft on the right hand side of the figure. A second motor rotates a shaft, on the left side of the shade, rolling the shade material around the shaft and under a pinching roller. The pinch roller is held tightly against the main roller shaft by a spring. Pinching the material between these two rollers keeps the material tightly rolled around the main roller. The pinch roller idles in a directions that is counter to the the motor driven shaft.

The sequence of operations for the device varies depending on whether the shade is being widened or narrowed. Widening of the shade requires that sufficient material first be rolled out from the left side of the device. The right and left sides are then translated to obtain the shade width corresponding to the desired focal length. Then any additional arc length adjustments are made. The motor on the left side of the shade must translate with the left edge of the shade to keep the shade symmetrical about the radiator. If narrowing the shade, the ends must first be translated and then the extra material must be rolled around the roller.

The frame of the device includes horizontal upper and lower tracks acting in the x-z plane (see Figure 6.1 for directional frame of reference). These tracks, which are on both ends of the frame, allow the translators to roll freely across them. Four vertical angle aluminum bars keep the structure upright, while two horizontal bars acting in the x-y plane, serve as a base for the structure. Two legs, one centered on each end of the frame act as supports for the radiator and decrease the possibility of deflection in the top roller track.

6.1.2 Embodiment Design

The following section contains the embodiment design of the prototype, consisting of the following components, and sub-components, listed in an order to best reflect the embodiment sequence:

1.   Rectangular frame for shade support

2.   Rolling and Translation for shape adjustment

        A.   Translators

        B.   Pinch roller

        C.   Roller and track assembly

3.   Rectangular end shielding

6.1.2.1 Shade Support: Rectangular Frame

The rectangular frame provides a basis for support of the shade, radiator, shape adjustment mechanisms, and end shields. The frame must support the components of the shade configuration with minimal deflection of its members. As previously stated, the frame maintains at least a 1 inch clearance from the ground level and its members are thin enough so that it will not shade the radiator significantly. Figure 6.1 presents a schematic of the frame.
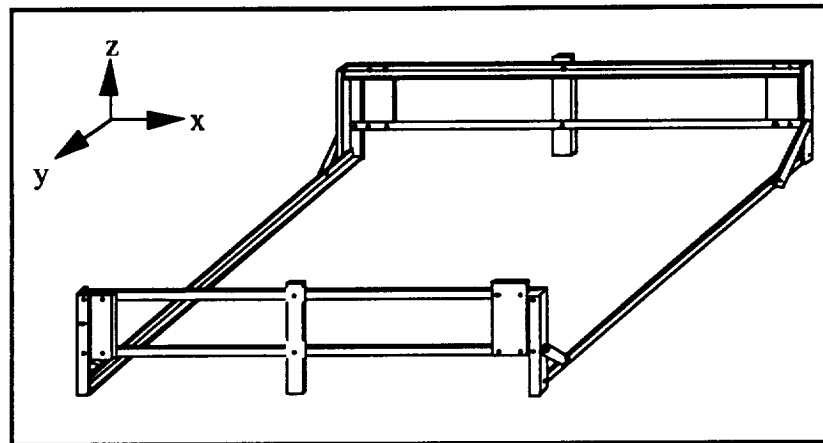

Figure 6.1: Shade Frame Design

The frame is rectangular in its construction. As the schematic points out, it consists of four vertical bars, one horizontal bar on each side, and two (upper and lower) tracks on each end. In the absence of a second bar on each side, diagonal struts in each corner, serve as added support for the structure. The design team considered different assemblies for the frame members with either one, two, or three side members. In any case, the design team found that the small load acting on the members would not require more than one side member (see Appendix D: Structural Analysis). Using more than one side member may cause extra shading of the radiator and an "over-design" of the structure.

The pre-approved material used for all frame members is Aluminum. Aluminum was chosen because of its strength, cost, and machinability. Stainless steel was also considered as a possible pre-approved material, however, it is harder to machine and more expensive than aluminum.

The design team considered several methods of connecting the members of the frame. Pin connections were considered, however, if pin connections are used at the ends of each bar, diagonal corner struts are necessary to keep the frame upright and stable (see Figure 6.2). Corner brackets were also considered because of their capability to add stability to the structure. The brackets are connected to the angle-aluminum by two stainless steel bolts on each side.(see Figure 6.3). The design team decided to use outer struts instead of corner brackets. The corner brackets are more difficult to machine than the side struts, and require horizontal members, at the same height, on adjacent sides which cause difficulty with bolt placement .

The member cross-section dimensions for the frame were chosen with the aid of a *Mathematica* computer program. Graphs of deflection versus cross-section dimension were computer generated for several cross-section thicknesses and both rectangular and right angle cross-sections using an estimated maximum mid-span load of 10 pounds for the long side and 15 pounds for each upper track roller. The design team then agreed on

acceptable deflections and used the graphs to identify the necessary member size and thickness. See Appendix D for further information concerning the deflection and dimensions of individual members. The final dimensions of the vertical angle-aluminum members are 1/8" x 1/2" x 2 7/8". The side bars, also in angle-aluminum, have dimensions of 1/8" x 1/2" x 26 1/2". The struts have dimensions of 1/8" x 1/2" x 2.0".
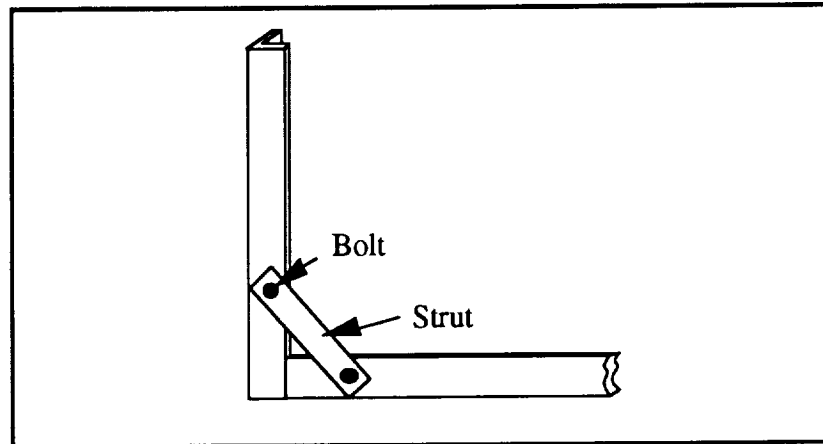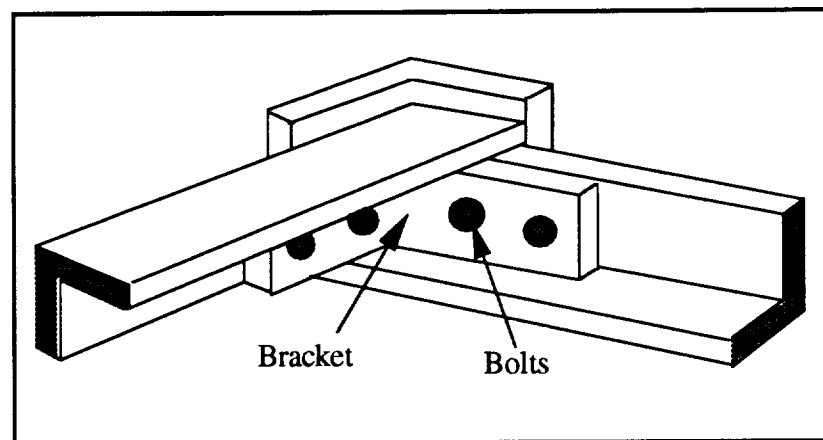

Figure 6.2: Corner Strut

Figure 6.3: Corner Brackets

6.1.2.2 Shape Adjustment: Trolley Cable Mechanism

Because of feasibility problems with the solution concepts that combined the arc length and width components of shade adjustment, the design team chose to perform the two adjustments separately with two different motors. This section begins by discussing embodiment of the chosen method of arc length adjustment and the main components used. The second subsection presents the embodiment and main components chosen for the width adjustment. Figure 6.4 shows the layout of the chosen solution concept.
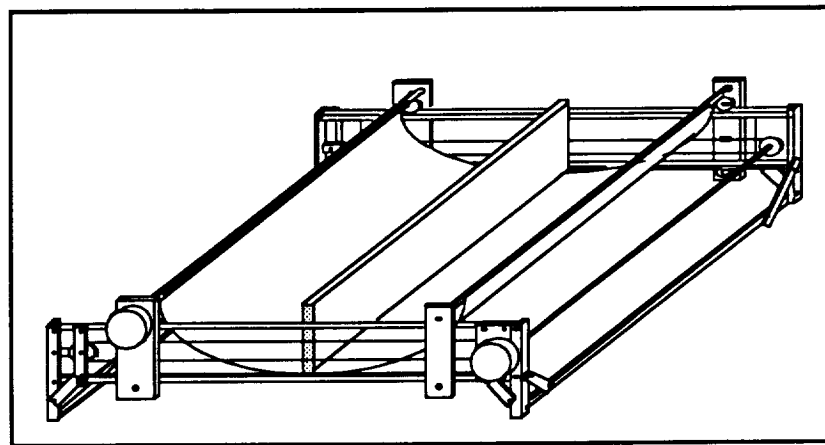

Figure 6.4: Isometric of combined solution concept.

Arc length adjustment The length of material used in the shade is adjusted by rolling or unrolling material at one end. The two main design challenges for embodiment of the shade material roller are keeping the material rolled tightly around the roller shaft and providing the proper end angle for the catenary shape.

In order to conserve space and reduce roller shading, the material is rolled around a relatively small shaft (3/4" diameter). Unlike the "ideal" thread used to develop the catenary equation, the shade material has some stiffness and must be forced to roll tightly

and held in place or it will spiral (see Figure 6.5). If the shade material is allowed to spiral the position of the shade end and the amount of material in the roll will vary with the temperature dependent stiffness of the material, the degree of set the material has attained from being rolled, and weather the material is being rolled or unrolled. These variables are minimized by using a pinch roller to press the material being rolled against the main roller at the point where the material is taken up (see Figure 6.6).
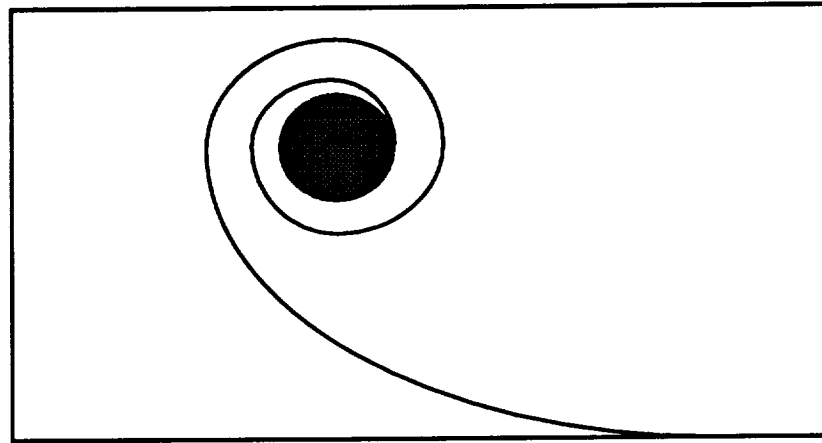

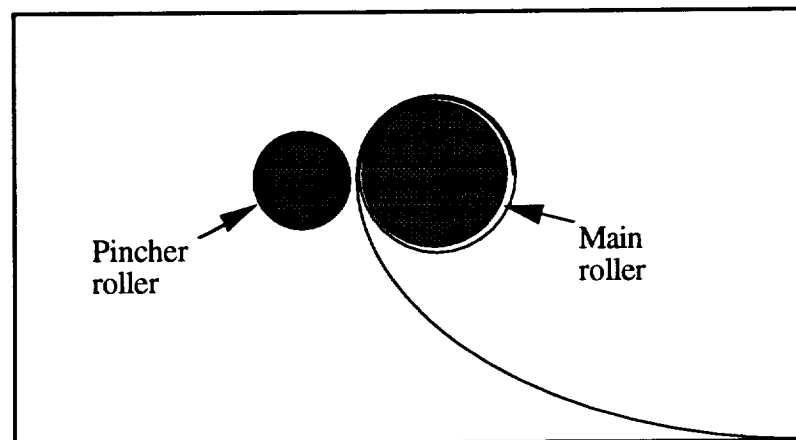Figure 6.5: Spiraling of material off roller shaft.

Figure 6.6: Pincher to press material against main roller.

In order to spiral, the length of material on the roll must increase without the roller turning. This requires that a layer of material between the pincher and the main roller slip relative to the other layers and/or the main roller. The pincher applies a normal force which allows friction to hold the material from slipping. The pincher is pulled against the main roller using two stainless steel springs at each end (see Figure 6.7). The springs allow the distance between the two centers to increase as extra layers of material are rolled around the main roller.
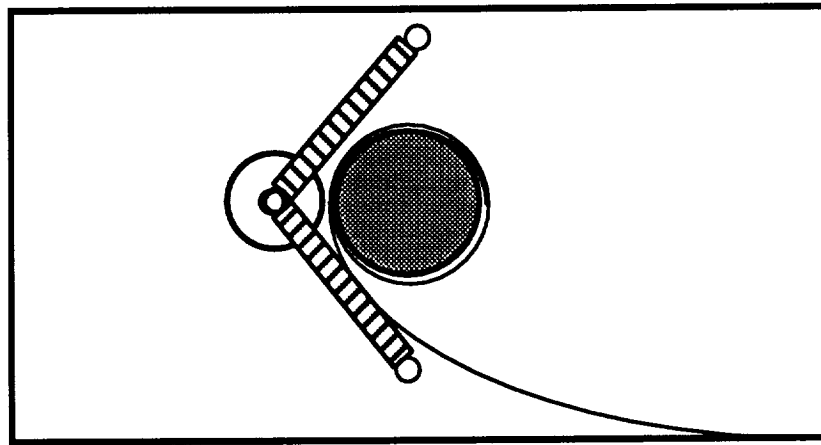

Figure 6.7: Springs to hold pincher against main roller.

Because of the real stiffness of the shade material, it is important that the material at the ends of the catenary shape not be held at an angle far from the natural slope of the catenary at that point. An incorrect angle would cause a torque in the material and deform the catenary shape. The angle with the horizontal formed by the edges of a catenary one unit high with a one unit focus is 45° (see Appendix C: Catenary/Parabolic Analysis, for calculations). For a one and a half unit focus, the angle is 39.2° and for the two unit focus it is 35.3°.

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The material is held tangent to the roller at the point where the pincher acts. The angle of this tangent line (the forced end angle of the catenary shape) can be varied by rotating the axis connecting the centers of the main roller and the pincher roller about the contact point (see Figure 6.8). Ideally, the precise end angle adjustment could be automatic if the roller/pincher arrangement were balanced and rotated freely about the contact point, and the material was stiff enough that its natural tendency to assume a parabolic shape could provide sufficient moment to power the rotation. However, because of the modest moment that the actual shade material can provide, and the difficulties in precisely balancing a roller as the amount of material rolled changes, the design team decided not to use a material powered adjustable end angle. Furthermore, the team decided that, considering the small range of end angles involved (+/- 5° about the median) and the flexibility of the material, the shape errors introduced by fixing the forced end angle at 40° are negligible and will not add significantly to existing inaccuracies in the adjustable shade's modeling of an actual lunar shade.
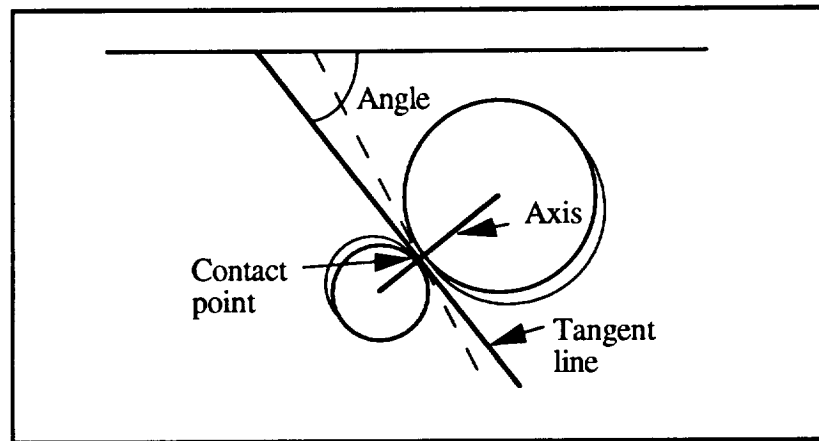

Figure 6.8: End angle change by rotating pincher/roller assembly.

