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Space Station Freedom Solar Array Design Development

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ABSTRACT
The Space Station Freedom Solar Array Program is required to provide a 75 kW power module that uses eight solar array (SA) wings over a four-year period in low Earth orbit (LEO). Each wing will be capable of providing 23.4 kW at the 4-year design point. LMSC is providing the flexible substrate SAs that must survive exposure to the space environment, including atomic oxygen, for an operating life of fifteen years. Trade studies and development testing, important for evolving any design to maturity, are presently underway at Lockheed Missiles & Space Company, Inc. (LMSC) on the flexible solar array. The trade study and development areas being investigated include solar cell module size, solar cell weld pads, panel stiffener frames, materials inherently resistant to atomic oxygen, and weight reduction design alternatives.

INTRODUCTION
Producibility and ease of replacement of damaged portions of the approximately 14.2 ft long SA panel during fabrication are the primary reasons for investigation of solar cell module size and dual n-type solar cell weld pad designs. Design optimization in both of these areas will reduce the labor hours associated with fabrication and rework (replacing broken solar cells) of the SA panels. Stiffener frame selection will be based on a cost/weight analysis. Candidate materials that are inherently resistant to atomic oxygen are being investigated as a backup to the baseline thin-film SiO₂ protection for the Kapton® substrate.

Alternative designs considerations to reduce SA wing weight include thinner solar cells, changing containment box and mast canister material from aluminum to graphite epoxy, using motors specifically designed for each task, and a combination of containment box and cradle latching mechanisms for launch and assembly.

The development test program will support the preliminary and final designs. Several subcontractors will support the above effort in the development of the designs for the solar cell assembly, the bypass diode, the Kapton film coated for AO protection, the collable longeron wing extension mast canister, the motor drive assembly (MDA), and the flat collector circuit. The test program emphasizes support for those aspects of the array wing design that are different from the SAFE array and other LMSC flexible SA programs. The test program will also aid in providing confidence that the fifteen-year array operating life requirement in LEO can be met. This paper briefly summarizes the array baseline design and describes the trade studies and development testing currently underway at LMSC.

DESIGN REQUIREMENTS
The major design requirements are shown in Figure 1. The fifteen-year on orbit operation life requirement and the large size of the SSF array wings present the major design challenges. Several other challenges are depicted in Figure 2.

Fig. 1 Space Station Array Design Requirements

BASELINE DESIGN
In the early 1970s basic design decisions were made on how to best approach the design of solar arrays capable of producing hundreds of kilowatts. Low weight, low launch volume, adequate deployed structural stiffness, fifteen-year temperature cycle life for the extended array, and adaptability of low-cost automated assembly were the key considerations. Current
Fig. 2 Space Station Freedom Technical and Program Challenges

designs reflect mature technology that has been developed and demonstrated while the basic concept remains unchanged. The technology used on the Space Station Freedom Solar Array (SSFSA) design is based largely on the Solar Array Flight Experiment (SAFE), while taking advantage of advances in large area solar cell design and adding protection for the array from the LEO atomic oxygen (AO) environment.

The SSFSA will support a 75 kW bus with eight array wings over a four-year period in LEO. The SSFSA is 33.8 ft by 113.7 ft when fully deployed; the mast canister is 32 inches in diameter and 9 ft tall. The current weight is 1650 lb. The flexible substrate array must survive the space environment for fifteen years. This includes AO exposure and 87,000 thermal cycles. The baseline AO protection is based on the results of the Photovoltaic Array Environmental Protection (PAEP) Program\(^1\) being performed by LMSC for NASA-LeRC. In addition to the SSFSA, two free-flying Platforms will use smaller array wings with maximum hardware commonality to reduce program cost.

The baseline SSF extended array configuration is shown in Figure 3. Figure 4 illustrates the panel elements. The mechanical design consists of two blanket boxes made of aluminum honeycomb panels, shown in Figure 5. Motor drive assemblies release the latches and relatch when required. The blanket tension and guidewire mechanisms are housed in the underside of the containment box, and three tensioned guidewires per blanket control the location of the blankets during extension and retraction. The tension mechanism applies 75 lbs of tension to each blanket.

