SPS STRUCTURAL DYNAMICS AND CONTROL WORKSHOP: FINDINGS AND RECOMMENDATIONS

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Recently a technical workshop was held at the Johnson Space Center to examine issues related to the structural dynamics and control of the Solar Power Satellite (SPS), a concept which holds promise for meeting a portion of the energy needs of the United States beyond the year 2000. The panel members, listed in Figure 1, represent some of the nation's leading experts in controls, structural dynamics, structures and materials. As listed in Figure 2, the objectives of the workshop were for this panel to: 1) assess and critique the assumptions, methodologies and conclusions of existing SPS studies in the areas of structural dynamics and control (with structural design and materials also being considered) and 2) identify critical issues in these areas and make recommendations for future work. Within the time and resources available it was not possible to provide the panel with a comprehensive review of the overall SPS system characteristics or to penetrate into the intersystem design issues and tradeoffs. In fact the workshop was only able to highlight the activities in structures, control and materials. In spite of these limitations the panel has afforded an excellent review and developed a valid perception as to the status of the SPS work in their areas of expertise. This paper is based on preliminary inputs from the panel members. The official panel findings are expressed in the panel's final report.

Comments and recommendations given include six categories as briefly addressed in:

Figure 3. Modeling/Dynamic Analysis of the Uncontrolled System
Figure 4. Structural Design
Figure 5. Control System Analysis/Design
Figure 6. Construction in Space
Figure 7. Structural Materials
Figure 8. Experiments

A seventh category, manned safety, was pointed out by the panel as an important factor to all aspects of system design, construction, maintenance and operation.

After considering each of these areas, the panel would like to have stated with some confidence that all of the problem areas had been brought to light and shown to be resolvable. In fact, they are generally optimistic that if sufficient resources are devoted to this effort, the same kind of technical know-how that has served us in the past will find ways to meet the challenges presented by the SPS. At the present time, however, such optimism would be based more on wishes and past success than on hard evidence. The work to date has simply not gone far enough or looked deep enough to provide real confidence in the ultimate viability of the SPS. A substantial amount of work must be done in areas like modeling, developing techniques for the active control of uncertain systems, and studying the long term physical properties of composites before this confidence will be warranted. Meanwhile, optimism must be balanced by a certain amount of caution combined with the determination to develop the tools and knowledge necessary to see if this much needed dream can be turned into reality.

Since the SPS system cannot be tested in the terrestrial environment, many types of experimental verification techniques possible for more conventional engineering projects are ruled out. Thus, the successful design, development and construction of the SPS will rely to an unusually high degree on modeling and dynamic analysis. The panel feels that substantial further work is required in the areas of modeling the system components and environment. These models are required to study the uncontrolled behavior of the spacecraft and to provide a basis for the control system design, development, and evaluation. It may be necessary to predict reliably hundreds or thousands of structural frequencies, mode shapes and damping ratios. Currently modeling procedures for structural dynamics are not so clearly established as to be able to estimate the reliability of a particular eigenvalue and eigenvector. Environmental disturbances and control hardware must also be modeled to assess system behavior and for suitable control system design.

Current SPS structural designs utilize forms which basically derive from 19th century bridge-building technology (not necessarily bad). As the overall concept evolves, as communication is developed between structures, materials and control specialists, and as an understanding of construction in space is developed, it is anticipated that more advanced concepts which exploit the potential of the nearly benign environment will emerge.

To approach this evolution, however, the panel felt that the controls problem had received disproportionately little attention. This included: recognition of modeling limitations as a key issue, tradeoffs among active surface control, tradeoffs between the bounds of structure and control, tradeoffs between electronic phasing and active figure control, analyses which penetrate to adequate depth for specific controls hardware considerations, and means to accomplish verification of the controlled system design. The controls problem for construction is compounded by the additional parameters of transient geometry and performance requirements.

A feature of the SPS which sets it apart from all spacecraft launched to date is the fact that it must be constructed automatically in space. Our lack of experience with systems of this type merits careful consideration of this feature. The construction phase may in fact be critical in terms of establishing structural and control system design requirements.

