IN-44
77712
P-25

NASA Contractor Report 189132

Design and Optimization of a Self–Deploying Single Axis Tracking PV Array

Anthony J. Colozza
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

March 1992

Prepared for
Lewis Research Center
Under Contracts NAS3–25266

NASA
National Aeronautics and
Space Administration

Design and Optimization of a Self-Deploying Single Axis Tracking PV Array

Anthony J. Colozza

Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio 44142

Abstract

This study was performed in order to design a tracking PV array and optimize the design for maximum specific power. The design considerations were minimal deployment time, high reliability and small stowage volume. The array design was self-deployable, from a compact stowage configuration, using a passive pressurized gas deployment mechanism. The array structural components consist of a combination of beams, columns and cables used to deploy and orient a flexible PV blanket.

Each structural component of the design was analyzed to determine the size necessary to withstand the various forces it would be subjected to. An optimization was performed to determine the array dimensions and blanket geometry which produce the maximum specific power. The optimization was performed for both lunar and Martian environments with 4 types of PV blankets (silicon, GaAs/Ge, GaAs CLEFT and amorphous silicon). For the lunar environment the amorphous silicon array produced the highest specific power where as for Mars the GaAs CLEFT array produced the highest specific power. A comparison was made to a fixed PV tent array of similar design. The tracking array produced a higher specific power with all types PV blankets examined except amorphous silicon at both locations.

Introduction

The production of power is an integral part of any exploration mission. The success of a mission may depend solely on the operation of the power source. Solar energy conversion by photovoltaic (PV) cells has been well established as one of the leading choices for remote environment power production. To maximize the power production capability of the PV cells, it is necessary to track the sun, keeping the in coming solar radiation perpendicular to the PV cells. However, when the complete system is considered, tradeoffs arise between tracking systems and fixed array systems in the areas of mass, stowage volume, implementation time and reliability for operation.

The goal of this study was to design and analyze the performance of a PV tracking array and compare it to that of a fixed tent array of similar design[1]. The tracking array was designed to be self-deploying from a compact stowed configuration using a flexible PV blanket for power generation. Pressurized gas expansion was chosen as the deployment mechanism because it reduced complexity over a mechanical system.

The array was analyzed with various PV blankets to determine the optimum PV blanket shape and array dimensions. The optimization was performed to maximize the array specific power. The array design was based on the ability to meet the desired characteristics for a planetary surface based power system and to withstand the environmental conditions at the proposed location of operation, either the Moon or Mars. The surface environment can substantially influence the array performance and configuration. Therefore an array optimized for the lunar environment is different form one optimized for the Martian environment.

Structural Design

The tracking array structure must be able to support and orient the PV blanket along with the capabilities of autonomous deployment and compact stowage. Its design is based on the tent array structural design given in reference 1. It uses a combination of cables, beams and columns to support and deploy the PV blanket. The cables used to support the PV blanket are attached to I- beams. The beams are held in their proper orientation by columns, which also act as the deployment mechanism for the array. The columns consist of a series of hollow telescoping cylinders which lock into place once extended.

Deployment of the array is accomplished by the use of compressed gas released into the columns from a storage tank located at the base of the array. As the gas pressure in the columns increases they extend, raising the tracking portion of the array and deploying the PV blanket. The array is stowed with the blanket either folded or rolled, depending on the particular blanket's flexibility.

The roll-out storage technique is preferable because it allows for easier repackaging if the array needs to be returned to its stowed configuration. Further details on the deployment mechanism and sequence are presented in reference 1.

An artist's conception of the deployment sequence for the single axis tracking array is shown in figures 1a, 1b and 1c. The top and sides of the stowed array box have been omitted from these figures so the internal structure is visible.

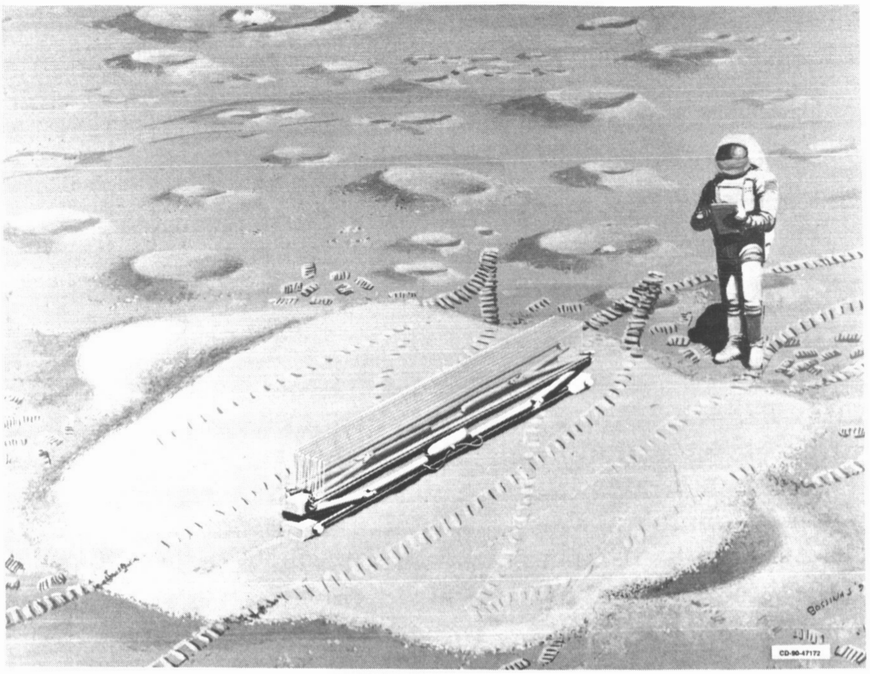
Analysis

The analysis took into account the various loadings on the structure and then determined the optimum component size necessary to withstand them. The structural loadings are dependent on the blanket and array geometry shown in figure A1 of the appendix. The analysis was performed with the array in the horizontal position, which is the orientation where the maximum structural loading is obtained. This orientation also simplifies the analysis since it produces a symmetry about the length of the array.

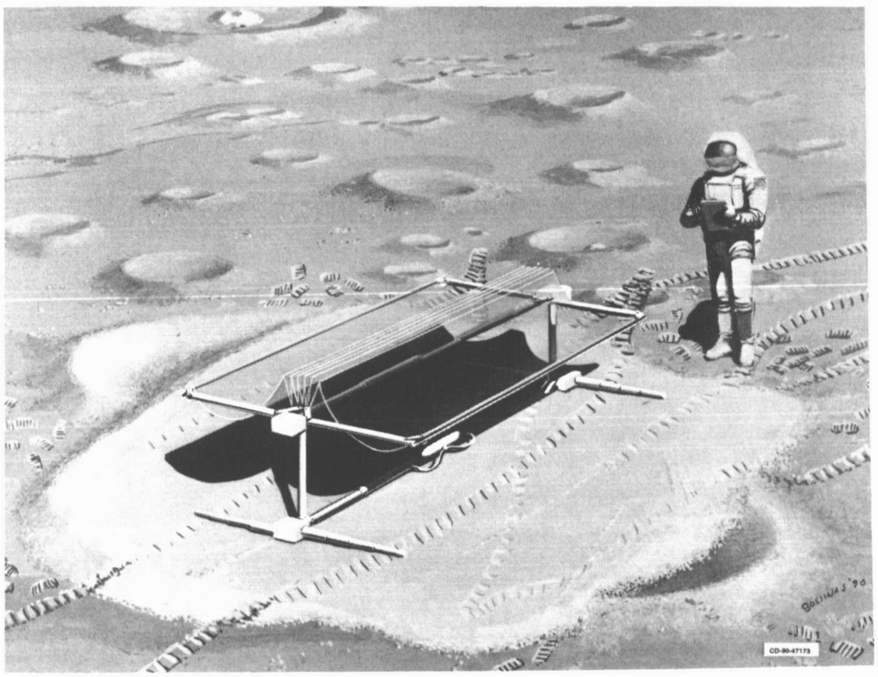
A detailed description of the structural analysis used to determine the component weights and dimensions for different array geometries is given in the appendix. To maximize the specific power (W/kg) of the array, the dimensions of the structure as well as the geometry of the PV blanket were iterated upon until a combination was found that produced the highest specific power. The variables were length and width of the array and end angle of the PV blanket. This optimization was performed with various types of structural materials and for four types of PV blankets in both the lunar and Martian environments. A list of the structural materials which were considered and their properties[2] are given in table 1. The four PV blankets which were considered are silicon, gallium arsenide over germanium, CLEFT gallium arsenide and amorphous silicon. These blankets represent either present day or near-term technology. The specifications for these blankets[3,4] are listed in table 2.