The positioning mechanism places the arrays in the ready-to-extend configuration, and returns them to the launch configuration. The mast draws out the blankets that are attached to the unlatched box covers and pulls the blanket

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\(^1\) Reference: Technical Datasheet

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Fig. 3 Space Station Freedom Solar Array Deployed Configuration

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Fig. 4 Space Station Freedom Panel
The stiffener frame provides rigidity to the panel to aid in joint retraction of the arrays. The baselines: material, beryllium, is currently being traded off against graphite/epoxy and a graphite/thermoplastic. Beryllium is stable in the AO environment. Three major concerns are: (1) handling (Be has low impact resistance and is toxic), (2) safety (Be is toxic), and (3) lack of flight history of Be in this application. Graphite thermoplastic is possibly stronger in the transverse direction than Gr/E, permitting the use of a unidirectional ply for construction. However, this laminate would need to be protected against AO, has no flight or manufacturing history, and would provide reduced stiffness across the cross-braced joint region.

Kapton with 1300Å of SiO₂ sputter-coated on both sides is the baseline SA panel substrate. It is transparent, flexible, AO resistant, and survives processing and handling for flexible printed circuitry fabrication. The potential formation of pin holes and the low flexibility of the material are concerns; therefore, alternate materials are being studied under the PAEP contract. These include: (1) DuPont 92-1, a proprietary material; (2) KJ 36, a multilayer with siloxypolyimide clad to Kapton both sides; (3) Kapton F, a multilayer laminate of FEP/Kapton/FEP; and (4) K/T/K, a laminate of Kapton/FEP/Kapton. Characteristics are provided in Figure 6.

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Fig. 6 Comparison of Kapton Substrates

Currently, weight reduction possibilities are being considered in seven areas of the SA wing design. Reducing the thickness of the baseline solar cell from 0.008 in. to 0.004 in could save 52-78 lbs per wing assembly, but will require resizing of the SA based on the reduced thin cell current output. Changing the material of the containment box and the mast canister from aluminum to graphite epoxy would save 8 lbs and 13 lbs respectively. Common MDA s are less costly, but 28 lbs could be saved if there were unique MDA designs for latching, positioning, and extension. If the deployment time required were greater than 15 minutes, the extension motor would weigh less. The repositioning mechanism mass could be lowered 30 lbs with manual positioning and 15 lbs with one short positioning out and in. Combining the containment box and launch cradle latching mechanisms could save 100 lbs on the wing, but only 25 lbs for the complete system.

**DEVELOPMENT TEST PLAN**

Proof of concept, manufacturability, and lower overall program risk are among the reasons for performing development testing on hardware. Early identification of tooling and manufacturing needs allows time to design and fabricate necessary tools; develop and plan effective manufacturing processes; integrate facilities, tooling and materials; and develop necessary skills.

The planned blanket, box, and wing component-level testing and the wing assembly evaluation testing are depicted in Figure...
The blanket components such as the solar cells, bypass diodes, coated Kapton, and flat collector circuit, undergo many development tests at the vendors subcontracted to LMSC. The solar cells and diodes will undergo weld development at LMSC. The reverse breakdown characteristics of the cell will be tested at LMSC, and verification of bypass diode operation with module shadowing will also take place.

The containment box latching/preload, guidewire, and tension mechanisms undergo functional and environmental testing. The structural properties of the box cover and base are evaluated, and the preload foam will be subjected to creep, compression, and environmental testing. The blanket/box assembly testing is shown in Figure 8.

**CONCLUDING REMARKS**

Currently, five 40-cell modules electrically connected per panel appears advantageous. The modules are of manageable size and do not tie up too many cells in case a repair is necessary, yet there is not an unwieldy amount of piece parts. Our circuitry has been designed to incorporate the twenty weld pads (ten double weld pads) now on the solar cell. Labor hours required for rework will decrease with this incorporation. Stiffener frame selection will be based on a cost/weight analysis. As a backup to the baseline thin-film SiO₂ protection for the Kapton substrate SA panels, several candidate materials that are resistant to atomic oxygen are being investigated.

Design changes to reduce the overall SA wing weight have been studied. These include a combination of containment box and cradle latching mechanisms for launch, thinner solar cells, changing containment box and mast-canister material from aluminum to graphite epoxy, and using motors specifically designed for each task. The development test program will provide confidence that the fifteen-year array operating life requirement in LEO can be met while emphasizing those aspects of the array wing design that are different from the SAFE array and from other LMSC flexible SA programs.

**ACKNOWLEDGEMENTS**

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REFERENCES


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