The panel felt that much additional work was required to provide a confidence level necessary for the selection of graphite composite as the SPS structural material. There are a number of design/structure/material tradeoff studies which should be performed. The basic question of the long term stability of materials and coatings in the space environment is crucial.

As outlined in Figure 8, the nature of the SPS is such that the design and proof of feasibility will rest primarily on a foundation of analysis. However, experiments are needed to verify the results of analysis insofar as possible. These experiments should be directed toward verification of modeling techniques, validation of control policies, and determination of material properties.

SPS STRUCTURES & CONTROL WORKSHOP

AT

NASA, JSC JANUARY 22, 23, 1980

CHAIRMAN: D. L. MINGORI - UNIVERSITY OF CALIFORNIA, L. A.

PANEL MEMBERS: K. T. ALFRIEND - NAVAL RESEARCH LABS
R. G. LOEWY - RENSSELAER POLYTECHNIC INSTITUTE
M. LYONS - LOCKHEED RESEARCH LABS
S. SELTZER - CONTROL DYNAMICS COMPANY
R. E. SKELTON - PURDUE UNIVERSITY
K. SOOSAAR - C. S. DRAPER LABS

FIGURE 1 - SPS STRUCTURES & CONTROL WORKSHOP PANEL

OBJECTIVES:

- ASSESS & CRITIQUE ASSUMPTIONS, METHODOLOGIES & CONCLUSIONS OF EXISTING SPS STUDIES IN THE AREAS OF STRUCTUAL DYNAMICS & CONTROL (STRUCTURAL DESIGN & MATERIALS ALSO CONSIDERED)
- IDENTIFY CRITICAL ISSUES IN THESE AREAS AND MAKE RECOMMENDATIONS FOR FUTURE WORK

SUMMARY OF FINDINGS:

- GENERALLY OPTIMISTIC THAT WITH SUFFICIENT RESOURCES TECHNICAL KNOW-HOW THAT HAS SERVED US IN THE PAST WILL FIND WAYS TO MEET SPS CHALLANGES.
  BUT WORK TO DATE HAS NOT PENETRATED ENOUGH TO PROVIDE REAL CONFIDENCE IN THE ULTIMATE VIABILITY OF SPS FROM THE STANDPOINT OF STRUCTURES AND CONTROLS.
  WORK REQUIRED IN:
  - MODELING
  - DEVELOPING TECHNIQUES FOR ACTIVE CONTROL OF UNCERTAIN SYSTEMS
  - STUDY OF LONG TERM PROPERTIES OF COMPOSITES

FIGURE 2 - WORKSHOP OBJECTIVES & FINDINGS

ISSUE:

SUCCESSFUL DESIGN & OPERATION OF SPS WILL RELY HEAVILY ON MODELING & DYNAMIC ANALYSIS

RECOMMENDATIONS:

- ADEQUATE MODAL ANALYSIS WILL REQUIRE DEVELOPMENT OF:
  - HIGHER ACCURACY FINITE ELEMENTS
  - IMPROVED EIGENVALUE EXTRACTION
  - CAREFUL ANALYSIS OF ERROR SOURCES
- NEED BETTER UNDERSTANDING OF HOW MODELING CRITERIA AFFECT RELIABILITY OF MODE SHAPES, FREQUENCIES
- ENVIRONMENTAL DISTURBANCE, & CONTROL HARDWARE MODELING REQUIRED FOR DYNAMIC PERFORMANCE & CONTROL SYSTEM DESIGN
- EXTEND FINITE ELEMENT ANALYSIS TO INCLUDE NON-LINEAR BEHAVIOR FOR, EG,
  - POTENTIAL LARGE SOLAR BLANKET DEFLECTIONS
  - NEAR BUCKLING MEMBER BEHAVIOR

FIGURE 3 - MODELING/DYNAMIC ANALYSIS OF THE UNCONTROLLED SYSTEM

ISSUES:

- PANEL CONSENSUS SUPPORTED STRUCTURAL FEASIBILITY
- CONCERN EXPRESSED AS TO WHETHER THE EXPECTED LOW STRUCTURAL MASS FRACTION IS BASED ON A REALISTIC STRUCTURAL CONCEPT AND PROPER ANALYSIS