Width adjustment The second adjustment necessary to change the shade focus is width adjustment. The width is adjusted by moving the two edges of the catenary shade closer together or farther apart. The motion is linear horizontal and symmetric about the radiator with the edges supported at a constant height (equal to the top of the radiator). See Figure 6.9 for the direction of motion. The edges of the shade material are glued to a roller shaft on one side and to a bar on the other. Each end of the bar or roller passes through a hole in a translator plate which simply supports it. The translator plates are confined to move linearly back and forth on the horizontal frame members at the ends of the shade. The design team considered an "H" shaped plate that slides on the frame members but rejected the ideal because of concerns about friction and binding in the vacuum environment where there is no water film on surfaces to reduce sliding friction like there is in a standard earth atmosphere. Instead, each translator plate is equipped with a pair of guide wheels which roll on the frame members (see Figure 6.10).
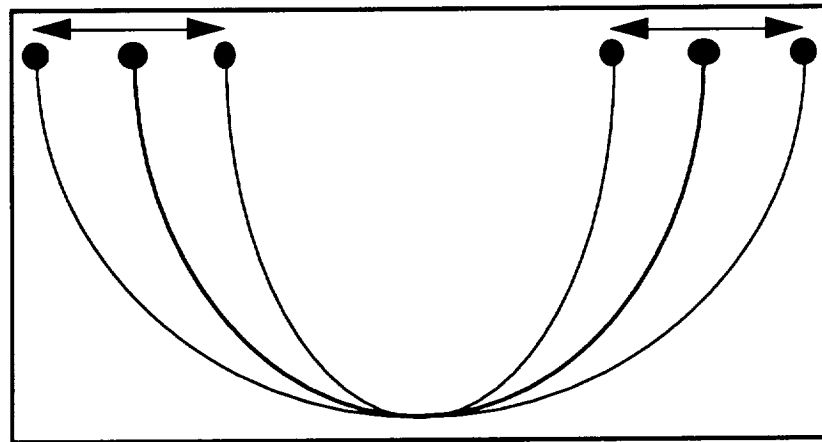
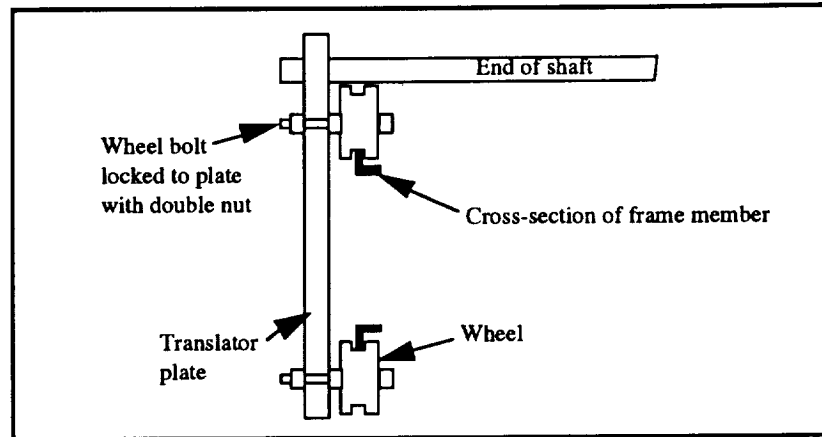Figure 6.9: Width Adjustment Direction of Motion

Figure 6.10: Translator Plate Guide Wheels

Although linear guide wheel systems are commercially available, the design team chose to manufacture wheels because none where located which met the material requirements for the vacuum chamber. Light weight wheels are generally made of plastics and the bearings in wheels rated for heavy loads are held in a nylon basket. The guide wheels manufactured by the team are one piece aluminum and have a 1/8" deep by 5/32" wide groove into which the edge of the 1/8" thick angle aluminum frame fits (see Figure 6.11). Once the frame is bolted together with the translator plates in place, the wheels can not jump off the frame "track" because one wheel is above the top track and the other below the bottom track. Two track members where chosen rather than one because the farther the top wheel is from the bottom wheel the more moment the translator bar can support around an axis parallel to the track (the "X" axis back in Figure 6.10). Close tolerances between the groove width and the width of the frame member will allow the translator plate to support a moment about a vertical axis (the "Y" axis). Finally, small tolerances between the groove bottom to groove bottom distance and the track to track distance enable the

translator plate to support a moment about an axis parallel to the radiator length ("Z" axis) with a minimal of rotational play about this axis.
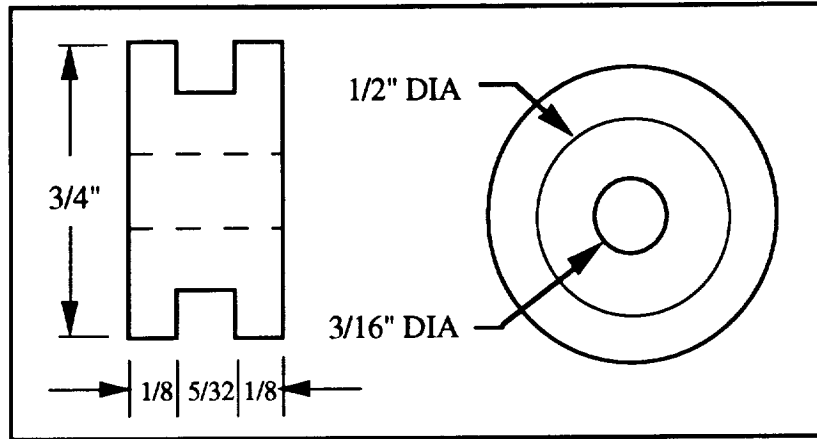

Figure 6.11: Guide Wheels

The wheel size of 3/4" outside diameter was chosen to keep the vertical height of the translator bar small. The wheel groove can not be cut deeper than 1/8" and still leave enough material between the bottom of the groove and the 3/16" diameter center hole for strength (accounting for wear and possible miscentering of the groove with respect to the center hole). With such a shallow groove, it is important that the wheels are rigidly and accurately mounted and that the distance between the two tracks remain constant. Careful mounting of the frame members to insure that they are parallel and the use of corner struts (described in the frame embodiment section) to prevent leaning of the frame (see Figure 6.12), are necessary to insure that at no point will the translator wheels be able to come off the track. Deflection of the top track under loading by the upper translator wheel is another scenario in which the tracks might move close enough together for derailment (see Figure 6.13). Deflection is kept under control by sufficient sizing of the frame member and use of

an additional leg supporting the members at their center (parallel to the end of the radiator). For 1/2" by 1/8" angle aluminum with the loading configuration shown, the maximum deflection is 0.006", far less than the 0.125" allowed by the wheel groove depth (see Appendix D for deflection calculations).
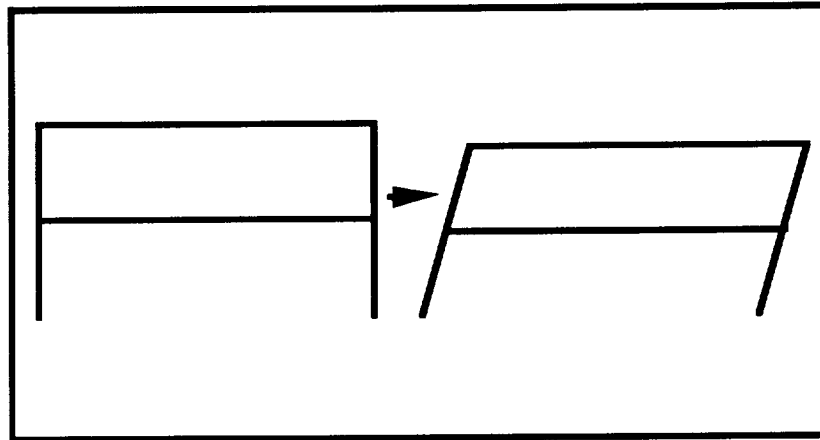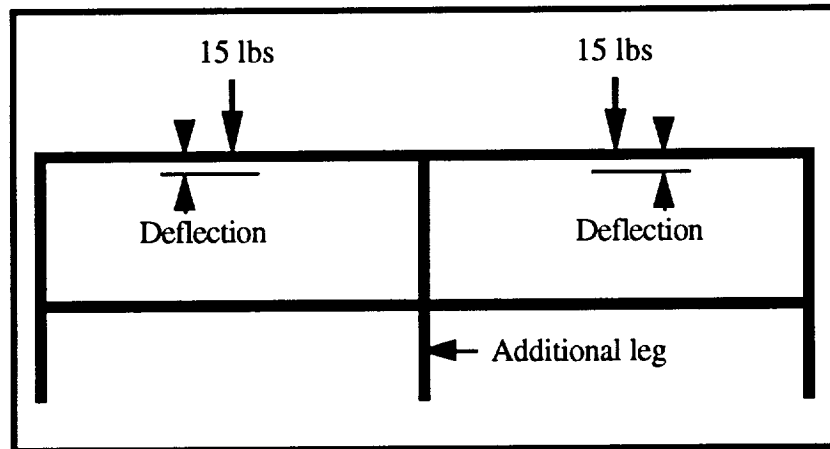

Figure 6.12: Frame Leaning

Figure 6.13: Track Deflection

The ends of the aluminum shafts rotate in holes drilled in the translator plates. The ends of the shafts are lathed to a smaller diameter (3/16") to reduce the moment arm with which the sliding friction can oppose rotation. Bearings or bushings are unnecessary because of the light loads and limited usage life of the test shade. Thrust is supported in the roller shaft by a pair of washers, one glued to the shaft on each side of a translator plate (see Figure 6.14). The motor supports thrust in the roller shaft and the bar at the non rolling shade edge is held in place by its size reduction at the point where it passes through the plate (see Figure 6.15).
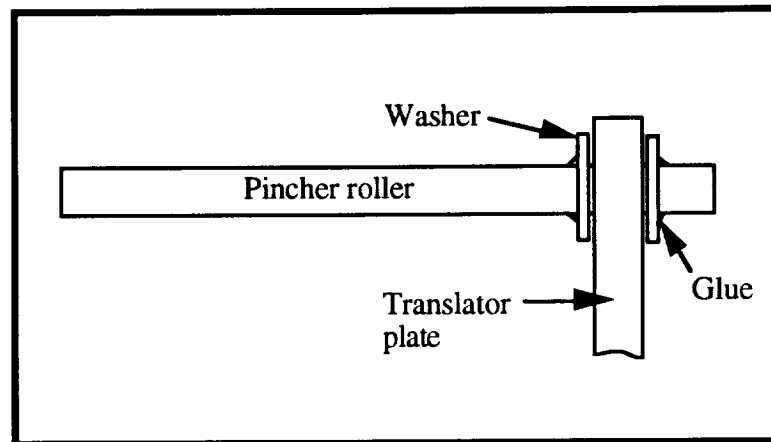

Figure 6.14: Thrust Washer

At one end of the roller an oversized translator plate supports the motor. The motor is face mounted to the plate and the shaft passes through an oversized hole in the plate (see Figure 6.16. The motor translator plate is 1/2" thick to allow for counter sinking of the wheel mounting bolt (so the bolt head doesn't interfere with the motor mounting). A 1/2" thick spacer plate fits between the motor and the translator plate. The spacer simulates a pressurized (and cooled) can which will be installed later to protect the motor from the

vacuum environment. The spacer allows sufficient shaft length and motor mounting bolt length so that extensive modifications are not required when the spacer is replaced by the can. If possible, the can should be designed with a 1/2" thick face.
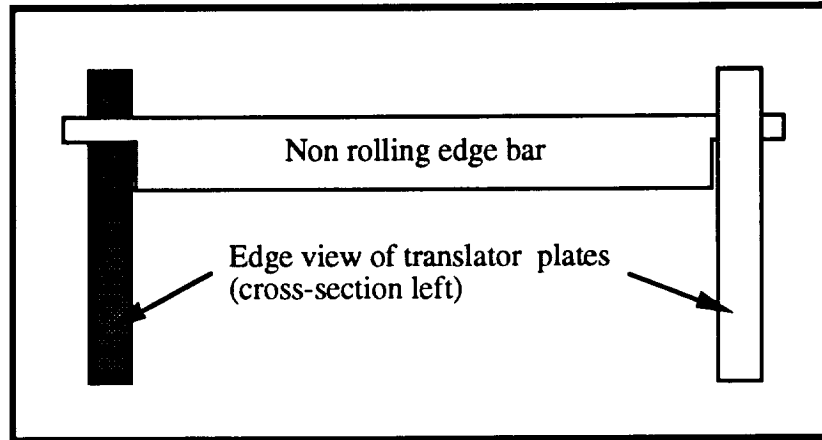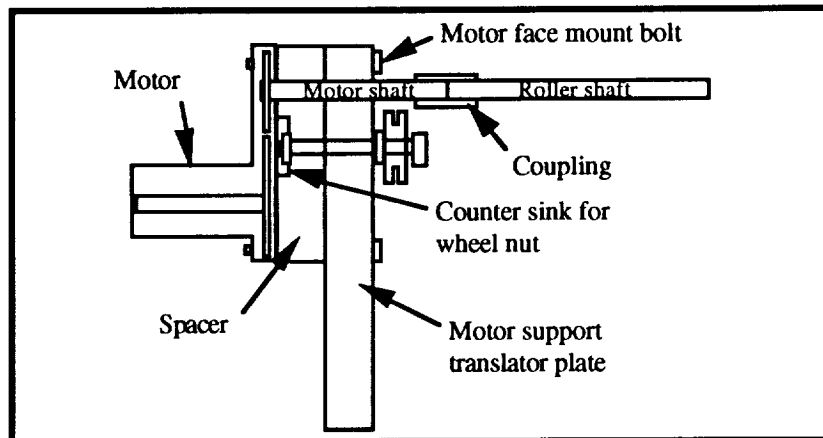

Figure 6.15: Edge Bar

Figure 6.16: Motor Mount

The translator plates allow the shade edges, pincher/roller assembly, and roller motor to move but a separate system is necessary to power and control the motion. This is accomplished using the trolley cable concept (see Figure 6.17). The cable is a small stainless steel ladder chain driven by a motor mounted to a stationary plate (also using a spacer plate). One translator is bolted to a point on the top pass of the chain and the other to the bottom pass. As the chain rotates the translators move equal distances in opposite direction. See Appendix I: Motor Analysis, for motor sizing and specifications.
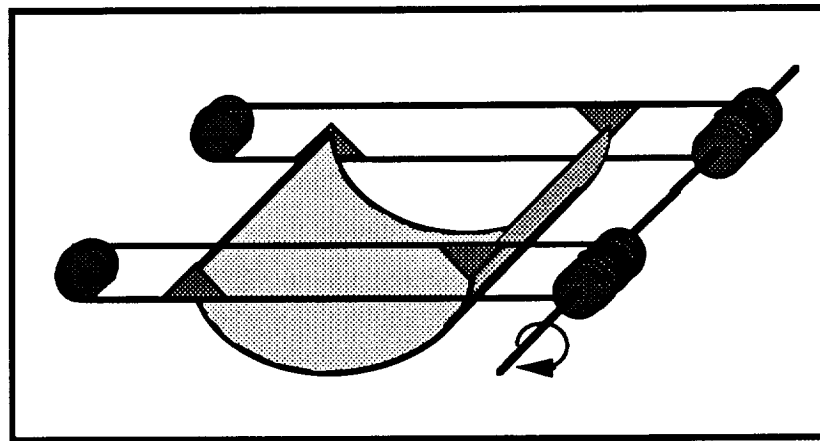

Figure 6.17: Trolley Cable Mechanism

6.1.2.3 End Shielding: Rectangular Shield Plate

The rectangular shield plate is designed to just cover the ends of the shade at its widest setting. Its top and bottom are aligned with the radiator to shield all solar radiation incident on the ends of the shade.

The shield plate is of the same material as the shade, aluminized polyimide. The minimum dimensions of the shield plate are approximately, 2.4" x 13.6". Where the 2.4 inches is the height of the radiator and the 13.6 inches is the width of the shade at its 2

radiator unit focus. The shield plate is connected to the ends of the frame, covering most of the chain and sprocket mechanism...(See figure 6.18 for a more detailed picture of the end shield attachment).
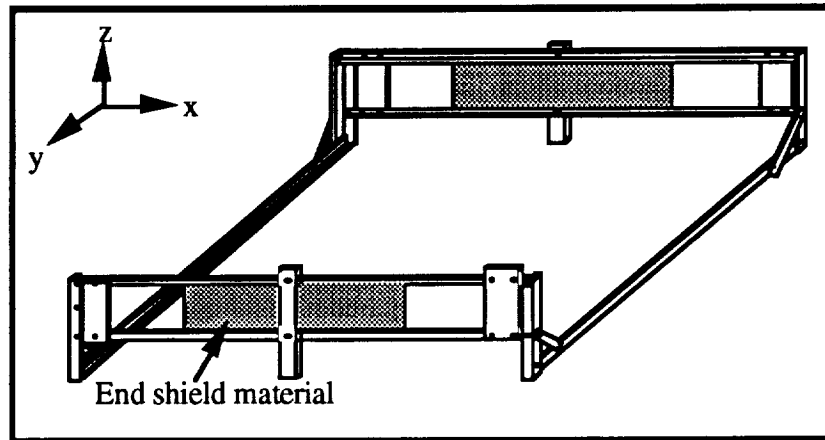

Figure 6.18: End Shield Attachment

6.1.3 Cost Analysis

The cost of building the test shade is projected to be approximately $400. As of publication time $320.11 worth of material has been purchased but the need for several small additional items has been foreseen. Cost of the test shade includes material and parts costs only. The prototype is to be machined at the University of Texas at Austin machine shop, by the design team. Therefore there will be no extra cost for the machining of parts. The bulk of the cost of the prototype extends from ordered parts such as motors, springs, sprockets, chains, screws and bolts, etc. The cost breakdown for the ordered parts is presented in Table 6.1. Materials, such as angle aluminum, flat bars, and round bars were also ordered for the building of the shade frame. These added materials are listed separately in Table 6.2.