	Carbon VHS Composite	Aramid Fiber Composite	Aluminum	Magnesium
Modulus (GPa)	124	76	72	45
Yield Strength (GPa)	1.9	1.38	0.41	0.28
Density (kg/m3)	1530	1380	2800	1800

Table 1 Structural Material Properties

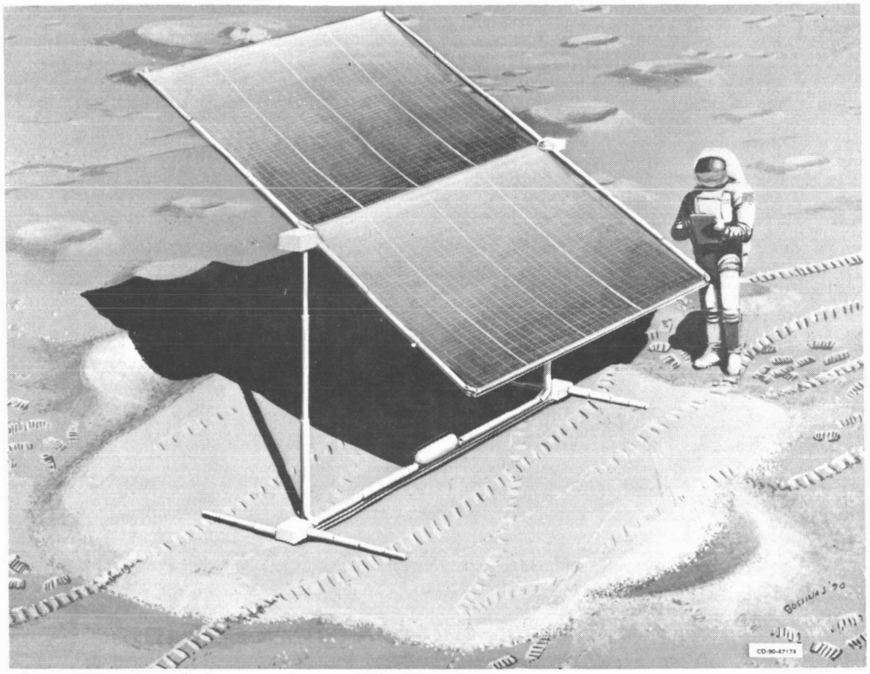


(a) Stowed configuration.



(b) Semi-deployed configuration.

Figure 1 Tracking array.



(c) Deployed configuration.

Figure 1 Concluded.

	Silicon	GaAs /Ge	GaAs CLEFT	Amorphous Silicon
Technology Status	Present Space Station Technology	Present	Near-term	Future
Efficiency (%)	14.5	19.5	20.0	10.0
Cell Thickness (μm)	250	~ 250	20	2
Blanket Specific Mass (kg/m2)	0.427	0.640	0.361	0.022

Table 2 PV Blanket Specifications

The structural loads occur from; wind loadings (Mars), the tension in the cables necessary to maintain a given blanket shape, and the force of gravity on the structure itself. For terrestrial applications, wind loadings are the dominant structural force. On Mars, however, the wind loadings are not as great, due to the substantially lower atmospheric density. On the Moon, where there is essentially no atmosphere, wind loadings are obviously not a concern. The cable tension, which is due to a combination of the desired blanket shape and the gravitational force, can be the driving structural force at locations where wind loadings are not severe. For the locations considered, the gravitational acceleration is as follow[5]: Mars, 3.75 m/s^2 and the Moon, 1.61 m/s^2. Each component of the array was sized to withstand the forces it would be exposed to. A nonsizeable component mass, estimated to be 8 kg, was used to account for such items as pressure lines, valves, column locking pins, tracking array sun sensor, array motor and drive shaft, pressurized seals and connection brackets for the columns and stowage box top and sides.

The PV blanket shape is determined by an optimization between cable tension and blanket area. Once the blanket shape is established, the optimum array dimensions can be found. The PV blanket shape and array dimension selected establish the array configuration or "design Point" which produces the maximum specific power under the given environmental conditions.

Results

The first step in the optimization process was to determine the PV blanket end angle, which designates the shape of the PV blanket. The end angle refers to the angle the PV blanket makes with the horizontal at the point where the PV blanket attaches to the array (angle θ_2 in figure A1). Once this angle is chosen the PV blanket curvature, which is based on a catenary curve, and therefore cable tension can be calculated for a particular size array. The PV blanket area was varied for different end angle values. The results for a Mars based array with

Aramid composite material, GaAs/Ge PV blanket, 20 m/sec wind velocity and a width of 6 m (see figure A1) is shown in figure 2. On each curve of this figure there is a PV blanket area which corresponds to a minimum structural specific mass value. As the end angle decreases these minimum points shift toward larger array areas and lower specific masses. The specific power for each of the minimum structural specific mass points was then calculated as shown in figure 3.

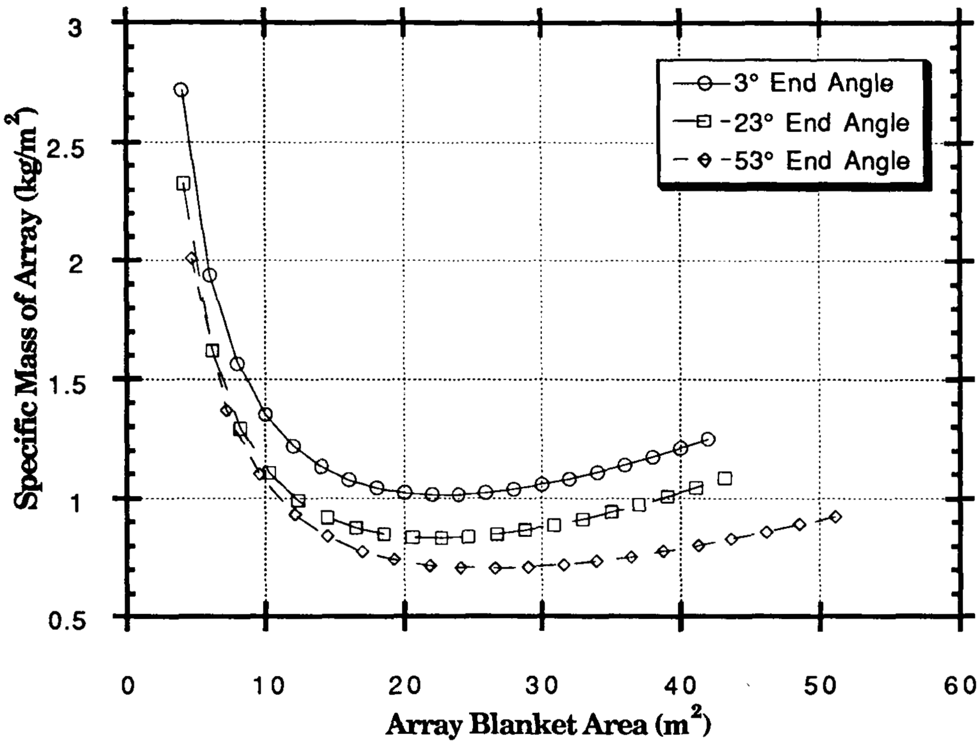


Figure 2 **Specific Mass for Various PV Blanket End Angles (Aramid Composite Material, GaAs/Ge Blanket and 20 m/s Wind Velocity)**

