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SATELLITE POWER SYSTEMS STRUCTURES—A 1980 TECHNOLOGY STATUS REVIEW

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In 1976, the Department of Energy and NASA initiated a broad concept evaluation program to develop, by 1980, an initial understanding of the economic practicality and socio/environmental acceptability of the Satellite Power System (SPS) program. An essential component of the program is the system definition studies, within which are the structure technology investigations. This paper reviews the current SPS structure technology status.

System definition studies for JSC (Boeing) and MSFC (Rockwell) are being focused on the class of configurations shown in Figure 1. The two configurations at the left capture sunlight on ultra-large arrays of either silicon or gallium arsenide solar cells and transmit the generated electrical energy through conductor runs and rotary joint to the microwave power transmission system (MPTS) composed of either solid-state power amplifiers or klystron tube devices. The solid-state configuration at the right delivers sunlight through primary and secondary reflectors (CR=5) to solar cells that are structurally integral with the solid-state amplifiers and, hence, eliminate electrical conductors and power transfer across a rotary joint.

The classes of major structural components and constructions utilized by these configurations are delineated in Table 1 along with designation of the general status of the technology. The overall technology is essentially at the preliminary design stage, with the exception of the machine-made beam developments. On May 4, 1978, a ground demonstration machine, developed by Grumman for MSFC, fabricated a 1-m-deep aluminum, triangular-shaped truss-type beam. A structural test of the beam verified its strength suitability. Graphite composite triangular and geodetic beams are being developed by General Dynamics and McDonnell Douglas for JSC, with the present progress as shown.

These structural components, in conjunction with the control system, must satisfy the regime of system dimensional stability requirements shown in Figure 2 during exposure to the varying environments shown. The most stringent of these requirements are those pertaining to the MPTS antenna. The curvature requirement translates into maintenance of flatness to essentially 0.5 m across a diameter of 1700 m. Satisfaction of such requirements with these ultra-large structures would be unthinkable if not for the benign external loading environment shown. For example, the entire solar pressure and gravity gradient load on a 1700-m-diameter aperture antenna is less than the design load on 13 cm^2 of the orbiter crew module (142 N). The most significant challenge, however, is presented by the combination of thermal environment and 30-year life requirements.

The major issues pertinent to SPS structures are:

- Choice of most cost-effective construction (truss configuration, machine-made beam, beam-to-beam joining)
- Choice of construction material
- In-depth definition of structural design requirements
- Knowledge of state of stress and dimensional integrity of as-built structure
- Predictability of strength and dynamic behavior
- Feasibility of passive figure control approach to MPTS flatness
- Feasibility of structure stiffness compatible with MPTS pointing
- Feasibility of passive control through damping
- Feasibility of space fabrication of ultra-large reflector surfaces
- Qualification, model verification, inspection

The construction in space rather than in the constant gravitational temperature-controlled environment of present ground airframe fabrication, presents questions. At best, with fixed solar orientation during the construction flow, thermal environment changes significant to the as-built state of stress and dimensional integrity can occur. Also, since size and strength preclude extensive ground testing, qualification can only be accomplished with extensive analysis employing detailed finite element models, verified by small component and scale model tests. In-space inspection during fabrication and potential repair capability is of vital concern. In the orbiter crew module all welds are inspected using dye penetrants and X rays. The current policy of inspection of the welded joints in

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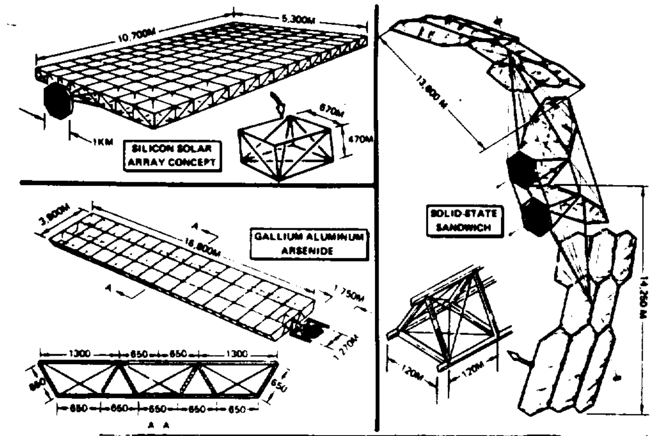
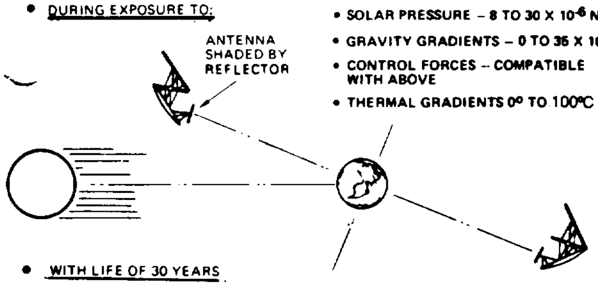