Table 6.1

Cost Breakdown for Ordered Parts

Part	Part No.	Size/Qty	Cost/Pkg	Total Cost
Ladder Chain	6YB-19	8 ft.	$ 26.88	$ 26.88
Brass Sprocket	6B8-1912	5 ea	$ 33.10	$ 33.10
Motor	4Z453	2 ea	$ 48.85	$ 97.70
Capacitor	3738	2 ea	$ 3.58	$ 7.16
Speed Control	78301	2 ea	$ 15.00	$ 30.00
Hex Head Bolt	10-32 x 3/4	80 ea	$ 358.95/1000	$ 28.72
Socket Head Bolt	10-32 x 1	10 ea	$ 37.18/1000	$ 3.72
Hex Nut	10-32	100 ea	$ 42.96/1000	$ 0.90
Split Lock Washer	#.10	100 ea	$ 8.99/1000	$ 4.30

Table 6.2

Cost Breakdown for Frame Material

Material	Size	Qty	Total Cost
Angle - Aluminum	1/2" x 1/2 "x 1/8"	(2) @ 16 ft	$ 13.86
Flat Bars (Al)	1/2" x 2" x 1'	4	$ 20.70
Flat Bars (Al)	3/4" x 3/16" x 2'	1	$ 6.11
Flat Bars (Al)	1/8" x 1/2" x 1'	(2) @ 16 ft	$ 7.18
Round Bars/Shafts	1/4" dia	(1) @ 3 ft	$ 10.26
Round Bars/Shafts	1/2" dia	(1) @ 3 ft	$ 7.33
Round Bars/Shafts	3/4" dia	(1) @ 3 ft	$ 5.57
Round Bars/Shafts	1" dia	(1) @ 2 ft	$ 16.80

The shade material, aluminized polyimide, is not included in the cost breakdown. This material was made available to the design team by NASA, and will be available for any further testing if it should have to be replaced. See Appendix G: Vendor Information, for additional information concerning the ordering of parts.

VII. CONCLUSIONS AND RECOMMENDATIONS

The National Aeronautics and Space Administration has identified heat rejection using external radiators as a key concern when planning manned space missions. To conserve energy, NASA wishes to avoid using a heat pump to raise the radiator temperature. This results in the radiator being cooler than the surrounding lunar surface during the lunar midday. Shading the radiator from planetary infrared and albedo is therefore deemed necessary to prevent a net heat transfer into the radiator. The design team has developed an adjustable shade for testing inside a solar lamp equipped vacuum chamber. The vacuum chamber simulates lunar midday conditions. The test shade will be used with the solar simulator to determine the optimal focal length setting of the radiator shade. With lower focal lengths the radiator will be struck by a greater proportion of the radiation that leaves the radiator diffusely and is then reflected off the shade in an unfocused but generally upward direction. The higher the focus of the parallel solar rays the greater the proportion of the unfocused radiation that will miss the radiator. The radiator will also be struck by some solar radiation that is scattered off imperfections in the reflective material. Again, the higher the focus, the less radiation striking the radiator. However, higher focuses are attained with wider shades which require more volume and mass to be transported to the moon.

The following subsections discuss the conclusions and recommendations for the test shade and some experimental procedures for ambient testing of its mechanical operation.

7.1   Test Shade

7.1.1 Conclusion for the Test Shade

As of the printing deadline for this report, construction of the test shade had not yet been completed. The test shade will be complete in time for the design project presentation. At that time a supplementary report detailing the results of ambient functional testing of the shade and any necessary design modifications will be provided.

The test device consists of.an aluminized polyimide film.shade, a roller mechanism to adjust the amount of material in the shade, a trolley translator mechanism to adjust the width of the shade, a pair of motors (to power the two adjustments), and a frame to support the entire apparatus. With completion of the test shade, the design team will have performed the required tasks.

The optional tasks of making the focal length remotely adjustable and making the shade focal length continuously adjustable within the specified focal range were integrated into the design. However, due to the large proportion of the allotted design time consumed investigation conceptual alternatives, the other optional tasks were not performed. The optional task to design and construct a simulated lunar surface doesn't appear to be closely intertwined with the design of the shade itself and hence can be completed separately without loss of overall system design efficiency. Likewise, the thermocouples may be attached later. To accommodate the future addition of motor isolator cans without changing the shaft lengths or motor mounting bolt lengths, a 1/2" spacer has been placed between each motor face and the bar it bolts to. An isolator can with a 1/2" thick or less face may then be used (after the spacer is removed) without changing the shaft or mounting bolt lengths (use spacer washers with thinner cans). The incomplete optional task that will be most constrained by the preexisting shade design is the test radiator design. Now that the test shade has been sized and constructed the radiator size is set (2.4" high by 24" long). Perhaps an off the shelf radiator could have been found that was near this size and the shade could have been scaled to fit it. Now, a radiator will almost certainly have to be specially designed and constructed to fit the required radiator size.

The two most important features incorporated in the design of the test shade are the roller and trolly mechanisms. The primary goal of the design project was to design an adjustable focal length shade. The roller and trolley mechanisms enable the two shade adjustments necessary for focal length adjustment in a shade with constant profile height . These two adjustments are arc length and width. With these adjustment capabilities, the shade can be tested in a simulated lunar environment to determine the optimal focal length setting balancing the trade offs between a small easily transported shade and a large efficient one.

7.1.2 Recommendations for the Prototype

The design team recommends that NASA complete the following tasks necessary for thermal vacuum chamber testing of the shade.

1. Design and construction of a test radiator.

2. Design and construction of a lunar surface simulator.

3. Attachment of thermocouples to the test shade, radiator, and simulated lunar surface.

4. Design and construction of cans to isolate the motors from the vacuum environment.

After completion of the aforementioned tasks the shade will be ready for use in a vacuum chamber to test the effects of shade width and focal length on radiator efficiency.

The design team also recommends that NASA consider adding redundant motors to the currently unpowered ends of the drive shafts. These motors would act as backups and allow testing to continue in the event of a motor failure.

7.2   Ambient Testing Procedures

Upon completion of the test shade, the design team will perform ambient environment tests to assure that the design is mechanically functional. The frame will be overloaded from various directions to test that it provides sufficient stability. The team will also torque the translator bars around all three axis to confirm that the wheel/track tolerances are sufficiently small to support all three moments as intended without excessive movement.

Finally, the shade device will be run through a series of tests in which the shade will be adjusted to approximately ten equally spaced focal settings. This will test the ability of the motors to be accurately controlled. At each setting, a low power laser will be used to test the actual focus of vertical rays striking the shade. Then the width position of the shade edge will be marked, perhaps on the top track where the various marks will create a visible rule for focal setting. Likewise, any modifications necessary to aid visible measurement of the arc length setting (i.e.unobstructed view of the gap between the bottom of the radiator and the shade) will be added and evaluated at this time.

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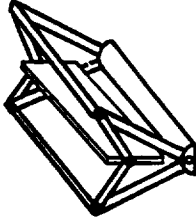
APPENDIX A
SPECIFICATION LIST

Appendix A
Specification List
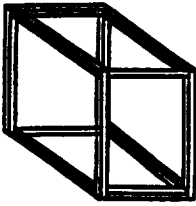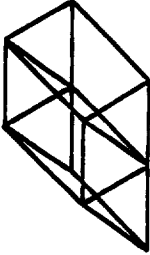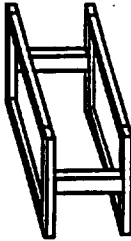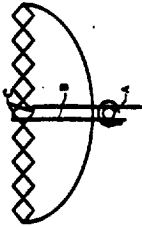
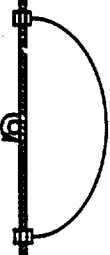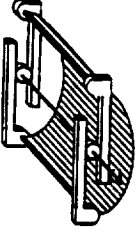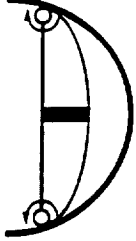| ME 466K DESIGN PROJECT		Specification for Lunar Radiator Test Article		Page: 1
Changes	D/W	Requirements		Resp.
		<u>Functional Requirements:</u>		
	D	-Provide support for shading device (test article)		
	D	-Provide shape changes for focal lengths of 1, 1.5, and 2 times the radiator height		
	D	-Provide end shield shading		
	W	-Check focal point distance/length		
		1. <u>Geometry</u>		
	W	-Frame to support shade must be at least 1 inch above the lunar/ground surface		
	W	-Length to height ratio of the shade must be at least 10		
	D	-Frame must minimize shading and be constructed to support shading device		
		2. <u>Costs</u>		
3/28/92	W	-Project budget must be kept within $ 1000		
		3. <u>Ergonomics</u>		
	W	-Must fit inside normal station wagon for ease of transportability		
	W	-Easy to install		
	W	-minimize number of moving parts for time efficiency during installation		
	W	-must be a stable structure		
2/10/92	W	-remotely adjustable		
		D- Demand W-Wishes		

ME 466K DESIGN PROJECT		Specification for Lunar Radiator Test Article		Page: 2
Changes	D/W	Requirements		Resp.
	D	**4. Maintenance** -shade material must be replaceable in case of tearing or other damage		
	W	-shade must be easy to clean or "sweep"		
	W	-minimize lunar dust collection		
	W	-maximum life for testing phase		
		5. Manufacturing		
	D	-1 unit (for prototype)		
2/10/92	W	-1 unit (for sample prototype)		
		6. Energy		
4/2/92	W	-manual operation		
3/27/92	D	-electric motor		
2/5/92	W	-electric radiator		
		7. Operation		
	W	-minimize noise		
	D	-manual operation		
	W	-continuous/adjustable operation		
2/5/92	D	-must be able to withstand vacuum chamber testing		
		8. Forces		
	D	-frame must be able to withstand weight of controls and shade		
	W	-minimize frictional forces		
		9. Material		
	D	-material must be able to withstand extreme		

ME 466K DESIGN PROJECT		Specification for Lunar Radiator Test Article		Page: 3
Changes	D/W	Requirements		Resp.
		temperatures, especially heat		
2/8/92	D	-materials must be pre-approved by NASA		
	D	-must withstand vacuum environment		
		10. Kinematics		
	D	-device must provide at least 2D motion		
	W	-3 degrees of freedom		
	W	-must minimize torque on material to maintain catenary/parabolic shape		
	W	-non-linear linkages		
		11. Assembly		
	W	-device must disassemble for ease of transportability		
	W	-minimize moving parts for ease of installation		
		12. Safety		
	D	-device must provide safe operation during testing		
	D	-electrical connections must be made safe for vacuum chamber testing		

APPENDIX B
MORPHOLOGICAL MATRIX

APPENDIX B

MORPHOLOGICAL MATRIX

VARIANT / FUNCTION	1	2	3	4	5
PROVIDE SUPPORT FOR SHADE					
PROVIDE END SHIELD SHADING					
PROVIDE SHAPE CHANGES FOR SHADE					

B-1

APPENDIX C
CATENARY/PARABOLIC ANALYSIS

This appendix contains calculations relating to the equations for the shape of the hanging shade. The first section, Catenary/Parabolic, compares the catenary and parabolic shapes. The next section, Parabolic/Stiff, compares the parabolic equation to the deflection shape of a stiff beam. The third section, Parabolic Arc Length, calculates the length of material in parabolic shapes with the desired three focal lengths. Finally, the Parabolic End Slope section calculates the angles between the ends of the parabolic shape and the horizontal for the three focal lengths.

Section I: Catenary/Parabolic Comparison

This section of the Catenary/Parabolic Analysis appendix compares parabolic shapes having the required three focal lengths with catenary shapes passing through the same vertex and end points. For each focal length (starting with one and ending with two), the parabolic equation is plotted first, then the respective catenary, and finally the two are overlaied on the same plot. Even for the one unit focus it is difficult to discern two separate lines on the overlaid plot.

```
f[p_]=(4*p*y)^0.5
```

$2. \ (p \ y)^{0.5}$

```
x1=f[1]/.y->1
```

2.

```
x2=f[1.5]/.y->1
```

2.44949

```
x3=f[2]/.y->1
```

2.82843

```
FindRoot[a*(Cosh[x1/a]-1)-1==0,{a,2}]
```

{a -> 2.14864}

```
a1=a/.%
```

2.14864

```
FindRoot[a*(Cosh[x2/a]-1)-1==0,{a,3}]
```
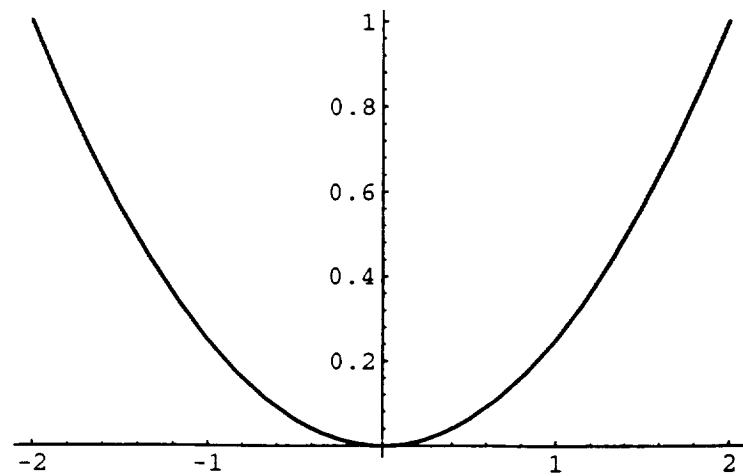
{a -> 3.15387}

```
a2=a/.%
```

3.15387

```
FindRoot[a*(Cosh[x3/a]-1)-1==0,{a,4}]
```
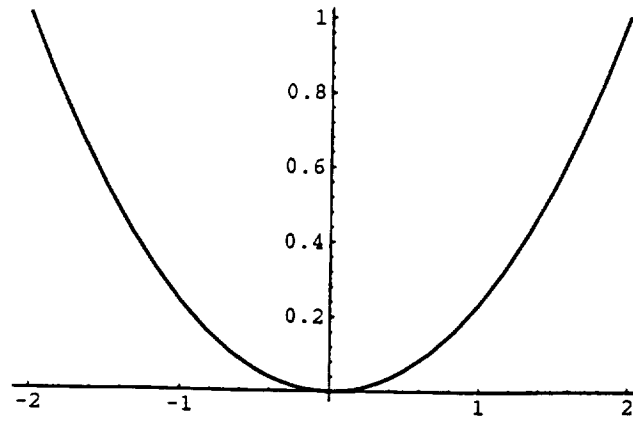
{a -> 4.15674}

```
a3=a/.%
```

4.15674

```
Plot[y=(x^2)/(4*p) /.p->1,{x,-x1,x1}]
```


-Graphics-
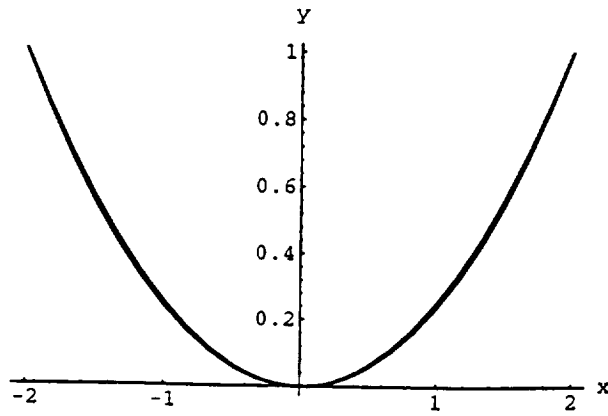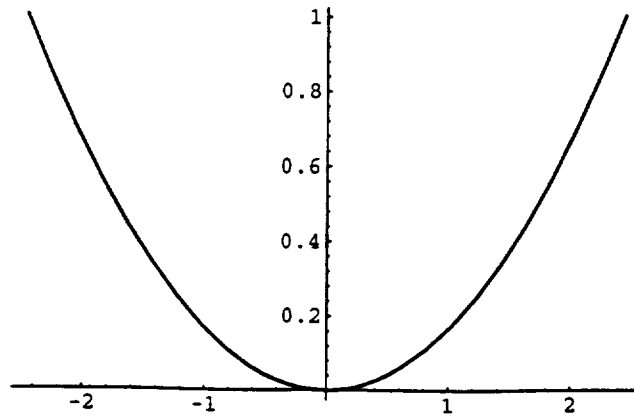
Plot[y=a1*(Cosh[x/a1]-1),{x,-x1,x1}]
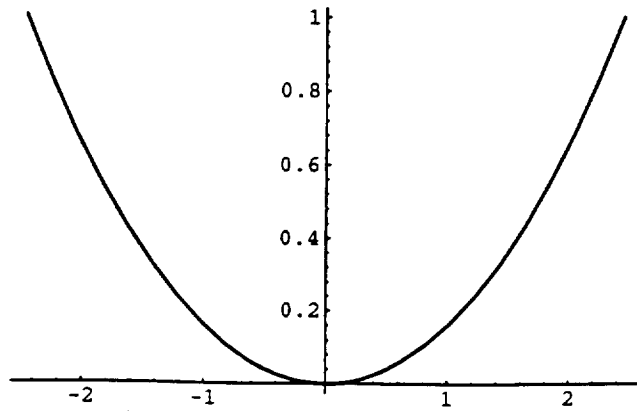