The value of 6 m for the array width was found (by iterations with various array sizes and end angles) to be the optimum for the Mars based array, as shown in figure 4. This curve corresponds to the minimum specific mass point of the 23° end angle curve in figure 2. Figures 2, 3 and 4 are the final result of a long iterative process to determine the array dimensions and blanket geometry which maximize the array specific power. The same optimization procedure was performed for the array within the lunar environment. In the lunar case the end angle optimized at 15° and the width optimized at 8 m.

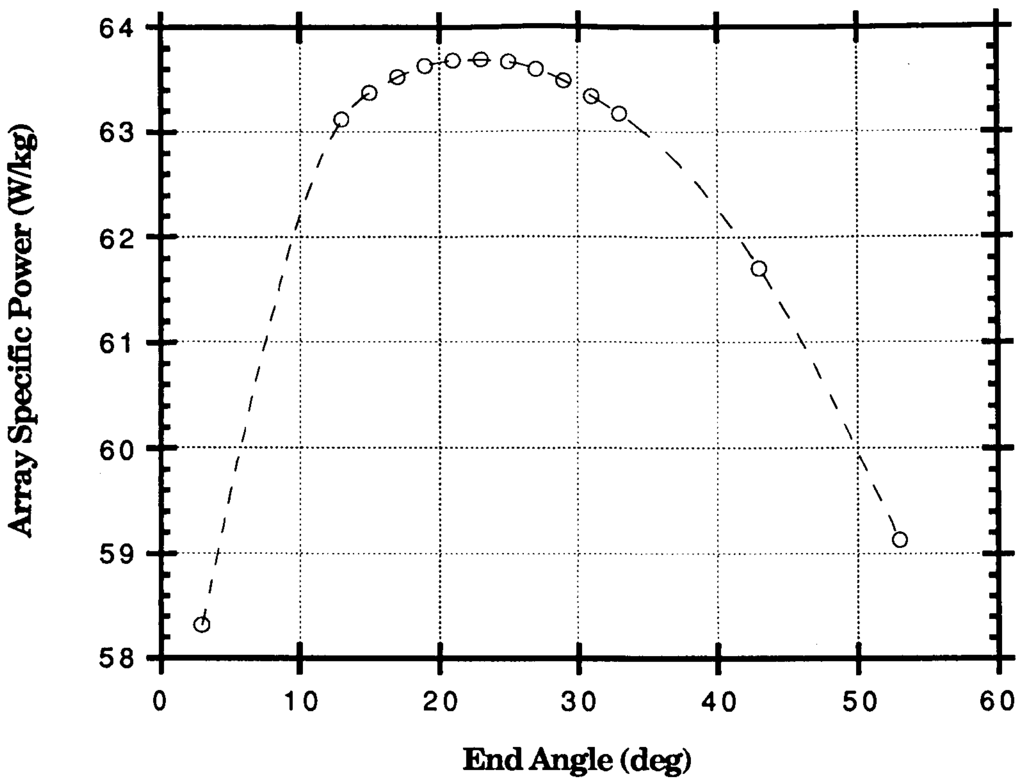


Figure 3 **Specific Power Curve for Mars PV Tracking Array at Minimum Specific Mass Points**

The array dimensions and blanket geometry, obtained from figures 2,3 and 4, which give the maximum specific power for the array are designated as "design points" for the array. The graphs presented so far are based on arrays which use Aramid fibers as the structural material, a GaAs/Ge cell PV blanket and a wind velocity of 20 m/s.

To determine what effect changing structural materials has on the design point, array specific mass was calculated for four different structural materials over a range of array sizes. The data for the Mars tracking array is shown in figure 5. These curves are based on an array with a 23° end angle and a width of 6 m. By examining these curves it should be noted that the minimum points vary somewhat with different materials. Therefore the design points are dependent on the type of structural material used. Throughout this study Aramid fiber composite was used as the baseline structural material. Of the materials examined, it produced the lowest array specific mass.

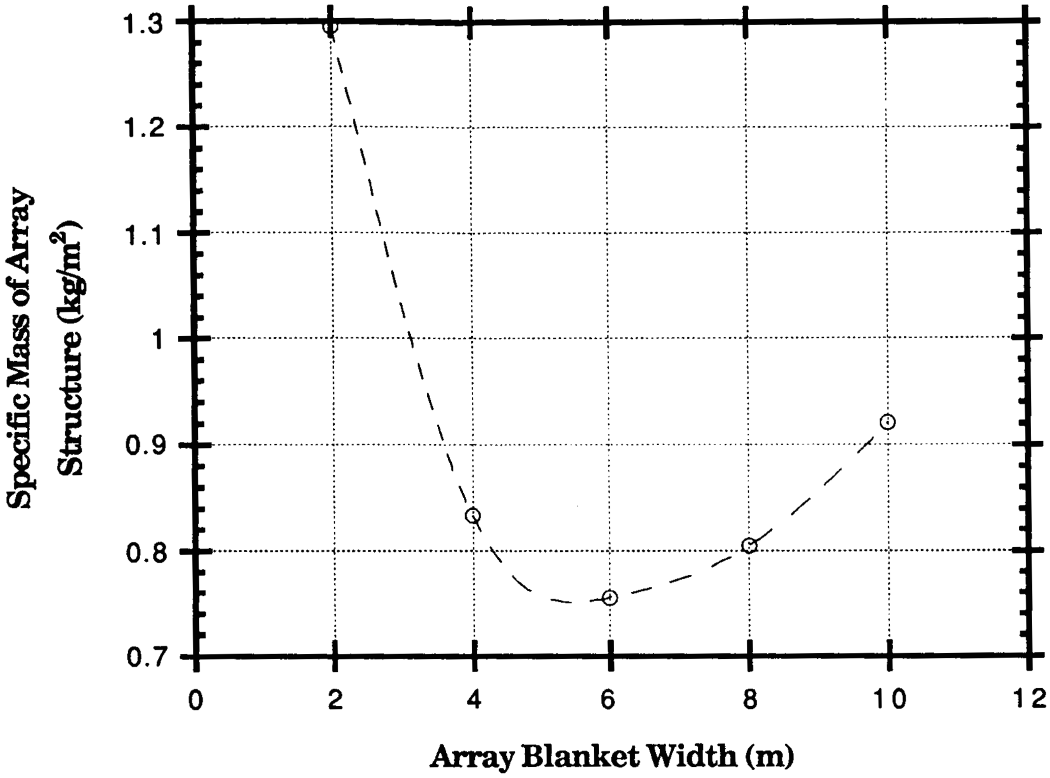


Figure 4 Specific Mass for Various Array Widths (23° End Angle, Arimid Composit Material, GaAs/Ge PV Blanket and 20 m/s Wind Velocity)

There are two parameters associated with the PV blanket which have an influence on the analysis results. These are its specific mass (kg/m^2) and its energy conversion efficiency (% at Air Mass Zero). The specific mass of the blanket directly affects the tension in the blanket support cables, thereby influencing the structural sizing. To determine what effect a change in blanket weight has on the design points, array specific masses for various types of PV blankets were calculated over a range of array sizes. Results are shown in figure 6. From this figure it can be seen that the minimum specific mass point is not dependent on blanket type. The energy conversion efficiency is used only to determine an absolute value for the specific power of the array. Since this does not effect the structural sizing and is used only as a means of estimating the overall performance of the array fitted with a particular PV blanket, it will not influence the design point.