Figure 1. SPS Current Configurations

- SATISFY REGIME OF FIGURE CONTROL REQUIREMENTS

STRUCTURE/CONTROL SYSTEM REQUIREMENT (DEGREES)					
PERFORMANCE PARAMETER	MPTS	PRIMARY REFLECTOR		SECONDARY REFLECTOR	SOLAR BLANKETS
		CR = 2	CR = 5	CR = 5	
POINTING	.05	.1 TO 2.5	.1 TO .5	.1 TO .5	10
SURFACE CURVATURE	.05	.5 TO 2	.2 TO .5	.5 TO 1	2 TO 5

- DURING EXPOSURE TO:
  - SOLAR PRESSURE – 8 TO 30 X 10^{-6} N/M²
  - GRAVITY GRADIENTS – 0 TO 35 X 10^{-6} N/M²
  - CONTROL FORCES – COMPATIBLE WITH ABOVE
  - THERMAL GRADIENTS 0° TO 100°C



- WITH LIFE OF 30 YEARS

Figure 2. SPS Requirements/Environments

Table 1. Major Structural Components/Status

Class and Components	Status* 1	2	3	4	5
Tension-Stabilized Surfaces					
Solar reflector surfaces	X				
Solar cell blankets	X		X		
Tension cable/surface attachment	X				
Tension devices	X	X	X	X	
Rigid Surfaces					
Klystron assemblies	X				
Solid-state sandwich	X				
Primary Structure Frameworks					
Platforms	X				
Polygonal compression frames	X				
Trusses of built-up tri-beams	X				
Tri-beams	X				
Machine-Made Beams					
Open cap, aluminum, triangular	X	X	X	X	X
Open cap, composite, triangular	X	X	X		
Closed cap, composite, triangular	X				
Composite geodetic	X	X	X	X	
Beam-to-Beam Joints					
Lap joint	X				
Concentric joint – fixed	X				
Concentric joint – pinned	X		X		
'X' – Bracing					
Tension cable and attach	X				

*Status Areas:
1–Preliminary concept
2–Mature concept
3–Article fabricated
4–Structure tested
5–Demonstration article

machine-made beams ranges from near total reliance on machine capability to monitoring of critical parameters. Beam-to-beam joint design inspectability and repairability remain to be studied.

At Rockwell, visibility on several of these issues has been achieved through the results of structural analyses in support of system studies of solid-state configurations. Structural analyses were performed to assess the structural feasibility of a hexagonal compression frame/tension cable array primary structure for the MPTS antenna. The orthotropic tension cable array provides support for the solid-state sandwich panels without obstruction of either the solar cell or microwave surface. Figure 3 illustrates the peak eclipse-induced thermal loads relative to the initial closed force cable pretension/frame compression loading. These loads are due to the thermal gradient between the tension cables and frame machine-made beam caps. Both elements are of graphite composite material ($\alpha = 0.36 \times 10^{-6}$ m/m °C). The peak thermal loads are 1 to 3%. With aluminum, the percentage changes would be 20 to 40%. Figure 4 illustrates the two principal thermal sources causing hexagonal frame deflection and deviation from surface flatness. These sources are thermal gradients across the tri-beam structure due to shadowing by the sandwich panel array and temperature differentials between the discrete groups of X-bracing, denoted by solid and dashed lines. The peak thermal deflections of point H are shown parametrically for the antenna apertures shown and for tri-beams designed to the surface restrictions shown as the abscissa. It is noteworthy that the 12-cm deflection