-Graphics-

Show[%11,%12,AxesLabel->{"x","y"}]

-Graphics-

Plot[y=(x^2)/(4*p) /.p->1.5,{x,-x2,x2}]
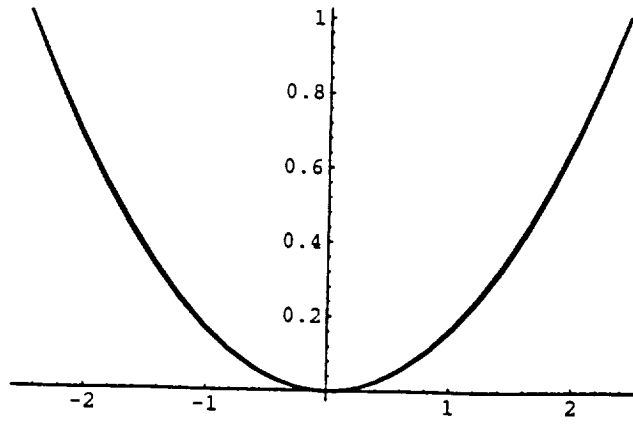

-Graphics-

Plot[y=a2*(Cosh[x/a2]-1),{x,-x2,x2}]

-Graphics-

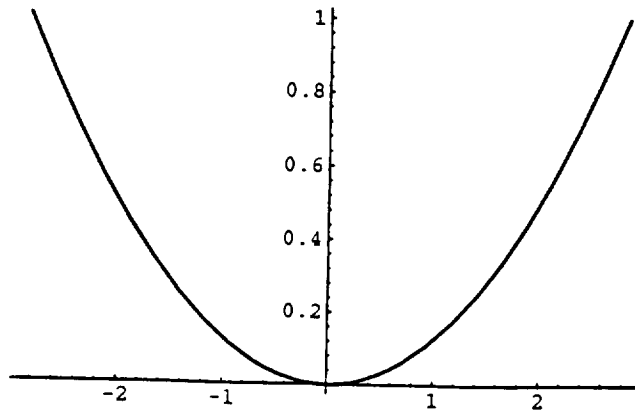**Show[%14,%15]**

-Graphics-
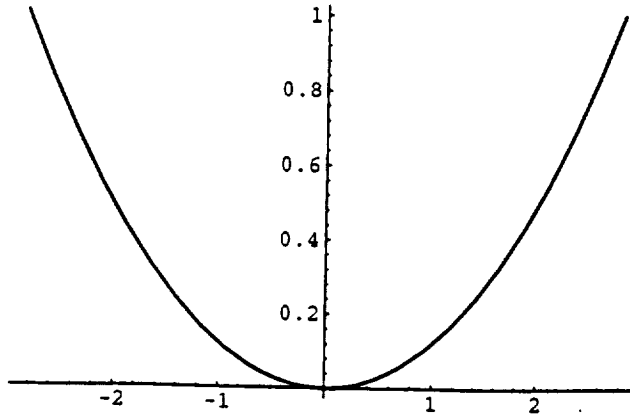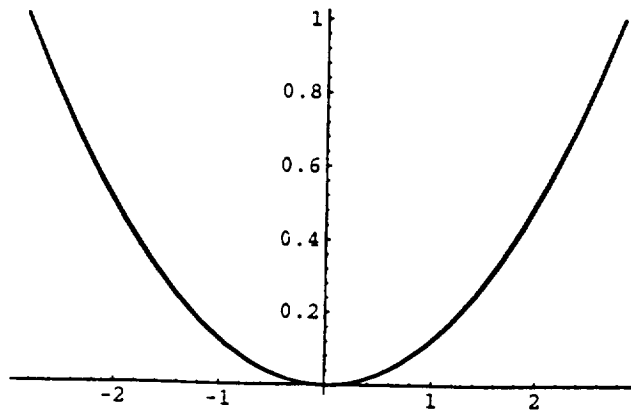
Plot[y=(x^2)/(4*p) /.p->2,{x,-x3,x3}]

-Graphics-

C-5

C-2

Plot[y=a3*(Cosh[x/a3]-1),{x,-x3,x3}]

-Graphics-

Show[%17,%18]

-Graphics-

C-6

Section II: Parabolic/Stiff Beam Deflection Comparison

In this section the stiff beam deflection equation is transformed from the form where the origin is at the left end of the beam and the deflections are below the X axis to the form where the origin is at the curve vertex and the entire curve above the X axis. This was performed so that the stiff beam deflection curve could be overlaid on the parabolic curve. However, when the transformation was complete and the results simplified the stiff beam deflection equation assumed the standard form of the parabolic equation. This shows that a stiff weightless beam deflects parabolicly when exposed to end moments and further confirms the validity of using the parabolic equation to approximate the shape of the hanging shade.

```
ys=c*(xs^2-L*xs)          (* The deflection equation for
                             a stiff beam subject to
                             equal but opposing moment
                             couples at its two ends *)

  c (-(L xs) + xs )
```
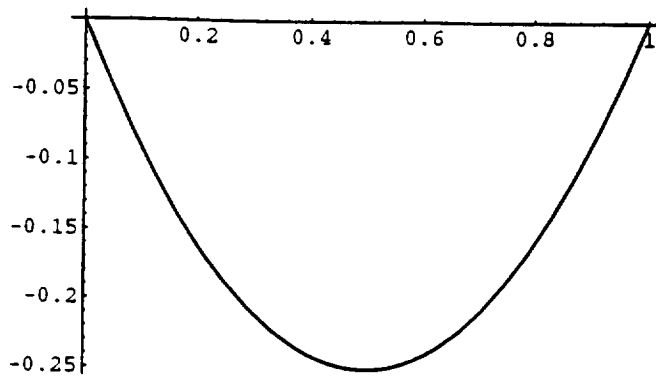
$$c \ (-(L \ xs) + xs^2)$$

```
c=1
L=1
Plot[ys,{xs,0,1}]

1

1
```



```
-Graphics-

c=.
L=.
```

```
                          (* We want to center and
                             scale this plot so that
                             it can be compared to a
                             parabolic plot with its
                             vertice at the origin *)

offset=ys/.xs->L/2        (* Find the offset neccisary
                             so that the deflection
                             curve is always above the
                             x axis *)
```
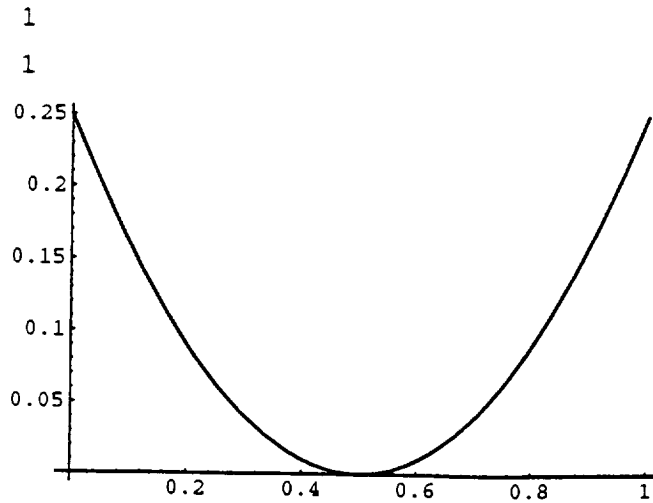
$$\frac{-(c \ L^2)}{4}$$

```
ys=ys-offset              (* Add the offset *)
```

$$\frac{c \ L^2}{4} + c \ (-(L \ xs) + xs^2)$$

```
L=1
c=1
Plot[ys,{xs,0,1}]
1

1
```



```
-Graphics-

L=.
c=.

xs=x+L/2                    (* Convert x variable so the
                            equation is symetric about
                            the y axis *)
```
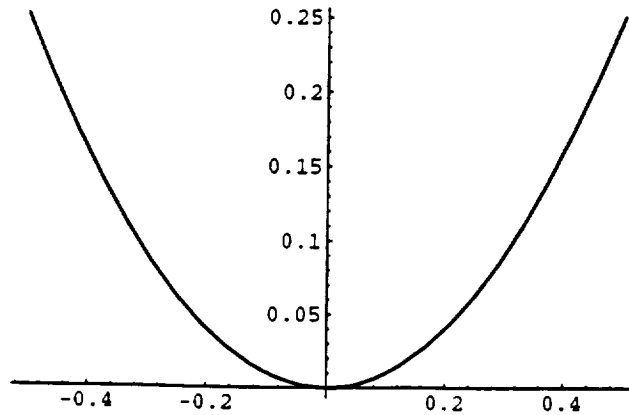
$$\frac{L}{2} + x$$

```
ys                          (* view transformed
                            equation *)
```

$$\frac{c\,L^2}{4} + c\,\left(-\left(L\,\left(\frac{L}{2} + x\right)\right) + \left(\frac{L}{2} + x\right)^2\right)$$

```
L=1
c=1
Plot[ys,{x,-0.5,0.5}]

1

1
```



```
-Graphics-

L=.
c=.

ys
```

$$\frac{c\,L^2}{4} + c\,(-(L\,(\frac{L}{2}+x)) + (\frac{L}{2}+x)^2)$$

```
Simplify[ys]
```

(* See if anything cancels
out of the repositioned
stiff beam deflection
equation *)

$$c\,x^2$$

(* Note that the stiff beam
deflection equation is of
the form y=constant x^2
i.e. the weightless stiff
beam subject to moments at
its ends deforms parabolicly
*)

```
yp=x^2/(4*p)
```
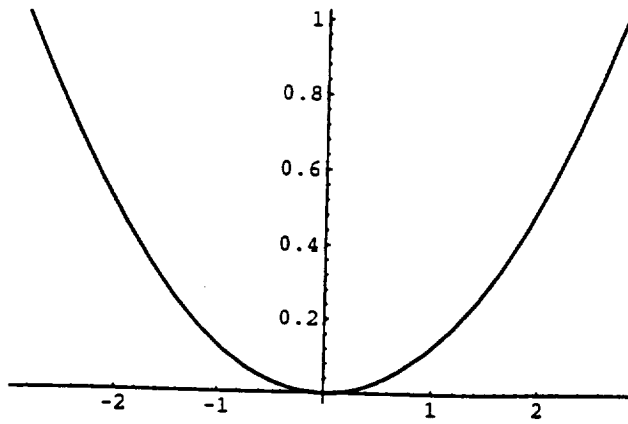
(* The parabolic equation *)

$$\frac{x^2}{4\,p}$$

```
ep=(4*p)^0.5                    (* The x end point of the
                                   parabolic shape 1 unit
                                   high *)
```

$2. \ p^{0.5}$

```
p=2                             (* Set focus at 2 units *)
```

2

```
Solve[1==c*ep^2,c]              (* Solve the stiff beam
                                   equation for the value
                                   of c that will allow it
                                   to pass through the same
                                   end points as the
                                   parabolic equation *)
```

`{{c -> 0.125}}`

`c=0.125`

`0.125`

`ys`

$0.03125 \ L^2 + 0.125 \ (-(L \ (\frac{L}{2} + x)) + (\frac{L}{2} + x)^2)$

`ys=Simplify[ys]`

$0.125 \ x^2$

`yp`

$\frac{x^2}{8}$

Plot[{ys,yp},{x,-ep,ep}]

-Graphics-

(* Because a stiff beam subject to bending moment
   deformes parabolicly it can (within material
   limits) be forced to overlay a any parabolic shape
   by specifying the end points and the vertex *)

Section III: Parabolic Arc Length Calculation

In this section the arc lengths of the parabolic shapes having the three required focal
lengths are calculated.

```
y=x^2/(4*p)                    (* The parabolic equation *)
 2
x
───
4 p

dac=(1+(D[y,x])^2)^0.5    (* Integrand of the arc
                              length equation for the
                              parabolic shape *)

        2
       x        0.5
(1 +  ───── )
          2
       4 p

ep=(4*p)^0.5                   (* The x end point of a one
                                  unit high (y=1) parabolic
                                  shape *)

      0.5
2. p

ac1=2*Integrate[dac,{x,0,ep}]

General::intinit: Loading integration packages.

Internal error: out of memory

                              (* Unsuccesful attempt to
                                 explicitly solve the
                                 arc length equation *)

p=1                           (* Seting a numeric value
                                 (1) to the focal length
                                 in order to apply numeric
                                 methods for solving the
                                 arc length equation *)

1

ac1=2*NIntegrate[dac,{x,0,ep}]
                              (* Numeric integration *)
4.59117

ac1in=ac1*2.4                 (* Converting the arc length
                                 from unit radiator
                                 heights (2.4 in) into
                                 inch units *)

11.0188

p=1.5                         (* Repeating for 1.5
                                 radiator height focus *)

1.5

ac1p5=2*NIntegrate[dac,{x,0,ep}]

5.39877
```

```
ac1p5in=ac1p5*2.4              (* Arc length (in inches)
                                  for 1.5 focus *)
12.9571

p=2

2

ac2=2*NIntegrate[dac,{x,0,ep}]
6.09802

ac2in=ac2*2.4                  (* Arc length for focus
                                  of 2 radiator heights *)
14.6352

rollinch=ac2in-ac1in           (* Length of material rolled
                                  between widest and
                                  narrowest focus *)
3.61642

rollrev=N[rollinch/(Pi*3/4)]
                               (* Revolutions of a 3/4"
                                  roller to take up material
                                  rolled *)
1.53486
```

Section IV: Parabolic End Angle Calculation

In this section the end angles for the parabolic shapes having the three required focal lengths are calculated.

```
y=x^2/(4*p)                (* The parabolic equation *)

 2
x
___
4 p

slope=D[y,x]               (* The slope of a line
                              tangent to the parabolic
                              equation *)

 x
___
2 p

endpoint=(4*p)^0.5         (* The x end point of a one
                              unit high (y=1) parabolic
                              shape *)

       0.5
2. p

endslope=slope/.x->endpoint
                           (* The slope at the
                              endpoint *)

 1.
____
 0.5
p

endangle=ArcTan[endslope]
                           (* Convert the end slope
                              into the angle with the
                              horizontal *)

         1.
ArcTan[ ____ ]
         0.5
        p

endangle1=endangle/.p->1
                           (* Find the end angle for
                              the one radiator height
                              focus *)

0.785398

endangle1deg=N[endangle1*180/Pi]
                           (* Convert the end angle
                              from radians to degrees *)

45.

endangle1p5=endangle/.p->1.5

0.684719

endangle1p5deg=N[endangle1p5*180/Pi]
                           (* The end angle to the
                              horizontal for a focal
                              length of 1.5 *)

39.2315
```

```
endangle2=endangle/.p->2
```

0.61548

```
endangle2deg=N[endangle2*180/Pi]
                              (* The end angle for a focal
                                 length of 2 *)
```
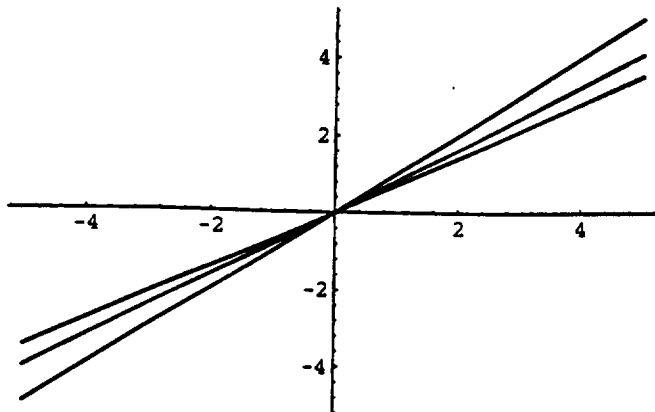
35.2644

```
(* Plot for visual comparison of end angles *)
yp=endslope*x
Plot[{yp/.p->1,yp/.p->1.5,yp/.p->2},{x,-5,5}]
```

$$\frac{1.\ x}{p^{0.5}}$$

-Graphics-

APPENDIX D
STRUCTURAL ANALYSIS

This appendix contains calculations and graphs used to pick the cross-section size and type for the aluminum frame members. The frame is comprised of four different types of members; two long members parallel to the radiator, four end track members, six vertical legs, and four corner struts. The struts only support small axial loads and the legs are too short for significant moments to accumulate under the modest loads within this small, lightweight system. In fact, the design team estimated the two critical system loads to be a maximum overload total of fifteen pounds per roller wheel on the top track member and perhaps ten pounds on the side member during lifting and transportation. Even when these loads are applied to the midspan of their respective members the cross sections required for strength is so small that downsizing was limited by allowable deflections and geometric considerations rather than by strength.