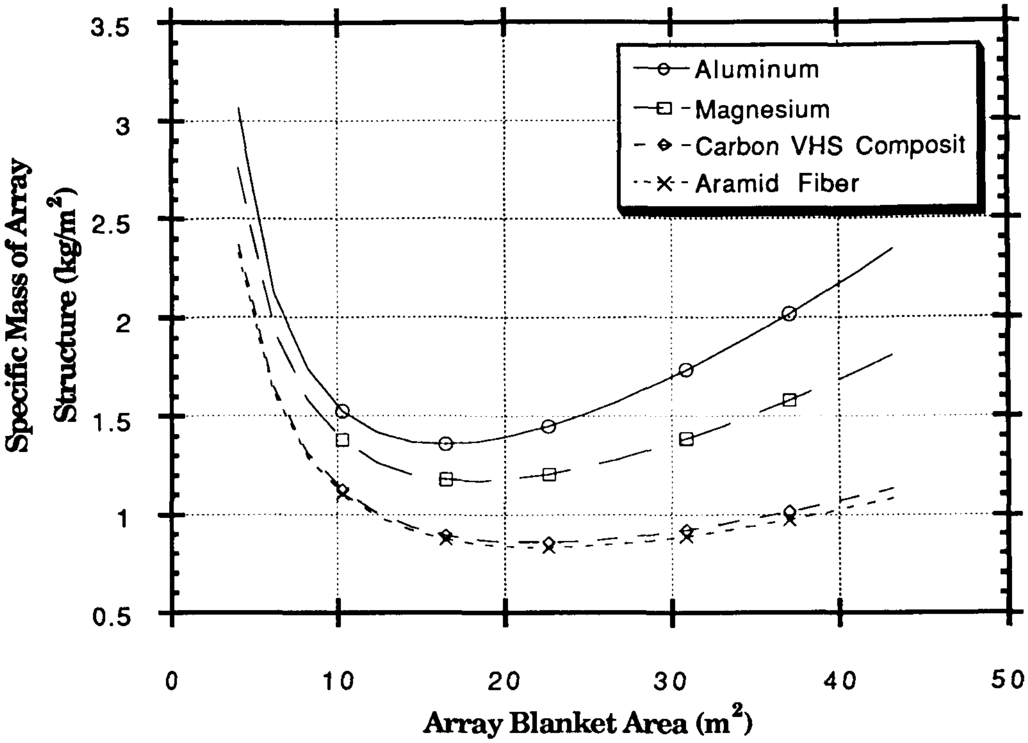


Figure 5 **Array Specific Mass for Various Structural Materials (23° End Angle, GaAs/Ge Blanket, 20 m/s Wind Velocity and 6 m Width)**

The last parameter examined was wind loading. This factor, of course, only pertains to the Mars based array. Array specific mass for a number of wind loadings over a range of array sizes is shown in figure 7. It was determined that variations in wind loading did not effect the design point. However, they do alter the actual value of array specific mass, and therefore array specific power (W/kg) for a given PV blanket.

Once the design points were established, calculations were made to determine the performance specifications of the array with each type of PV blanket. The design points, for both lunar and Mars arrays, are given in table 3. The performance specifications for all array/PV blanket type combinations are given in tables 4 and 5.

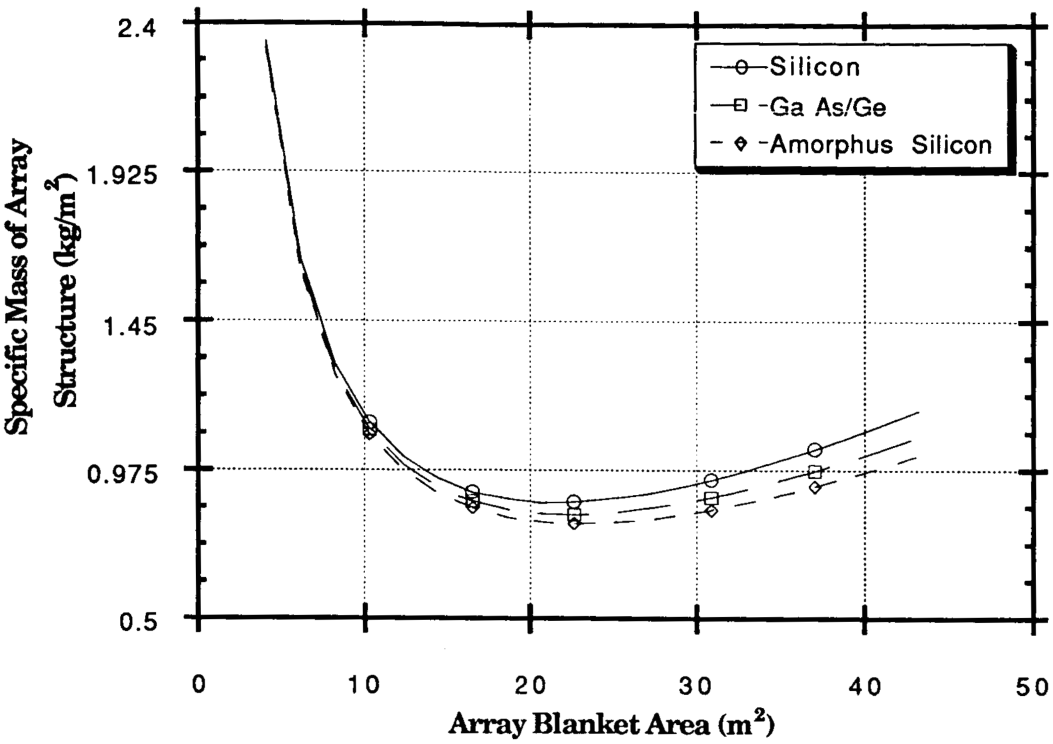


Figure 6 **Array Specific Mass for Various Types of PV Blankets (23° End Angle, Aramid Composit Material, 20 m/s Wind Velocity and 5 m Width)**

	lunar Based	Mars Based
End Angle	15°	23°
Array Width (m)	8.00	6.00
Blanket Length (m)	6.07	5.66
Blanket Area (m^2)	48.57	33.96

Table 3 Geometry Characteristics for Array Design Points

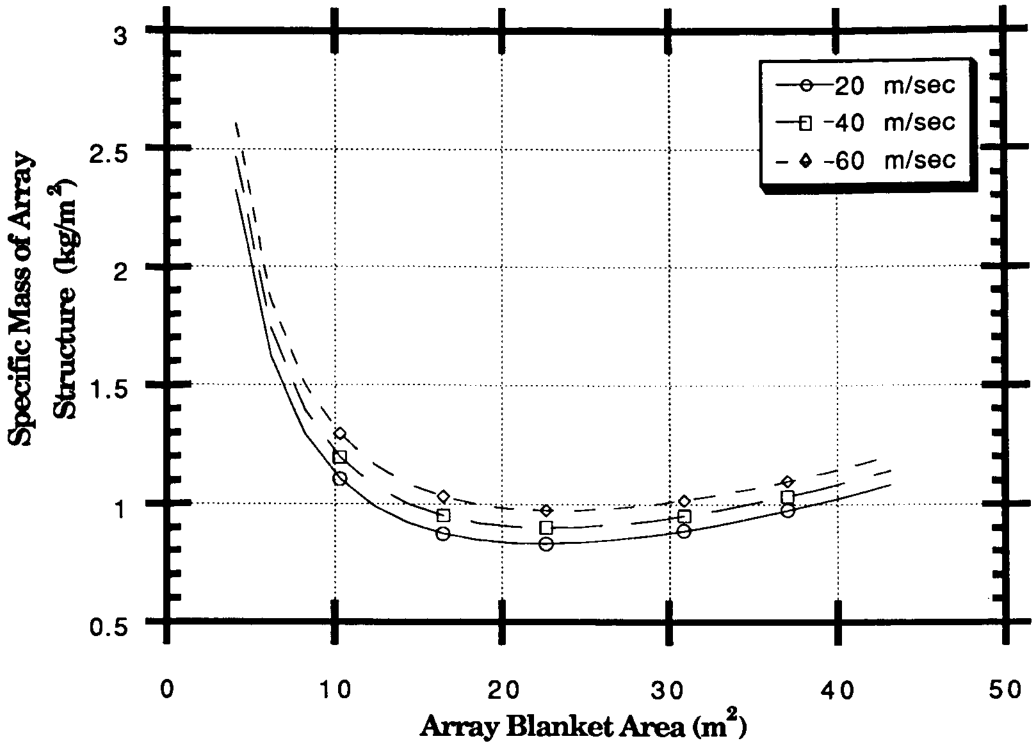


Figure 7 **Array Specific Mass for Various Wind Velocities (23° End Angle, Aramid Composit Material, GaAs/Ge Blanket and 5 m Width)**

PV Cell Type	Silicon	GaAs/Ge	GaAs CLEFT	Amorphous Silicon
Structure Mass (kg)	26.15	28.13	25.44	19.43
Blanket Mass (kg)	20.73	31.09	17.53	1.07
Total Mass (kg)	46.88	59.22	42.97	20.50
Structure Specific Mass (kg/m^2)	0.54	0.58	0.52	0.40
Array Total Specific Mass (kg/m^2)	0.93	1.22	0.89	0.42
Average Output Power (kW)	9.43	12.68	13.01	6.50
Array Specific Power (W/kg)	201.15	214.15	302.70	317.26

Table 4 Performance Results for lunar Tracking Array

PV Cell Type	Silicon	GaAs/Ge	GaAs CLEFT	Amorphous Silicon
Structure Mass (kg)	24.71	25.66	24.40	22.49
Blanket Mass (kg)	14.50	21.72	12.26	0.75
Total Mass (kg)	39.20	47.40	36.66	23.23
Structure Specific Mass (kg/m^2)	0.73	0.76	0.72	0.66
Array Total Specific Mass (kg/m^2)	1.15	1.40	1.08	0.68
Average Output Power (kW)	2.37	3.19	3.27	1.03
Array Specific Power (W/kg)	60.44	67.27	89.15	70.39

Table 5 Performance Results for Mars Tracking Array

Tent and Tracking Array Comparison

When comparing a tracking array to a fixed array, the performance specifications as well as any accompanying system's characteristics and constraints must be taken into consideration. Both tracking and fixed tent arrays have advantages and disadvantages with regard to the perceived requirements for a planetary surface power system. Examples of these would be, the tracking array produces the highest amount of power per PV blanket area, whereas the fixed tent array, once deployed, has a very high reliability for operation since it is a passive system. When other components of the power system, such as power management and distribution equipment or energy storage devices are considered, it is desirable to have a flat or constant output power level from the PV array. A tracking system's output power curve is constant throughout the day. For a fixed tent array, a tent angle of 60° is needed to minimize output power variation over a day cycle.[1] With this tent angle the power variation throughout a day is 15%. However, if total daily power is more of a concern then the variation of output power, the tent array's daily power output can be increased by using a lower tent angle such as 45° or 30° at the expense of increased daily power variation.[1]

Since both the tent and tracking array's structural components and deployment mechanism are similar, a comparison between their performance specifications can be made. The comparable results for both the lunar and Martian environments are given in figures 8 and 9 respectively. These results are based on array dimensions and PV blanket geometry which maximized specific power. Aramid fiber composite was used as the structural material for both array types.

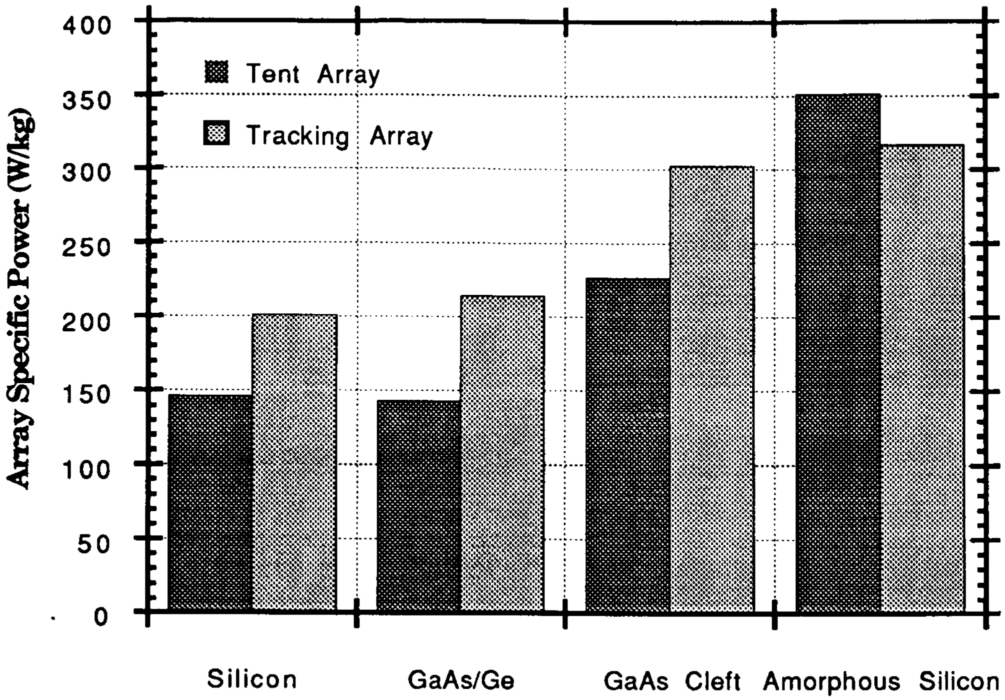


Figure 8 Comparison of Tent and Tracking Array Performance for the Lunar Environment

The array specific power values show that for the tracking array, in both the lunar and Martian environments, there is an increase in array specific power over that of the tent array for 3 of the 4 PV blankets examined. The amorphous silicon blanket is the only one where the specific power of the tent array is higher then that of the tracking array. The properties of the PV blankets given in table 2 show that the amorphous silicon blanket has a substantially lower specific mass than the other blankets. Therefore the actual weight of the blanket is incidental in the overall mass of the array. So a tent array, which uses a substantially larger blanket area then a comparably powered tracking array, does not pay much of a mass penalty for the additional blanket area or for the structure needed to support it. Where as, the tracking array which has inherently more structural mass per unit area of PV blanket, does not benefit as much by using lighter weight, lower efficiency PV blankets.