The following deflection analysis was performed using the Mathematica computer program. Analysis was performed for both the track member and the side member loaded by their respective overload estimates (15 and 10 pounds) at the midspan length. For each beam, a series of graphs were generated showing deflection as a function of cross-section length dimension for various standard cross-section thicknesses. These graphs were generated for both an angular cross-section and a rectangular one. Next, the design team agreed on an acceptable deflection for each beam and used the graphs to identify the combinations of cross-section length dimension and thickness which were acceptable. The team then chose one of the acceptable combinations such as the 1/2" (length dimension) X 1/8" (thickness) angle aluminum on the basis of geometric considerations (compatibility with frame bolting and wheel support, etc).

d1=(W*l^3)/(48*e*i)

$$\frac{l^3\ W}{48\ e\ i}$$

d2=(W*al*(3*l^2-4*al^2))/(24*e*i)

$$\frac{al\ (-4\ al^2 + 3\ l^2)\ W}{24\ e\ i}$$

i=(1/3)*(B*c1^3-b*h^3+a*c2^3)

$$\frac{B\ c1^3 + a\ c2^3 - b\ h^3}{3}$$

h=c1-d

c1 - d

c1=(a*H^2+b*d^2)/(2*(a*H+b*d))

$$\frac{b\ d^2 + a\ H^2}{2\ (b\ d + a\ H)}$$

c2=H-c1

$$H - \frac{b\ d^2 + a\ H^2}{2\ (b\ d + a\ H)}$$

B=L

L

H=L

L

b=L-t

L - t

d=t

t

a=t

t

i

$$(\frac{L\ (L^2\ t + (L - t)\ t^2)^3}{8\ (L\ t + (L - t)\ t)^3} + t\ (L - \frac{L^2\ t + (L - t)\ t^2}{2\ (L\ t + (L - t)\ t)})^3 -$$

$$(L - t)\ (-t + \frac{L^2\ t + (L - t)\ t^2}{2\ (L\ t + (L - t)\ t)})^3)\ /\ 3$$

```
i=Simplify[%]
```

$$\frac{t\ (5\ L^4 - 10\ L^3\ t + 11\ L^2\ t^2 - 6\ L\ t^3 + t^4)}{12\ (2\ L - t)}$$

```
d1=Simplify[d1]
```

$$\frac{l^3\ (2\ L - t)\ W}{4\ e\ t\ (5\ L^4 - 10\ L^3\ t + 11\ L^2\ t^2 - 6\ L\ t^3 + t^4)}$$

```
d2=Simplify[d2]
```

$$\frac{al\ (4\ al^2 - 3\ l^2)\ (-2\ L + t)\ W}{2\ e\ t\ (5\ L^4 - 10\ L^3\ t + 11\ L^2\ t^2 - 6\ L\ t^3 + t^4)}$$

```
e=10000000
```

10000000

```
(* For long side under 10 lbs load at the midle.*)
W=10
1=27.5
```
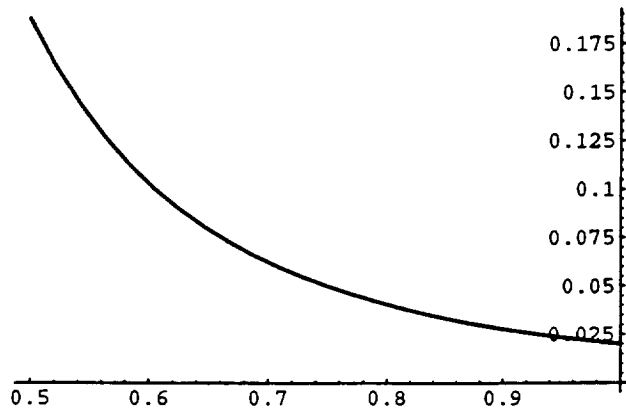
10

27.5

```
(* For 1/8 thickness, plot of deflection:vert -vs-
   length on both sides of angle *)
t=1/8
```

$$\frac{1}{8}$$

```
Plot[d1,{L,1/2,1}]
```


-Graphics-

(* same but thickness is 3/16 *)
t=3/16

$$\frac{3}{16}$$

Plot[d1,{L,1/2,1}]
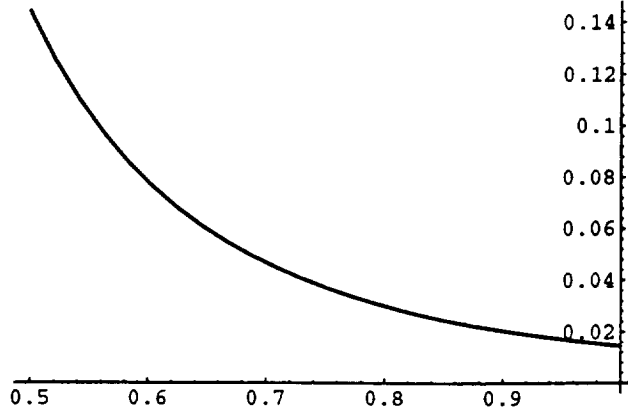
-Graphics-

(* same but 1/4 thick *)
t=1/4

$$\frac{1}{4}$$

Plot[d1,{L,1/2,1}]
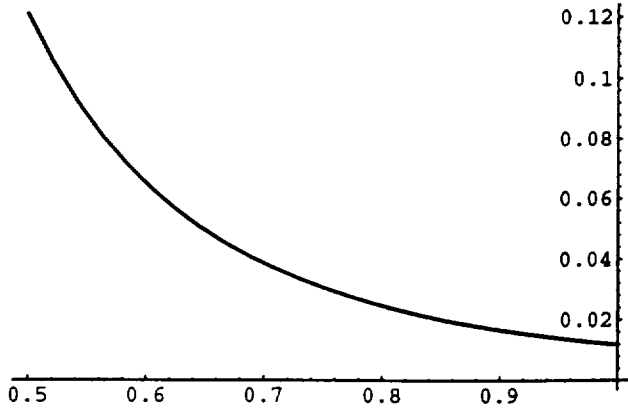
-Graphics-

```
(* New senerio, short side split by a leg at
   the midpoint, a 15 lb load is midway (4 3/8 in)
   between each leg *)
l=8+3/4
```
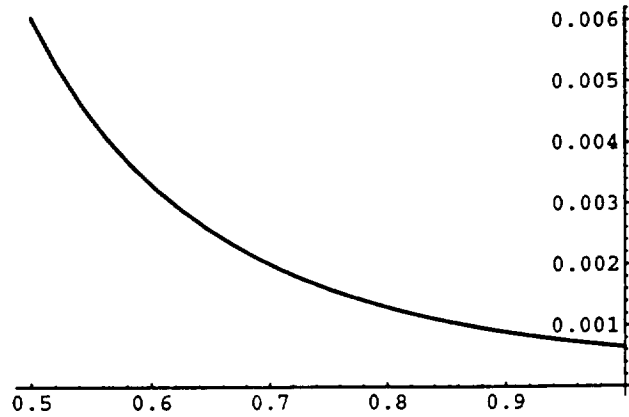
$$\frac{35}{4}$$

```
(* 1/8 thickness *)
t=1/8
```
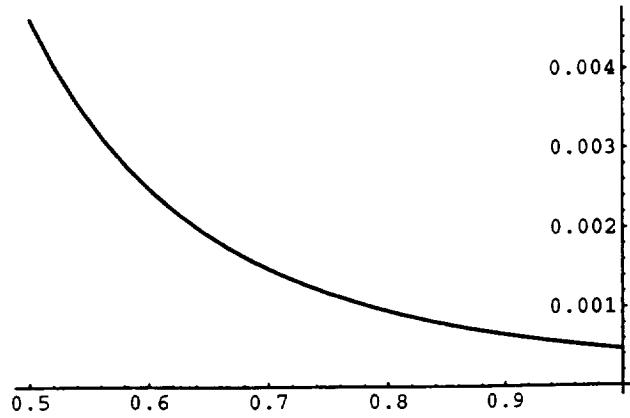
$$\frac{1}{8}$$

```
Plot[d1,{L,1/2,1}]
```



```
-Graphics-
```

```
(* 3/16 thickness *)
t=3/16
```

$$\frac{3}{16}$$

Plot[d1,{L,1/2,1}]

-Graphics-

(* 1/4 thickness *)
t=1/4

$$\frac{1}{4}$$

Plot[d1,{L,1/2,1}]

-Graphics-

D-6

```
d1=(W*l^3)/(48*e*i)
```

$$\frac{l^3\ W}{48\ e\ i}$$

```
d2=(W*al*(3*l^2-4*al^2))/(24*e*i)
```
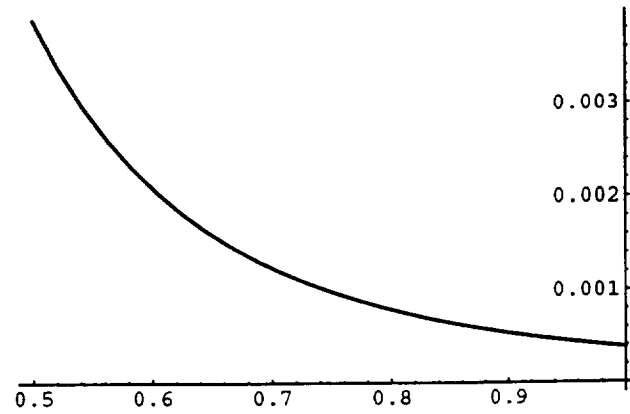
$$\frac{al\ (-4\ al^2\ +\ 3\ l^2)\ W}{24\ e\ i}$$

```
i=b*h^3/12
```

$$\frac{b\ h^3}{12}$$

```
e=10000000
```

10000000

d1

$$\frac{l^3\ W}{40000000\ b\ h^3}$$

```
(* Long bar loaded at midpoint with 10 lbs in
   weak direction *)
l=27.5
W=10
```
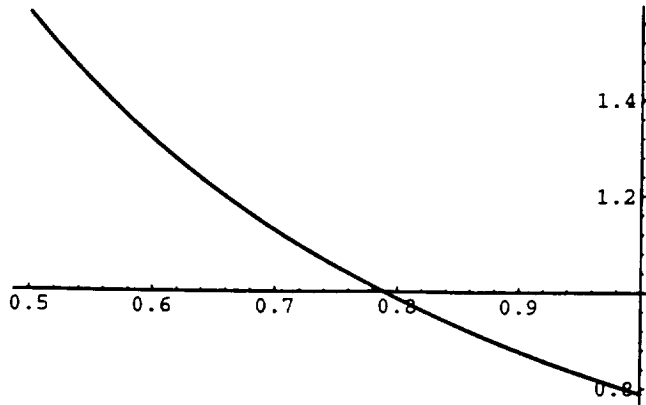
27.5

10

```
(* 3/16 thick bar *)
h=3/16
```
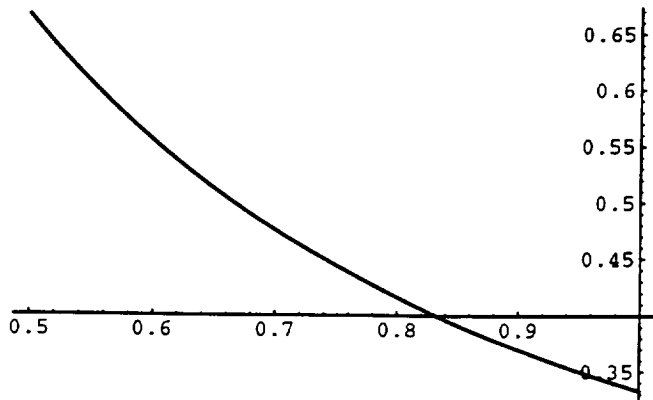
$$\frac{3}{16}$$

Plot[d1,{b,1/2,1}]

-Graphics-

(* 1/4 thickness *)
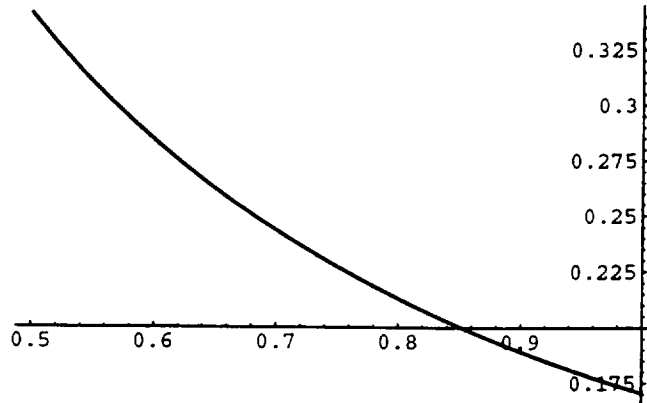**h=1/4**

$\dfrac{1}{4}$

Plot[d1,{b,1/2,1}]

-Graphics-

(* 5/16 thickness *)
h=5/16

$\dfrac{5}{16}$

D-8

Plot[d1,{b,1/2,1}]
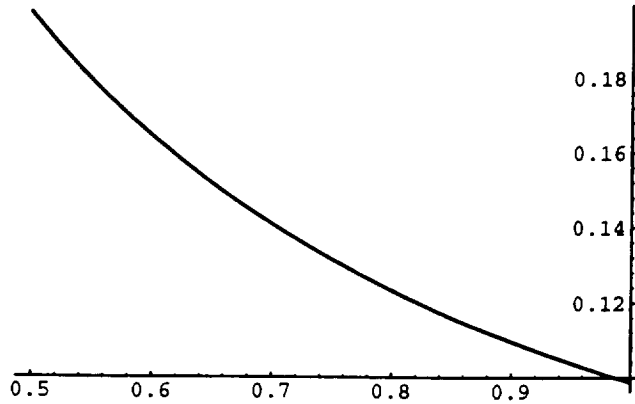

-Graphics-

(* 3/8 thickness *)

h=3/8

$\frac{3}{8}$

Plot[d1,{b,1/2,1}]

-Graphics-

(* New senerio: short side/roller rack loaded
**   with 15 lbs half way {4 3/8"} between end leg**
**   and midle leg *)**
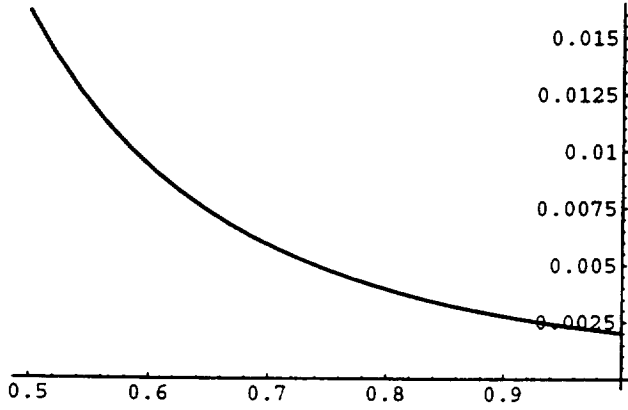**l=8.75**
W=15

8.75

15

```
(* 1/8 thickness *)
b=1/8
```

$\dfrac{1}{8}$

```
Plot[d1,{h,1/2,1}]
```



```
-Graphics-
```

```
(* 3/16 thickness *)
t=3/16
```