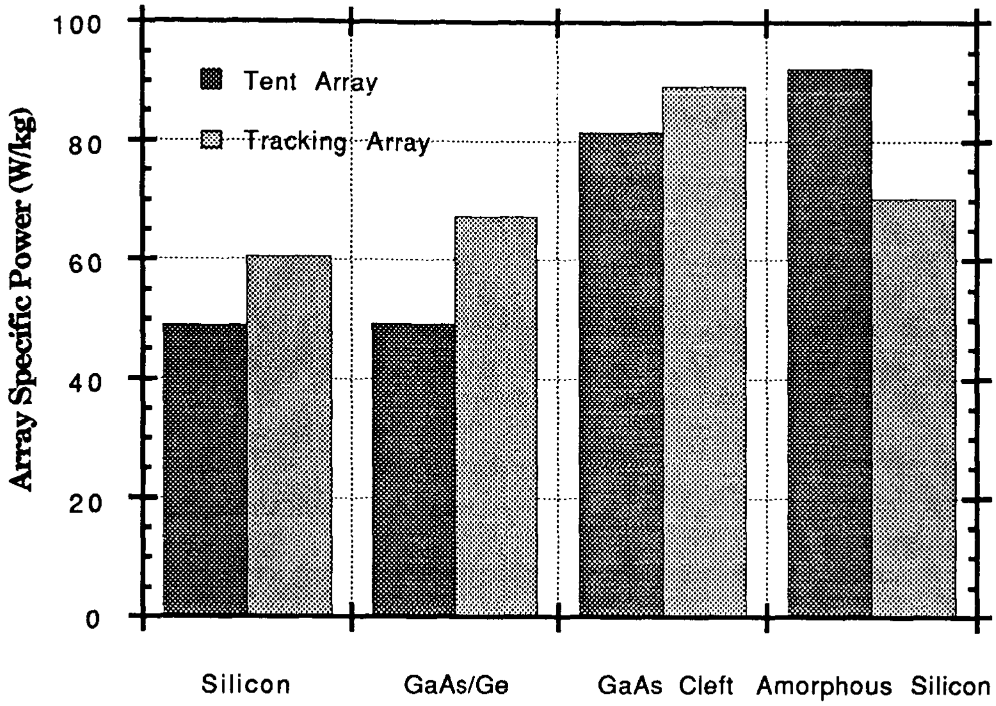


Figure 9 **Comparison of Tent and Tracking Array Performance for Martian Environment**

Conclusion and Observations

The assumptions or approximations which were made throughout the analysis can have varying effects on the results which were obtained. For example the structural analysis results (design points) are not very sensitive to any moderate change in the assumptions, whereas the array performance specifications, such as specific power, can be significantly affected.

The electrical power calculation was based on the normal component of solar radiation falling on the projected blanket area. The analysis did not include reflected radiation or the thermal variation of the PV blanket. These two factors could alter the calculated output power of the array. However, it should be noted that the thermal variation of the blanket would tend to reduce the PV cell efficiency, while the reflected sunlight from the surroundings would increase the array output. Also the interaction between the blanket cover glass and the solar radiation can also affect the power output. At high solar incidence angles most of the solar radiation is reflected. The amount of radiation reflected in this manner through a day cycle depends on both the cover glass properties and the blanket configuration.

There are other PV blanket characteristics, such as PV cell packing factor and blanket tensile strength, which can affect the structural design and array specifications. On most PV blankets the cell packing factor is fairly high, therefore, this should not substantially degrade the assumed blanket performance. The actual strength of the blanket can be a design consideration, since the cables are spaced every 0.5 m and the PV blanket would have to support its own weight between the cables. For the Mars based arrays, this issue is compounded by the force exerted on the PV blanket by the wind. For very fragile PV blankets such as amorphous silicon, it is very likely that some form of backing material would have to be used to help support the blanket.

The configuration of the array which produced the maximum specific power was dependent on blanket end angle, array dimensions and structural material. Other factors such as blanket type and (for Mars) wind velocity, only affected the array performance specifications but did not change the design point.

The comparison between the tent and tracking arrays has shown that, except for very light PV blankets, the tracking array produces a higher specific power under comparable environmental conditions. Both types of arrays, however, have their advantages and disadvantages and the performance difference between them is not that great. The choice of which type of array to use depends on the particular mission's priorities and requirements. If a tracking array is desired, the array design presented in this study has the characteristics, of small storage volume, passive deployment mechanism and high estimated performance, which enable it to be applicable to a wide variety of missions.

Appendix

A	Blanket Area, m^2	T_1	Tension in Cable at Point 1, N
A_{be}	Beam Cross Sectional Area, m^2	T_2	Tension in Cable at Point 2, N
b	Beam width, m	v	Velocity, m/s^2
c	Catenary Curve Constant, m	V_{tank}	Pressurized Gas Tank Volume, m^3
C_l	Lift Coefficient	V_{total}	Total System Gas Volume, m^3
E	Young's Modulus of Elasticity, Pa	w_b	Distributed Load on Beam, N/m
F	Applied Force, N	w_c	Distributed Weight of PV Blanket Per Cable, N/m
h	Beam Height, m	x_1	Horizontal Coordinate of pt. 1, m
I	Moment of Inertia, m^4	x_2	Horizontal Coordinate of pt. 2, m
L	Straight Line Length Between PV Blanket Points 1 and 2, m	y_1	Vertical Coordinate of pt. 1, m
L_b	Length of Beam, m	y_2	Vertical Coordinate of pt. 2, m
L_{hc}	Length of Horizontal Column, m	α	Angle of Incident Solar Radiation
L_{vc}	Length of Vertical Column, m	β	Solar Elevation Angle
m_{tr}	Mass of Tracking Portion of Array, kg	ε	Maximum Beam Bending, m
P	Pressure, Pa	η_{sc}	Solar Cell Efficiency, %
P_o	Array Output Power, W	θ	Angle of Blanket Normal to Horizontal
R_e	Reynolds Number		
r_i	Inner Radius, m	θ_2	Blanket End Angle at pt. 2
r_o	Outer Radius, m	ρ	Density, kg/m^3
SI	Solar Intensity, W/m^2	σ	Stress, Pa
s_2	PV Blanket Length from Axis to pt. 2, m	τ	Atmospheric Attenuation Factor
t	Thickness, m		

Array Structural Analysis

The array structure is composed of beams, columns, cables, a pressurized gas tank and various other components such as pressure lines and movable brackets. Drawings showing the array and certain components are given in figure 1 in the main text. The size of each component was determined by calculating the moment of inertia required to withstand the various forces acting on that component. A factor of safety of 2 was incorporated into the component designs, except for the pressurized gas tank, where a factor of safety of 2.5 was used.

The main contribution to the stress in the structure is due to the tension in the cables which support the PV blanket. It was assumed that the cables would be incorporated within the array blanket and spaced every 0.5 m. Under the force of gravity a cable carrying a uniformly distributed load will take the shape of a catenary curve. The array was analyzed with the tracking portion in the horizontal position. This orientation produces the maximum cable tension and therefore maximum structural loading. In the horizontal configuration the blanket shape will be symmetrical about the centerline of the array. A diagram of the blanket geometry is shown in figure A1. The following equations are used to model the blanket as well as determine the tension in the support cables.

$$s_2 = c\ \mathrm{Sinh}\left(\frac{x_2}{c}\right) \qquad 1a$$

$$\theta_2 = \tan^{-1}\left(\frac{s_2}{c}\right) \qquad 2a$$

$$y_2 = \sqrt{c^2 + s_2^2} \qquad 3a$$

$$T_2 = w_c\, y_2 \qquad 4a$$

The components of tension from each cable contribute to the horizontal and vertical forces seen by the beam on which they are attached. Using the tension values as point loads along the beam, the required moment of inertia and hence size of the beam can be calculated. An I-beam shape was assumed, of which the expression for the moment of inertia is:

$$I = \frac{2bt^3 + th^3}{12} + bt(t + h)^2 \qquad 5a$$

where b,t and h are dimensions of the I-beam and are defined by figure A2.