$\dfrac{3}{16}$

```
Plot[d1,{h,1/2,1}]
```
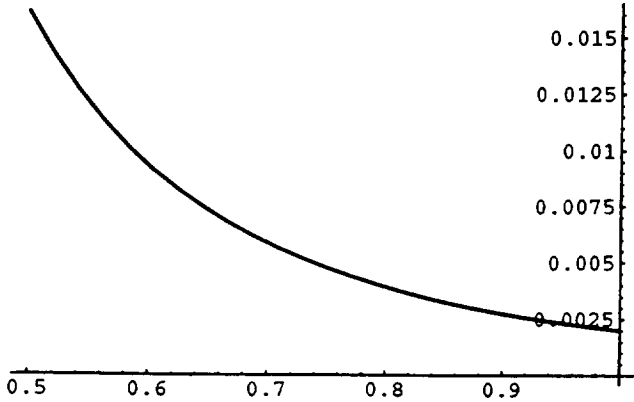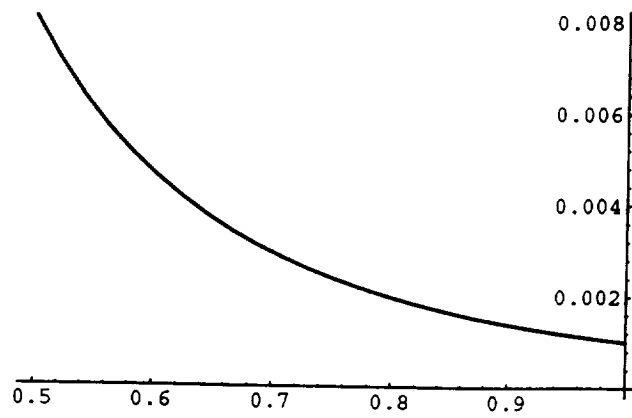


```
-Graphics-
```

```
(* 1/4 thickness *)
b=1/4
```

$\dfrac{1}{4}$

Plot[d1,{h,1/2,1}]

-Graphics-

(* 5/16 thickness *)
b=5/16

$$\frac{5}{16}$$

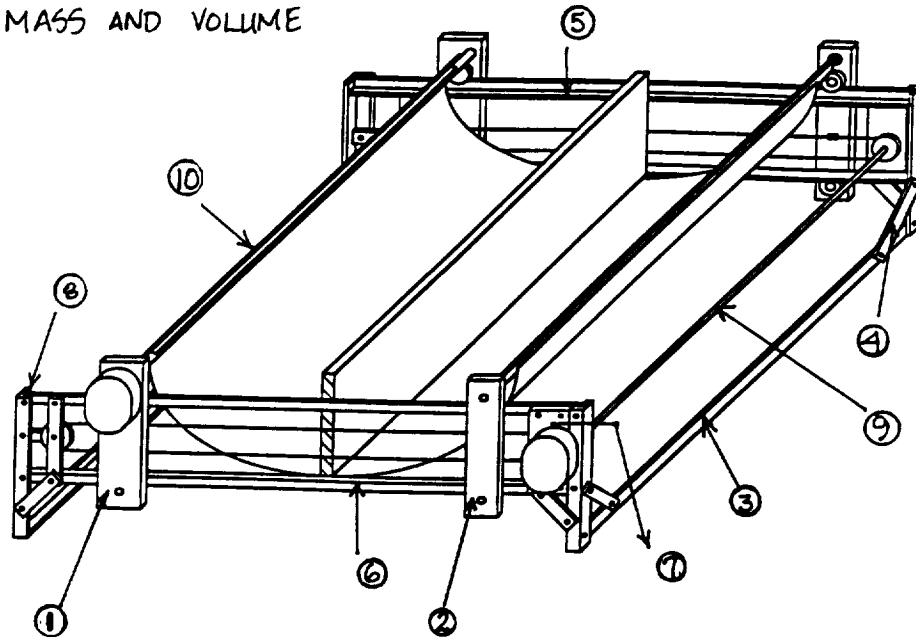**Plot[d1,{h,1/2,1}]**

-Graphics-

D-11
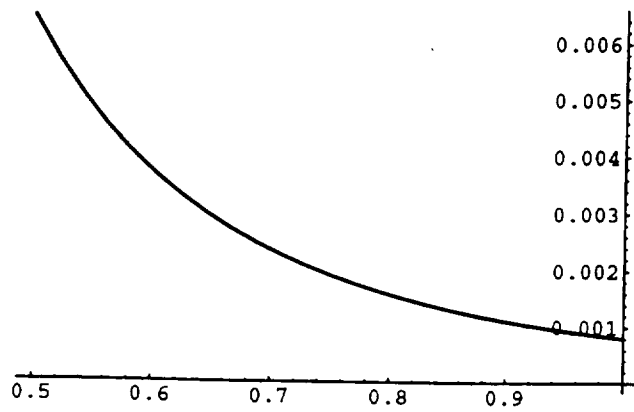
APPENDIX E
MASS AND VOLUME CALCULATIONS

MASS AND VOLUME

MASS AND VOLUME CALCULATIONS WILL BE TAKEN
FROM THE MAJOR COMPONENTS 1-10

NOTE : ALL BOLT HOLES NEGLECTED (VOLUME WISE)

$$\rho_{AL} = .098 \text{ }^{lb}/_{in^3}$$

* MASS APPROXIMATE FOR ENTIRE DEVICE → " M "

* ASSUMING MOTOR MASS $\approx$ 3 lbs

* SHADE MATERIAL MASS (approx.) $\approx$ 1 lb

① DIMENSIONS → $5 \frac{5}{16}'' \times 2 \frac{3}{16}'' \times \frac{3}{8}''$

$V = L \times b \times h = 5.3125 \times 2.1875 \times .375 = 4.358$ (in^3)

$M = \rho V = .098 \ lb/in^3 \ (4.358 \ in^3)$

$= .42 \ lb$

$V = 2(4.358)$
$= \underline{8.716 \ in^3}$

2 Pieces → $M = 2(.42) = \underline{.84 \ lb}$

② DIMENSIONS → $5 \frac{5}{16}'' \times 2 \frac{3}{16}'' \times \frac{3}{8}''$

(SAME AS ABOVE) $V = 4.358 \ in^3 \rightarrow \underline{8.716 \ in^3}$

$M = .42 \ lb \rightarrow \underline{.84 \ lb}$

2 Pieces →

③ DIMENSIONS → Angle Aluminum : APPROX. AS TWO BARS

$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{8} \times 26\frac{1}{2}$

2 BARS : (1) $\frac{1}{2} \times \frac{1}{8} \times 26\frac{1}{2}$ } 2 Pieces

(2) $\frac{3}{8} \times \frac{1}{8} \times 26\frac{1}{2}$

$V_{(1)} = 1.66 \ in^3 \xrightarrow{\times 2} \underline{\underline{3.32 \ in^3}}$

$V_{(2)} = 1.24 \ in^3 \xrightarrow{\times 2} \underline{\underline{2.48 \ in^3}}$

$$M_{(1)} = (.098)(3.32) = \underline{\underline{.325 \text{ lb}}}$$

$$M_{(2)} = (.098)(2.48) = \underline{\underline{.243 \text{ lb}}}$$

④ DIMENSIONS → $1/2 \times 1/8 \times 2^{9}/_{16} (\pm 1/16)$

$V = .5 \times .125 \times 2.585$ 4 Pieces

$\underline{\underline{= .162 \text{ in}^3}} \times 4 \longrightarrow \underline{\underline{.648 \text{ in}^3}}$

$$M = (.098)(.162) = .016 \text{ lb} \longrightarrow \underline{\underline{.0633 \text{ lb}}}$$

⑤ DIMENSIONS → Angle Aluminim

$1/2 \times 1/2 \times 1/8 \times 23$

2 BARS :   (1) $1/2 \times 1/8 \times 23$
　　　　　　(2) $3/8 \times 1/8 \times 23$ } 2 Pieces

$V_{(1)} = 1.4375 \longrightarrow 2.875 \text{ in}^3$

(See #6 for M)

$V_{(2)} = 1.078 \longrightarrow \underline{2.156 \text{ in}^3}$

⑥ DIMENSIONS → $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{8} \times 23$

SAME AS #5

$V_{(1)} = \underline{2.875\,in^3}$ (for 2 Pieces)

$V_{(2)} = \underline{2.156\,in^3}$ (for 2 Pieces)

$M_{(1)} = 2.875\,(.098) = \underline{.282\,lb}$ (for 2)

$M_{(2)} = 2.156\,(.098) = \underline{.211\,lb}$ (for 2)

⑦ DIMENSIONS → $\frac{1}{4} \times 2\frac{1}{8}\,(\pm\frac{1}{8}) \times 4\,(\pm\frac{1}{8})$

$V = .25 \times 2.18 \times 4\,035$

$= 2.199\,in^3$ 4 PIECES

$\overset{\times 4}{\Longrightarrow} \underline{8.79\,in^3}$

$M = (.098)(2.199)$

$= .2155$

$\overset{\times 4}{\Longrightarrow} \underline{.86\,lb}$

⑧ DIMENSIONS $\longrightarrow$ $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{8} \times 2\frac{7}{8}$

2 BARS : (1) $\frac{1}{2} \times \frac{1}{8} \times 2\frac{7}{8}$

(2) $\frac{3}{8} \times \frac{1}{8} \times 2$

$V_{(1)} = .1797 \text{ in}^3$ 4 Pieces

$\overset{\times 4}{\Longrightarrow} \underline{\underline{.718 \text{ in}^3}}$

$V_{(2)} = .1347 \text{ in}^3$

$\overset{\times 4}{\Longrightarrow} \underline{\underline{.539 \text{ in}^3}}$

$M_{(1)} = (.098)(.718)$

$= \underline{\underline{.0703 \text{ lb}}}$

$M_{(2)} = (.098)(.539)$

$= \underline{\underline{.053 \text{ lb}}}$

SHAFTS

⑨

DIMENSIONS → ¼ Dia × 26 3/8

$$V = \pi r^2 \ell = \pi \times (.125)^2 \times 26.375$$

$$= \underline{\underline{1.294 \text{ in}^3}}$$

$$M = (.098)(1.294)$$

$$= \underline{\underline{.0127 \text{ lb}}}$$

⑩ DIMENSIONS → ½ Dia × 27 3/16

$$V = \pi r^2 \ell = \pi \times (.25)^2 \times 27.1875$$

$$= \underline{\underline{5.33 \text{ in}^3}}$$

$$M = (.098)(5.33)$$

$$= \underline{\underline{.523 \text{ lb}}}$$

TOTAL APPROXIMATE VOLUME (w/o MOTOR)

$$V_{Tot} = 50.61 \ in^3$$

TOTAL APPROXIMATE MASS

$$M_{TOT} = 3.1336 \ lb$$
$$+ \ 3 \ lb \ (Motor)$$
$$+ \ 1 \ lb \ (Shade \ Material)$$
$$\underline{7.1336 \ lb} \quad for$$

* The device will probably be up to 5 lbs heavier when the springs, screws, nuts, bolts etc... are added in

* Device is predicted to have a mass of 10 - 15 lbs.

OUTER DIMENSIONS OF SHADE : L, H, W

4 "

26.5 "

23 "
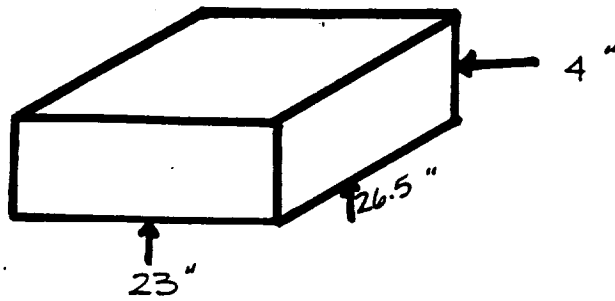
* WHAT CIRCULAR DIAMETER CAN THE
SHADE FIT (IF A SMALLER VACUUM CHAMBER)
MUST BE USED)?

26.5 "

23 "
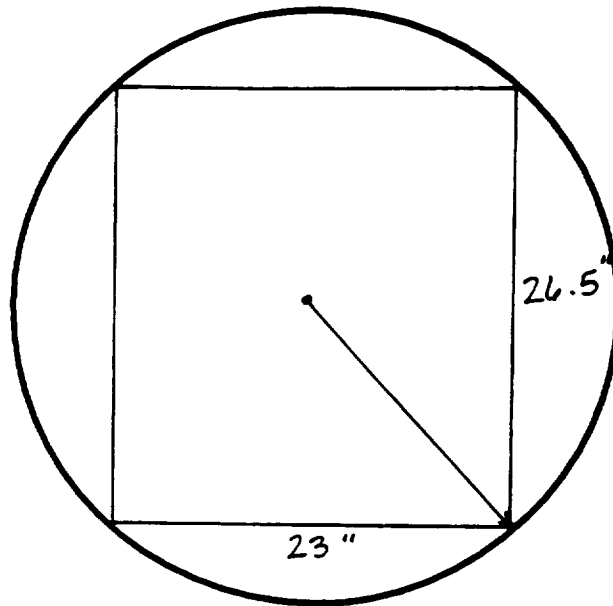
Pyth Thm.

$$11.5^2 + 13.25^2 = R^2$$

$$175.5625 + 132.25$$

$$= \sqrt{307.81}$$

$$R = 17.54 \text{ inches}$$

Circular Diameter Chamber of 35" or more can be used.

APPENDIX F
DECISION MATRIX

Appendix F
Decision Matrix

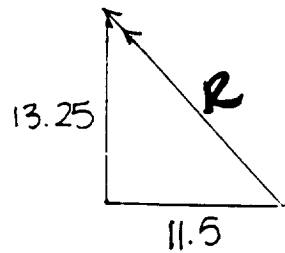| CRITERIA	Weighting Factors	Two Belt Rack and Pinion		Rolling and Translating		I-Frame Rack and Pinion		Climbing Track		Rack and Pinion	
ALTERNATIVE DESIGNS		Rank	Weighted Rank	Rank	Weighted Rank	Rank	Weighted Rank	Rank	Weighted Rank	Rank	Weighted Rank
Ease of Automation	0.15	6.66	1	6	.90	7	1.05	4.33	.65	5.66	.85
Ability to Keep Catenary Shape	0.15	3.33	.50	7	1.05	3.66	.55	6.33	.95	6.66	1
Transportabilty	0.05	7	.35	6.66	.33	6	.30	4	.20	6.66	.33
Collapsibility	0.04	8	.32	5.67	.23	4.33	.17	1.33	.05	4.33	.17
Ease of Manufacturing	0.19	4.66	.87	5.66	1.08	5	.95	2.33	.44	4.66	.89
Simplicity (no. of moving parts)	0.22	3	.66	6.33	1.39	4.33	.95	3.33	.75	5	1.10
Mass and Volume	0.05	7	.35	6.66	.33	7	.35	4	.20	6.66	.33
Elimination of Material at Top and Bottom	0.15	4.33	.65	7.33	1.10	4.33	.65	7	1.05	7	1.05
Final Rank	1.0		4.7		6.41		4.97		4.27		5.27

CRITERIA	Weighting Factors	Hanging Shade and Rectangular Frame		Translating Mechanism			Rank	Weighted Rank		Rank	Weighted Rank	Rank	Weighted Rank
ALTERNATIVE DESIGNS		Rank	Weighted Rank	Rank	Weighted Rank								
Ease of Automation	0.15	7.33	1.10	6.33	.95								
Ability to Keep Catenary Shape	0.15	6	.90	6.66	1								
Ease of Transportability	0.05	7	.35	6.66	.33								
Collapsibility	0.04	5.33	.21	5.33	.21								
Ease of Manufacturing	0.19	6.33	1.20	6.66	1.27								
Simplicity (no. of moving parts)	0.22	6.66	1.47	6.17	1.36								
Mass and Volume	0.05	7	.35	7	.35								
Elimination of Material at Top and Bottom	0.15	6.33	.95	7.33	1.10								
Final Rank	1.0		6.53		6.57								

F-2

APPENDIX G
VENDOR INFORMATION

OPERATING INSTRUCTIONS

PERMANENT SPLIT CAPACITOR BRAKE GEARMOTORS

MODELS 4Z451 thru 4Z459

READ INSTRUCTIONS CAREFULLY BEFORE ATTEMPTING TO INSTALL OR OPERATE DAYTON GEARMOTORS! RETAIN INSTRUCTIONS FOR FUTURE REFERENCE.

Description

Dayton brake gearmotors are designed for continuous duty, and are powered by permanent split capacitor 3-wire reversible motors. The gear housing is made from high strength zinc die casing with steel cover. First step gear is phenolic, all others are precision cut or sintered steel. Bearings are porous bronze factory lubricated. Units are operable in horizontal mounting positions only.

Gearmotors are equipped with spring loaded friction brake providing positive stopping and holding action. Output shaft overtravel approximately 1° (4Z451) to 100° (4Z459) when motor is de-energized.

General Safety Information

Follow all local electrical and safety codes, as well as the National Electrical Code (NEC) and the Occupational Safety and Health Act (OSHA).

WARNING: DISCONNECT FROM POWER SOURCE BEFORE SERVICING OR INSPECTING FOR ANY REASON. FAILURE TO DO SO COULD RESULT IN FATAL ELECTRICAL SHOCK.

WARNING: DO NOT INSTALL IN AN EXPLOSIVE ENVIRONMENT.

1. Follow all local electrical and safety codes, as well as the National Electrical Code (NEC) and the Occupational Safety and Health Act (OSHA).

2. Motor must be securely and adequately grounded. This can be accomplished by wiring with a grounded, metal-clad raceway system by using a separate ground wire connected to the bare metal of the motor frame, or other suitable means. Refer to NEC Article 250 (Grounding) for additional information.