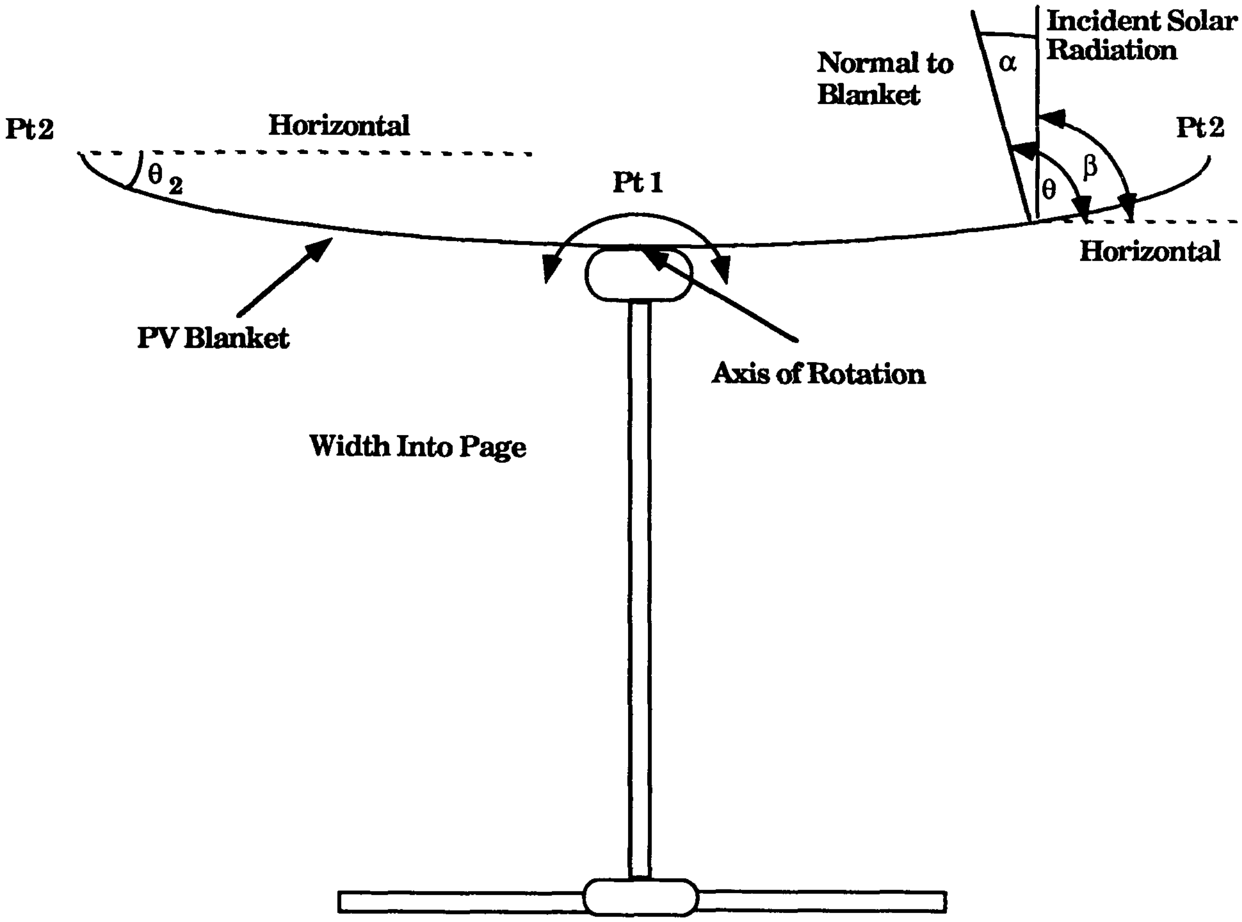


Figure A1 Tracking Array, PV Blanket and Solar Radiation Geometry

Various combinations of b,t and h can be used to obtain a given value of I. However to minimize mass one would like to choose the dimensions so that the minimum cross-sectional area is used while still maintaining the desired moment of inertia value. For a h/t ratio of 16 the minimum area for a given I value is:

$$A_{be} = \frac{I}{289.16\, t^2} + 12.82t^2 \qquad 6a$$

$$t = 0.128\, I^{.25} \qquad 7a$$

The required I value is obtained by selecting a maximum beam bending value and solving the following beam deflection equation.

$$I = \frac{5\left(\frac{L_b}{2}\right)^4 w_b}{384E\varepsilon} \qquad 8a$$

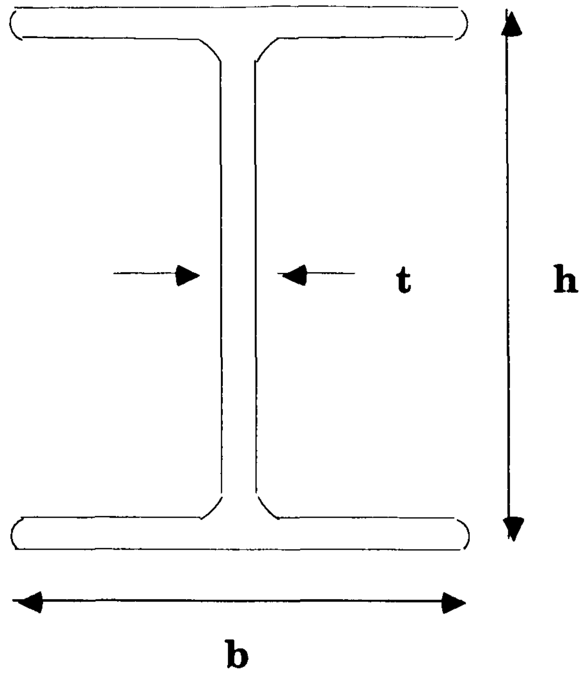


Figure A2 I - Beam Dimensions

where the maximum allowed beam bending ε was set at 0.01 m. Solving this equation yields the required dimensions and therefore weight of the horizontal beams. To minimize mass it is also assumed the beams would be oriented so that the tension is applied axially through the center of the beam.

The columns consist of a series of telescoping tubes which lock into place once fully extended. The columns are used as part of the base structure, the main supports for the tracking portion of the array and to support the beams on which the PV blanket is attached. These different positions produce different loadings and therefore different requirements for the columns. The vertical columns will experience compressive loads as well as a bending moment induced by the rotation of the tracking portion of the array. The columns used to support the blanket attachment beams must be capable of withstanding various combinations of compressive and bending loads due to the tracking motion of the array. The base columns, used to support and stabilize the array, will only experience bending loads due to the tracking motion of the array and wind loadings on Mars. Moment of inertia values necessary to withstand the various loadings were calculated for each column. The columns were then sized to accommodate the moment of inertia value necessary to withstand the forces exerted on it. The equations for the compressive and bending moment of inertia values are as follows:

For Compression $$I = \frac{F L_{vc}^2}{\pi^2 E} \qquad \text{9a}$$

For Bending $$I = \frac{FL_{hc}^3}{3E\varepsilon} \quad \text{10a}$$

The force exerted on the structure due to the acceleration and deceleration of the tracking portion of the array is given by:

$$F = 0.0175 m_{tr} L \quad \text{11a}$$

The maximum array rotational velocity was set at 2° per second with a deceleration time of 1 second from the maximum velocity to zero. This produces an angular acceleration of 0.035 rad/sec^2.