3. Do not depend on motor control devices (motor starters, etc.) to prevent unexpected motor start ups. Always disconnect power source before working on or near a motor or its connected load. If the power disconnect point is out of sight, lock it in the open position and tag it to prevent unexpected application of power.

4. All moving parts should be guarded.

5. Be careful when touching the exterior of an operating motor — it may be hot enough to be painful or cause injury. Modern-design motors normally run hot when operating at rated voltage and load.

6. Protect the power cable from coming in contact with sharp objects.

7. Do not kink power cable and never allow the cable to come in contact with oil, grease, hot surfaces, or chemicals.

8. Make certain that the power source conforms to the requirements of your equipment.

9. When cleaning electrical or electronic equipment, always use an approved cleaning agent such as dry cleaning solvent.
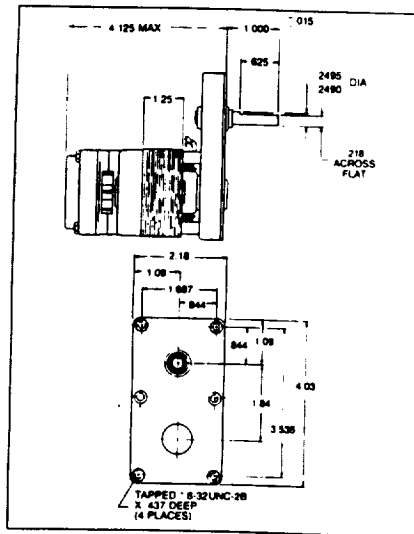

Figure 1 — Dimensions

Installation

1. Use only in a clean and dry location with adequate supply of cooling air. Ambient temperature should not exceed 40°C. For outdoor installation, gearmotor must be protected by a cover that does not block air flow to and around the motor.

WARNING: NOT TO BE USED IN HAZARDOUS LOCATIONS. CONSULT YOUR LOCAL GOVERNMENT INSPECTION AGENCY FOR GUIDANCE.

2. Mount gearmotor to rigid flat surface using four 8-32 self-tapping screws.

3. Wiring connections: All wiring and electrical connections comply with the National Electrical Code and local electrical codes. In particular, refer to Article 430 (Motors, Motor Circuits and Controllers) of the NEC.

4. Voltage, frequency and phase of power supply must be the same as that shown on the motor nameplate.

Operation

1. When using a direct coupling check carefully the alignment, making sure that they are in direct alignment after bolting down. Shim if required. If using a flexible coupling do not depend on it to compensate for misalignment.

2. Do not exceed torque shown. Avoid shock load. For 24-hour service reduce torque rating by 25%.

3. When used with belt or chain do not side load output shaft bearing in excess of 3.5 lbs. located midway on output shaft.

4. Unit is not designed for axial thrust load.

5. 4X426 oil-filled capacitor (4MFD) is required for operation.

Connection for Clockwise (CW) rotation facing output shaft: Connect 115V power to black and grey leads. To reverse, connect power to black and yellow leads.
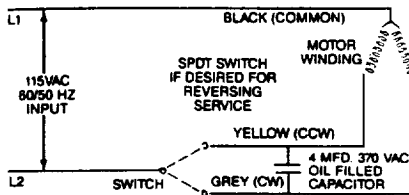

Figure 2 — Wiring Diagram

Troubleshooting Chart

SYMPTOM	POSSIBLE CAUSE(S)	CORRECTIVE ACTION(S)
Won't start	1. No input power	1a. Check voltage available.
		b. If no voltage is present check fuse.
	2. Self aligning bearings not in alignment	2. With power off, inspect motor bearing alignment first by trying to rotate rotor shaft of motor. If a binding condition exists, tap slightly on the side of motor with a plastic hammer. Do not tap on motor bobbin or coil. Apply power to see if problem has been corrected.
	3. Overloaded	3a. Check load and alignment of coupling.
		b. Too much side load.
Motor runs but output shaft doesn't turn	Stripped gears due to overload condition	Replace unit — eliminate shock load condition or use larger capacity gearmotor using correct service factor.

Specifications & Performance

MODEL	AT 60 Hz: 1/100 HP, 0.35 FULL-LOAD AMPS			AT 50 Hz: 1/120 HP, 0.32 FULL-LOAD AMPS		
		TORQUE			TORQUE	
	NOM. F/L RPM	IN-LBS. START	IN-LBS. RUN	NOM. F/L RPM	IN-LBS. START	IN-LBS. RUN
4Z451	1	56	42	.83	45	42
4Z452	4	35	26	3.3	28	26
4Z453	7	24	18	5.8	21	18
4Z454	12	15	11	10.0	13	11
4Z455	18	11	8	15.0	9.5	8
4Z456	25	8	6	20.8	6.8	6
4Z457	35	5	4	29.1	4.3	4
4Z458	55	3.5	2.6	46	3	2.6
4Z459	98	2	1.5	82	1.7	1.5

All units recognized by Underwriters Laboratories for construction under the Motor Component Recognition Program.
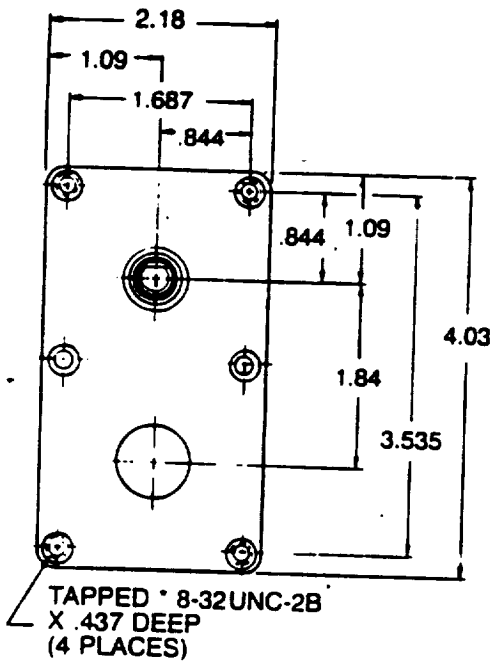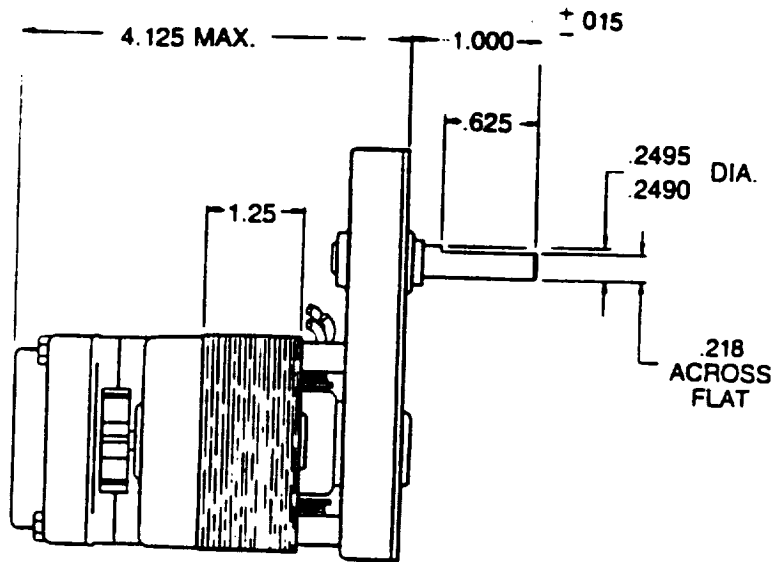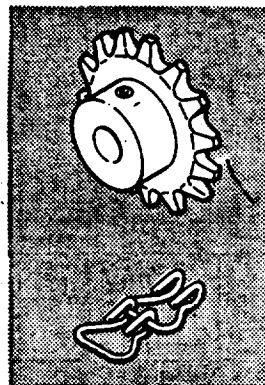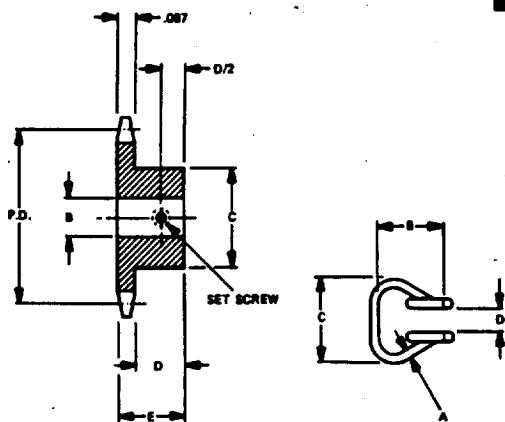
4.125 MAX. —— 1.000 —— ± .015

.625

.2495 DIA.
.2490

1.25

.218 ACROSS FLAT

2.18
1.09
1.687
.844

.844   1.09

4.03

1.84

3.535

TAPPED 8-32 UNC-2B
X .437 DEEP
(4 PLACES)

■ SIZE 19

SET SCREW

Ladder Chain*							
Catalog Number	Material	Yield Point Lbs.	Links Per Foot	A Wire Dia.	B Pitch	C Outside Width	D Inside Width
6C8-19	Basic Steel	30	65	.041	.1852	.297	.110
6C88-19	Hi-Tensile Steel	55					
6B8-19	Brass	18					
6Y8-19	Stainless	30					

MATERIAL: Brass   *NOTE: Priced per foot.   ■ .087 FACE

Sprockets							
Catalog Number	No. of Teeth	P.D.	B Bore	C Hub Dia.	D Hub Proj.	E Length	Type
** 6B8-1906	6	.36		1/4			
** 6B8-1907	7	.41					
** 6B8-1908	8	.47	1/8	5/16			
6B8-1909	9	.53					
6B8-1910	10	.59		3/8			
6B8-1912	12	.70		7/16	1/4	11/32	
6B8-1915	15	.87					
6B8-1916	16	.93	3/16				Plain
6B8-1918	18	1.06		1/2			
6B8-1920	20	1.16					
6B8-1924	24	1.38					
6B8-1932	32	1.86	1/4	5/8		—	
△ 6B8-1936	36	2.12					
△ 6B8-1948	48	2.78	5/16	11/16	5/16	13/32	
△ 6B8-1960	60	3.48					
6B8-1972	72	4.21					Cast

9 & 10 Tooth Sprockets Have #6-32 Set Screws. 12 Thru 32 Tooth
Sprockets Have #8-32 Set Screws. 36 Thru 72 Tooth Sprockets Have
#10-32 Set Screws.

440

** Do Not Have Set Screws. Have Recessed Groove In Hub For Chain Clearance.
△ 2 Piece Assembly 3/8 Bore Max.

■ SIZE 19
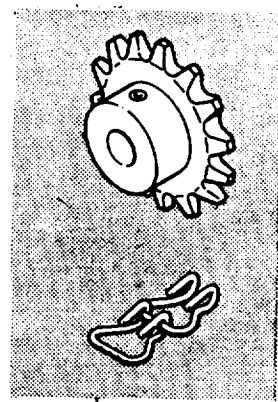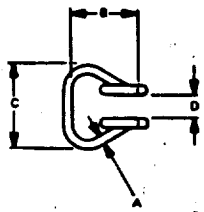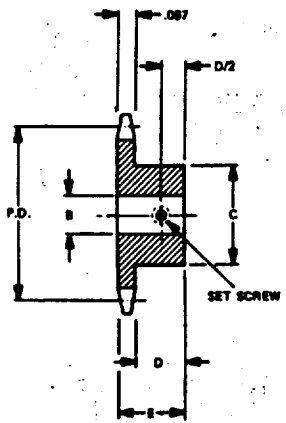
SET SCREW

■.087 FACE

Ladder Chain°							
Catalog Number	Material	Yield Point Lbs.	Links Per Foot	A Wire Dia.	B Pitch	C Outside Width	D Inside Width
6C8-19	Basic Steel	30	65	.041	.185	.297	.110
6C88-19	Hi-Tensile Steel	55					
6B8-19	Brass	18					
6Y8-19	Stainless	30					

°NOTE: Priced per foot.

MATERIAL: Steel

Sprockets							
Catalog Number	No. of Teeth	P.D.	B Bore	C Hub Dia.	D Hub Proj.	E Length	Type
6C8-1907	7	.41	3/16	3/8	1/2	19/32	Plain
6C8-1908	8	.47		7/16			
6C8-1909	9	.53		1/2			
6C8-1910	10	.59	1/4	9/16			
6C8-1912	12	.70		11/16			
6C8-1914	14	.83		3/4			
6C8-1916	16	.93	5/16	7/8			
6C8-1920	20	1.16			13/32	1/2	
6C8-1924	24	1.38					

7 & 8 Tooth Sprockets Have #8-32 Set Screws.
9 Thru 24 Tooth Sprockets Have #10-32 Set Screws

441

The DUA-L-VEE® System:
Three Components, Four Sizes

The DUA-L-VEE® Guide Wheel System is a proven, economical method of obtaining precision linear moti for all types of mechanical applications.

A low friction accurate slide, such as the one illustrated below, can be made quickly and inexpensive without the aid of costly machine tools. All that is needed is a rule and a drill press. There are no linear sea to wear out.

The guide wheels are precision ground, double row angular contact ball bearings, which are pre-lubricate and available shielded or sealed.

The track is cold formed from medium carbon steel and is available as formed or hardened and polishe on the top contact surfaces. The lower portion of the track is left soft to permit drilling for mounting.

Eccentric bushings are used opposite concentric bushings to provide a simple and effective means adjusting the free play of the system.

Since the circumference of the wheels is greater at the major diameter than the minor diameter, there a constant wiping action on the track which gives a self-cleaning effect. Contaminants do not cause any gre. loss of efficiency in the system.

Wheels

Track

Bushings
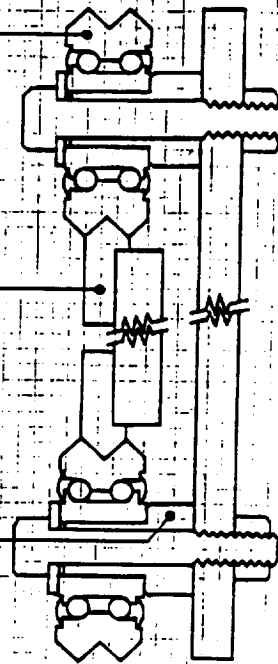
Guide Wheels: Sizes
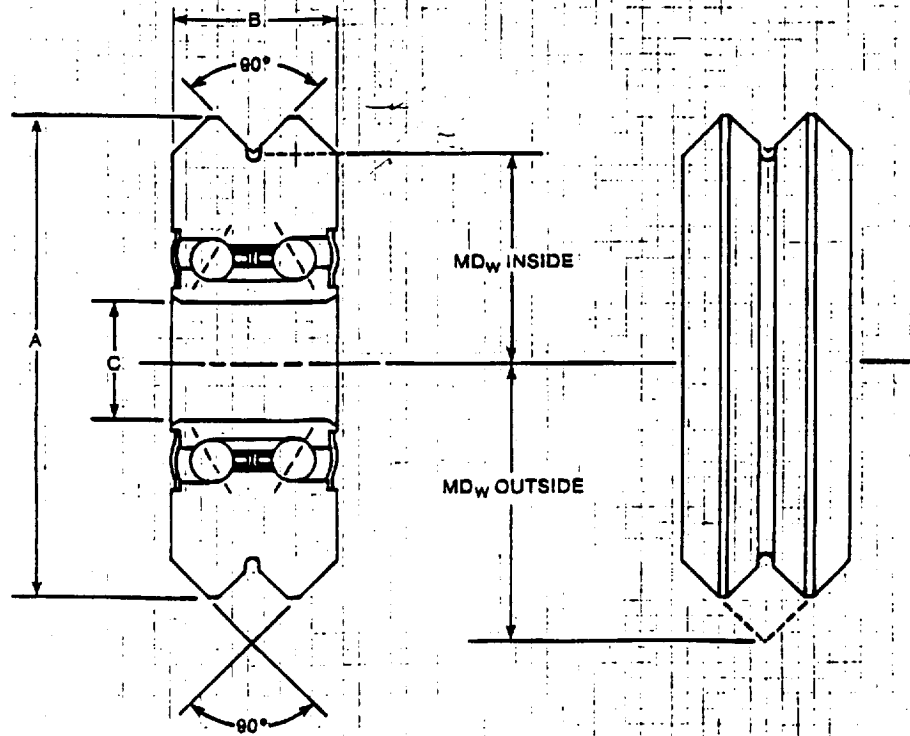
SIZE	A"	B	C	MD$_W$ INSIDE	MD$_W$ OUTSIDE	WT./lbs.
1	.77"	.310"	.1875"	.312"	.467"	.027
2	1.21"	.437"	.3750"	.500"	.718"	.087
3	1.80"	.625"	.4724"	.750"	1.062"	.300
4	2.36"	.750"	.5906"	1.000"	1.375"	.630

Mounting Dimensions
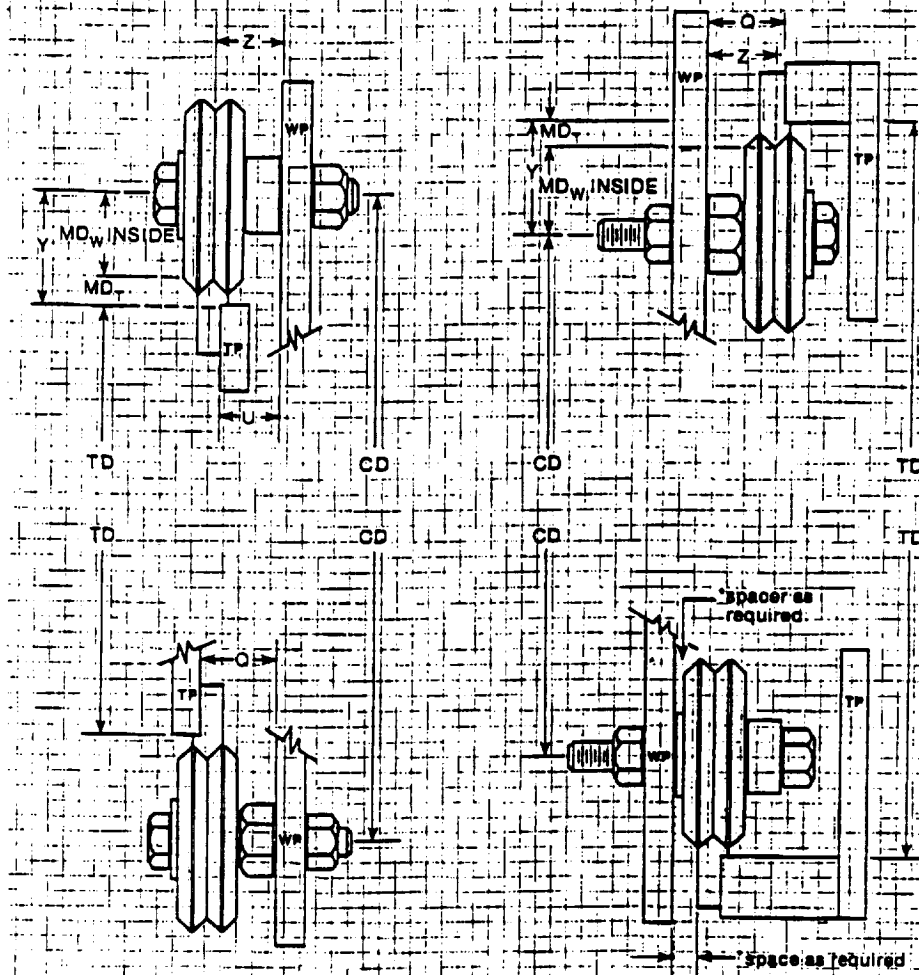
OUTBOARD MOUNTING FORMULA
TD + 2Y = CD

INBOARD MOUNTING FORMULA
TD – 2Y = CD

† Where CD is less than wheel diameter. Guide
Wheels must be offset for proper clearance. †

APPENDIX H
VACUUM CHAMBER STATISTICS

JOHNSON SPACE CENTER

NASA
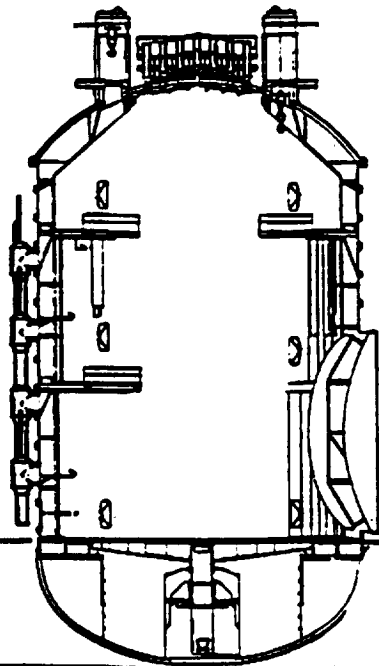
CREW AND THERMAL SYSTEMS DIVISION VACUUM LABORATORIES

USER GUIDE

STS-F-885 A

CHAMBER B

MANNED THERMAL-VACUUM TEST COMPLEX WITH SOLAR

Chamber B, the smaller of the large chambers, has the same basic capability as Chamber A and can accommodate a variety of smaller scale tests more economically, with faster response and is man-rated. Major structural elements of the chamber are the removable top head, the fixed chamber floor, and a dual manlock at the floor level.

The load-bearing floor area is 6.1m(20 ft) in diameter and will support a concentric load of 34 000 kg (75 000 lb).

Two rolling bridge cranes with a capacity of 45 400 kg(100 000 lb) are used to remove the chamber top and to insert large test articles.

The dual manlock provides easy access to the test articles as well as a means of transporting test crewmen to the test environment and back during manned tests. The manlock can also be used as an altitude chamber for independent tests. In addition, one manlock is equipped with a water deluge system and other features that permit its use for manned operations with oxygen-rich residual atmospheres.

A solar simulation array, mounted on the top head, is modular in design to facilitate changes in location and beam size to accommodate test requirements. The solar simulation modules are on-axis with xenon lamp sources. The source and collection optics are located outside the chamber, with the collimating optics inside the chamber. Solar incident angles other than vertical can be achieved by installing mirrors in the chamber to redirect the solar beam.
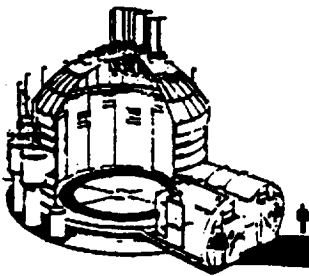
Chamber B

General Characteristics	Outside dimensions	10.7-m (35 ft) diameter by 13.1-m (43 ft) height
	Working dimensions	7.6-m (25 ft) diameter by 7.9-m (26 ft) height
	Test article weight	34 000 kg (75 000 lb) concentric load maximum
	Instrumentation	Real-time data acquisition and remote control
	Access	10.7-m (35 ft) diameter removable top head
		Dual manlock at floor level

Vacuum Systems	Types of pumps	Valved and trapped oil diffusion pumps and 20 K cryopumps
	Pumpdown time	5 hours to test conditions
	Pumping capacity	1×10^7 liters/sec condensibles and 2×10^5 liters/sec noncondensibles at 1.33×10^{-4} Pa (1×10^{-6} torr) pressure
		Note: Usual chamber inleakage less than 3×10^5 liters/sec of air at 1.33×10^{-4} Pa (1×10^{-6} torr) pressure
	Repressurization	Controllable from 90 sec minimum; chamber dryout using dry gas purge, and heated floor at vacuum

Chamber 5
Pumpdown Curve

Pressure, pascals

Time, hours
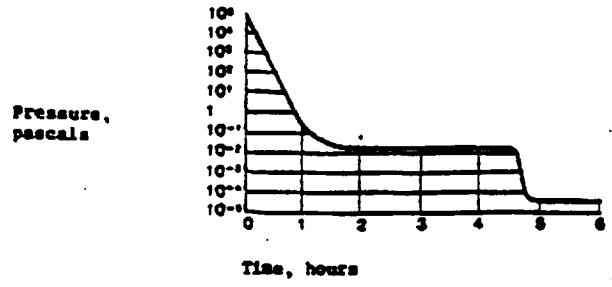
Heat Sink and Special thermal Simulators	Full chamber shroud	Subcooled 90 K LN_2 shroud
		130 000 W total heat absorption capacity
		1393 W/m (150 W/ft) maximum heat flux
	Wall emissivity	0.95
	Special simulators	Solar, albedo, and planetary radiation, as required

Solar   Top sun   1 to 19 xenon modules producing a 4-m (13 ft)
Simulation   diameter beam maximum; modules can be located
                                   anywhere within a 6.1-m (20 ft) diameter circle

                 Decollimation   90-min half angle
                 Intensity   622 to 1353 W/m (controllable)
                 Uniformity $\pm$5 percent measured with 930 -cm sensor
                 Measurement   Real-time traversing radiometer system

Spectrum of Xenon
Solar Simulator
Module

Spectral Irradiance, W/cm - m vs Wavelength, micrometers
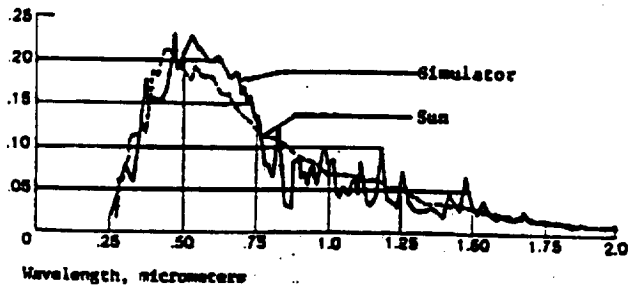
APPENDIX I
MOTOR ANALYSIS

MOTOR RANGE CALCULATIONS

SHAFT DIAMETER RANGES

$$\frac{1}{2}" \longrightarrow 1\frac{1}{2}"$$

SMALLEST $D = \frac{1}{2}"$

$C = 2\pi r$

$= 1.57"/rev$

rolling up material $4"/30$ sec
(mat'l. speed)

$$\approx \frac{.133"}{sec}$$

(rev/sec) rps $rev/sec = \dfrac{mat'l.\,speed\ (in/sec)}{Circumference\ (in/rev)}$

$$rps \approx \frac{4"/30\ sec}{4.7\ in/rev}$$

$$\approx .028\ rps \longrightarrow 1.7\ rpm$$

[SMALLEST]

LARGEST $D = 1\frac{1}{2}''$

$C = 2\pi r$
$= 4.7$ in/rev ✓

rolling (mat'l. speed) $\frac{1}{2}''/sec$
up
material $\approx .5''/sec$

rps $=$ mat'l speed
(rev/sec)   circumference

$$\frac{\frac{1}{2}''/sec}{1.57 \text{ in/rev}} = .32 rps$$

$.32 rps \longrightarrow 19.1$ rpm

MOTOR RPM RANGE : $\boxed{2 \longrightarrow 20 \text{ rpm}}$

APPENDIX J
SORT PROGRAM

```
10     LPRINT "Support","Shield","Move"
20     LET CNT=0
30     A=4
40     B=5
50     C=5
60     MAX=A*B*C
70     DIM M(MAX)
80     FOR I=0 TO (A-1)
90      FOR J=0 TO (B-1)
100      FOR K=1 TO C
110             COMB=I*25+J*5+K
120             LET M(COMB)=1
130             IF M(COMB)=1 THEN LPRINT (I+1),(J+1),K : LET CNT=CNT+1
140       NEXT K
150      NEXT J
160     NEXT I
170     LPRINT "ACCEPTABLY COMBINATIONS =";CNT
180     LPRINT
190     END
```

Support	Shield	Move
1	1	1
1	1	2
1	1	3
1	1	4
1	1	5
1	2	1
1	2	2
1	2	3
1	2	4
1	2	5
1	3	1
1	3	2
1	3	3
1	3	4
1	3	5
1	4	1
1	4	2
1	4	3
1	4	4
1	4	5
1	5	1
1	5	2
1	5	3
1	5	4
1	5	5
2	1	1
2	1	2
2	1	3
2	1	4
2	1	5
2	2	1
2	2	2
2	2	3
2	2	4
2	2	5
2	3	1
2	3	2
2	3	3
2	3	4
2	3	5
2	4	1
2	4	2
2	4	3
2	4	4
2	4	5

2	5	1
2	5	2
2	5	3
2	5	4
3	5	5
3	1	1
3	1	2
3	1·	3
3	1	4
3	1	5
3	2	1
3	2	2
3	2	3
3	2	4
3	3	5
3	3	1
3	3	2
3	3	3
3	4	4
3	4	5
3	4	1
3	4	2
3	5	3
3	5	4
3	5	5
4	1	1
4	1	2
4	1	3
4	1	4
4	2	5
4	2	1
4	2	2
4	2	3
4	3	4
4	3	5
4	3	1
4	3	2
4	4	3
4	4	4
4	4	5
4	4	1
4	5	2
4	5	3
4	5	4
4	5	5

ACCEPTABLY COMBINATIONS = 100

```
10        LPRINT "Support","Shield","Move"
20     `\ LET CNT=0
30        A=4
40        B=5
50        C=5
60        MAX=A*B*C
70        DIM M(MAX)
80        FOR I=0 TO (A-1)
90          FOR J=0 TO (B-1)
100           FOR K=1 TO C
110               COMB=I*25+J*5+K
120               LET M(COMB)=1
130               IF I=2 AND K=2 THEN LET M(COMB)=0
140 REM           "I" FRAME NOT SUITED FOR UNBALLANCED LOAD OF TROLLY CABLE
150               IF I=2 AND K=4 THEN LET M(COMB)=0
160 REM           "I" FRAME NOT SUITED FOR LARGE LOAD OF CLIMBING TRACK
170               IF J=0 THEN LET M(COMB)=0
180 REM           CAN'T ROLL UP MATERIAL WITH ATTACHED END SHEILD
190               IF M(COMB)=1 THEN LPRINT (I+1),(J+1),K : LET CNT=CNT+1
200           NEXT K
210         NEXT J
220       NEXT I
230       LPRINT "ACCEPTABLY COMBINATIONS =";CNT
240       LPRINT
250       END
```

Support	Shield	Move
1	2	1
1	2	2
1	2	3
1	2	4
1	2	5
1	3	1
1	3	2
1	3	3
1	3	4
1	3	5
1	4	1
1	4	2
1	4	3
1	4	4
1	4	5
1	5	1
1	5	2
1	5	3
1	5	4
1	5	5
2	2	1
2	2	2
2	2	3
2	2	4
2	2	5
2	3	1
2	3	2
2	3	3
2	3	4
2	3	5
2	4	1
2	4	2
2	4	3
2	4	4
2	4	5
2	5	1
2	5	2
2	5	3
2	5	4

2	5	5
3	2	1
3	2	3
3	3	5
3	3	1
3	4	3
3	4	5
3	4	1
3	5	3
3	5	5
3	5	1
4	2	3
4	2	5
4	2	1
4	2	2
4	3	3
4	3	4
4	3	5
4	3	1
4	4	2
4	4	3
4	4	4
4	4	5
4	5	1
4	5	2
4	5	3
4	5	4
4	5	5

ACCEPTABLY COMBINATIONS = 72

ERRATA SHEET
NASA/USRA Radiator Shade Project
Spring 1992

Correction #	Page #	Correction
1.	ii	title: "ACKNOWLEDGEMENTS" should read "ACKNOWLEDGMENTS"
2.	iii	first line: "ACKNOWLEDGEMENTS" should read "ACKNOWLEDGMENTS"
3.	iii	I. 1.4: "requirement" should read "requirements"
4.	iii	II. 2.2: "Alternate" should read "Alternatives"
5.	iv	II. 2.4: "Alternate" should read "Alternatives"
6.	iv	IV. 4.1.7: "Shad" should read "Shade"
7.	2	next to last paragraph second sentence: "is to" should be eliminated
8.	2	last line: "plan" should read "plane".
9.	12	2.1.3 first sentence: "articles" should read "article"
10.	13	last sentence: "...a radiator, a shade, (see Appendix A), certain criteria..." should read "...a radiator, a shade, and adjustment mechanisms for both shade width and arc length adjustments. Based on the project specifications (see Appendix A), certain criteria..."
11.	23	second to last line: "Scissors" should read "Scissor"
12.	24	one in each of the first three lines: "scissors" should read "scissor"
13.	33	Disadvantage 1.: "...absorbs heat trough..." should read "absorb heat through..."
14.	36	third line from end: "design" should read "designs"
15.	37	last sentence of first paragraph: "to" should read "too"
16.	37	first sentence of second paragraph: "combination" should read "combinations"
17.	40	first line: "adjust" should read "adjusts"
18.	40	seventh line: "direction" should be removed

Correction #	Page #	Correction
19.	50	last sentence: two spaces should precede "Ranking..."
20.	50	Table 5.1: "HangingShade" should read "Hanging Shade"
21.	51	second paragraph third line: two spaces should follow the period
22.	52	second paragraph third line: "Figure 6.1" should be followed by a period
23.	72	second paragraph first line: periods between "of" and "an" and also between "film" and "shade" should be replaced by spaces
24.	A-3	title block: "for Lunar Radiator Test Article" should be centered
25.	C-1	second to last line: "overlaied" should read "overlaid"
26.	C-8	fifth text line from the bottom: "neccisary" should read "necessary"
27.	C-12	last sentence: the last "a" should be removed.
28.	D-3	last sentence: should read "For 1/8 inch thickness, plot of deflection (vertical axis) -vs.- side length for symmetric angle aluminum."
29.	E-8	second to last sentence: first ")" should be removed