To aid in supporting the vertical columns from bending, Guy wires are attached to the top of the column and secured to the ground.The weight of using these wires is substantially less then that of columns structurally rigid enough to withstand the various bending moments they may be subjected to. After the necessary moment of inertia was determined, the column dimensions were calculated using the following equation:

$$I = \frac{\pi}{4}\left(r_o^4 - r_i^4\right) \quad \text{12a}$$

The column thickness was chosen to be 0.001 m.

Pressurized gas is used to extend the columns to deploy the array. The gas is stored in a tank which is connected to the columns by valves and pressure lines. As the array is deployed the total volume occupied by the gas increases and the pressure of the gas decreases. The initial gas pressure must be sufficient to overcome the greatest force on the columns while the gas occupies the total volume of the tank, lines and columns. The tank size was set at 0.5 m long with a 0.1 m inner radius. The tank thickness was calculated so that it could accommodate the required pressure. The equation for tank thickness is as follows:

$$t = \frac{P r_i}{\sigma} \quad \text{13a}$$

$$P = \frac{F V_{total}}{\pi r_i^2 V_{tank}} \quad \text{14a}$$

The dimensions and weight of the beam used to support the pressurized gas tank and initial deployment columns are calculated in the same manner as those for the beams used to support the PV blanket.

The array structural analysis given above was based on lunar surface conditions. To adapt the analysis to Mars, different environmental conditions must be incorporated into the calculations. These include an increase in gravitational field strength and the addition of wind loadings due to the Martian atmosphere. The increase in gravitational field strength requires the various structural components to withstand greater forces, thereby increasing their size and hence mass. The wind loading on a structure can greatly increase the structural component sizing. The average wind velocity on Mars is 6 to 8 m/s. [5] The design wind velocity for the arrays was 20 m/s. This was chosen since 99.9% of the winds experienced on Mars are below 20 m/s. [5] The wind will generate its largest force on the structure when it is oriented along the length of the array. In this situation the blanket would act as a sail. For an optimum wind angle of attack of 15°, and considering a low Reynolds number flow ($Re \leq 10^5$), the assumed maximum lift coefficient (C_l) is 1.5. The ideal conditions necessary to produce a lift coefficient for the blanket of 1.5 would be very rare. The equation which describes the force exerted on the structure by the wind is:

$$F = 0.5\,\rho\,v^2\,A\,C_l \qquad \text{15a}$$

The force is assumed to be exerted downward on the array, thereby adding to the gravitational and tension forces.

The specific power (W/kg) of the array was calculated with each type of PV blanket in order to enable an accurate comparison of performance between the arrays. The approximate power profiles which are used to determine the specific power of each array are based on incident solar radiation. The power profiles are considered approximate, because factors such as reflected radiation and the blanket thermal profile have been neglected. Also, the analysis assumes that the array axis is perpendicular to the incident solar radiation. In other words, as the array tracks the sun the incident radiation remains perpendicular to the plane of the array.

For the purposes of this study, however, the approximate power profiles are sufficient for calculating the performance of the array with the various PV blankets. An in-depth power analysis may change the absolute specific power values but the trends should remain as reported.

The power profile was generated by:

$$P_o = \eta_{sc}\,\tau\,A\,SI\cos\alpha \qquad \text{16a}$$

$$\alpha = |\theta - \beta| \qquad \text{17a}$$

Where the value of τ for the Moon is 1 since there is no atmosphere and it is assumed to be 0.85 for Mars. A diagram showing the incident solar radiation angle and blanket geometry is shown in figure A1.

References

1. Colozza, A.J., "Design, Optimization and Analysis of a Self-Deploying PV Tent Array," NASA CR-187119, June 1991.

2. Lovell, D.R., "Carbon Fiber Composite Reciprocating Guide Bar," Carbon Fibers, Technology, Uses and Prospects, The Plastic and Rubber Institute, London, England, 1986, pp 176-182.

3. Piszczor, M., "Specifications of Various PV Blankets," Internal Report, Photovoltaic Branch NASA Lewis Research Center, June 1990.

4. Hawak, J.J., Fulton, C., Myutt, A., Nath, P. and Woodyard, J.R., "Ultra-light Amorphous Silicon Alloy Photovoltaic Modules for Space and Terrestrial Applications," IECEC Paper # 869329, 1986.

5. "Space and Planetary Environmental Criteria Guidelines for Use in Space Vehicle Development," NASA TM-78119, 1977 Revision.

6. Gaier, J.R., Perez-Davis, M.E. and Marabito, M., "Aeolian Removal of Dust from Photovoltaic Surfaces on Mars," NASA TM-102507, February 1990.

7. Appelbaum, J. and Flood, D.J., "Photovoltaic Power System Operation in the Mars Environment," NASA TM-102075, August, 1989.

8. Allen, D.H. and Haisler, W.E., Introduction to Aerospace Structural Analysis, John Wiley and Sons, New York, 1985.

9. Appelbaum, J. and Flood, D.J., "The Mars Climate for a Photovoltaic System Operation," NASA TM-101994, June, 1989.

10. Beer, F.P. and Johnston, E.R.Jr., Vector Mechanics for Engineers, Statics and Dynamics, McGraw-Hill, New York, 1984.

11. Beer,F.P. and Johnston, E.R.Jr., Mechanics of Materials, McGraw-Hill, New York, 1981.

12. Iles, P.A., Ho, F., Yeh, M., Datum, G. and Billets, S., "Gallium Arsenide-on -Germanium Solar Cells," IECEC Paper # 899223, 1989.

13. Rauscherbach, H.S., Solar Cell Array Design Handbook, Van Nostrand Reinhold, New York.

14. Winslow, C., Bilger, K. and Baraona, C., "Space Station Freedom Solar Array Design Development," IECEC Paper # 899272, 1989.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1992	Final Contractor Report

4. TITLE AND SUBTITLE

Design and Optimization of a Self-Deploying Single Axis Tracking PV Array

5. FUNDING NUMBERS

WU-591-14-11
C-NAS3-25266

6. AUTHOR(S)

Anthony J. Colozza

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Sverdrup Technology, Inc.
Lewis Research Center Group
2001 Aerospace Parkway
Brook Park, Ohio 44142

8. PERFORMING ORGANIZATION REPORT NUMBER

E-6911

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR-189132

11. SUPPLEMENTARY NOTES

Project Manager, David J. Bents, Power Technology Division, NASA Lewis Research Center, (216) 433-6135.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories 44 and 91

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study was performed in order to design a tracking PV array and optimize the design for maximum specific power. The design considerations were minimal deployment time, high reliability and small stowage volume. The array design was self-deployable, from a compact stowage configuration, using a passive pressurized gas deployment mechanism. The array structural components consist of a combination of beams, columns and cables used to deploy and orient a flexible PV blanket. Each structural component of the design was analyzed to determine the size necessary to withstand the various forces it would be subjected to. An optimization was performed to determine the array dimensions and blanket geometry which produce the maximum specific power. The optimization was performed for both lunar and Martian environments with 4 types of PV blankets (silicon, GaAs/Ge, GaAs CLEFT and amorphous silicon). For the lunar environment the amorphous silicon array produced the highest specific power where as for Mars the GaAs CLEFT array produced the highest specific power. A comparison was made to a fixed PV tent array of similar design. The tracking array produced a higher specific power with all types PV blankets examined except amorphous silicon at both locations.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Solar generators; Solar arrays; Structural design	24
	16. PRICE CODE
	A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	