RECOMENDATIONS:

- EXPLORARATION OF MORE ADVANCED CONCEPTS WHICH UTILIZE FULL POTENTIAL OFFERED BY NEARLY BENIGN ENVIRONMENT
- MORE COMPREHENSIVE STRUCTURAL ANALYSES INCLUDING CONTROL ACTUATORS AND TRANSIENT, NON-UNIFORM THERMAL ENVIRONMENT

FIGURE 4 - STRUCTURAL DESIGN

ISSUES:

- SIGNIFICANCE OF MODELING ERRORS ON PERFORMANCE IS A KEY ISSUE FOR CONTROL SYSTEM ANALYSIS & DESIGN
- TRADEOFFS AMONG ACTIVE SURFACE CONTROL MAY LEAD TO MORE EFFICIENT DESIGN (POTENTIAL DYNAMIC/MICROWAVE PHASING INTERACTION)
- SPECIFIC CONTROLS HARDWARE MAY IMPACT OVERALL DESIGN
- STRUCTURE, CONTROL & MATERIALS DESIGN AND DEVELOPMENT SHOULD BE CARRIED ON IN PARALLEL WITH ADEQUATE COOPERATION, COMMUNICATION AND FUNDING. CONTROL HAS NOT RECEIVED APPROPIATE ATTENTION

RECOMMENDATIONS:

- BETTER MATHEMATICAL METHODS NEED DEVELOPMENT FOR ROBUST CONTROL POLICIES
- MORE ATTENTION TO ORBITAL VERIFICATION OF CONTROLLED SYSTEM
- TRADE PASSIVE STRUCTURE/ACTIVE FIGURE CONTROL/ELECTRONIC PHASING (IMPACT MATERIAL, CONFIGURATION, RISK)
- CAREFUL STUDY OF ACTUATOR, SENSOR OPTIONS FOR IMPROVED CONTROL PERFORMANCE
- GREATER ATTENTION NEEDED ON CONTROL PROBLEM

FIGURE 5 - CONTROL SYSTEM ANALYSIS/DESIGN

ISSUES:

- LACK OF EXPERIENCE WITH SYSTEMS OF THIS TYPE MERITS CAREFUL CONSIDERATION
- MODELING AND CONTROL OF TRANSIENT PROPERTIES
- EFFECT OF THERMAL DEFORMATIONS ON ASSEMBLY

RECOMENDATIONS:

- CONTROL UNDER CONSTRUCTION SHOULD BE ADDRESSED
- CONTROL THEORIES MUST BE DEVELOPED TO ACCOUNT FOR GROSSLY CHANGING PLANT
- STUDY OF STRUCTURES WITH MINIMUM REDUNDANCE
- ALTERNATE MEANS FOR HANDLING THERMAL DISTORTION BESIDES LOW CTE MATERIAL SHOULD BE STUDIED

FIGURE 6 - CONSTRUCTION IN SPACE

ISSUES:

- CURRENT FAVOR OF COMPOSITES MAY ULTIMATELY BE CORRECT BUT MUCH ADDITIONAL WORK REQUIRED TO MAKE THIS DECISION WITH CONFIDENCE
- LONG TERM STABILITY OF MATERIALS IN SPACE ENVIRONMENT
- DESIGN/STRUCTURE/MATERIAL TRADEOFFS

RECOMENDATIONS:

- INVESTIGATE DESIGN SOLUTIONS TO EASE MATERIAL REQUIREMENTS (INCLUDING THERMAL CONTROL)
- EXPLORE USE OF OTHER MATERIALS SINCE COMPOSITES ARE RELATIVELY NEW
- DEVELOP PROCEDURES TO EXTROPOLATE PERFORMANCE TO LONG LIFE (INCLUDING FATIGUE, THERMAL CYCLING, ENVIRONMENTAL EXPOSURE AND COMBINED EFFECTS)
- DEVELOP AUTOMATED FABRICATION OF STRUCTURAL ELEMENTS FOR GROUND SIMULATION, STRUCTURAL CHARACTERIZATION OF PRODUCTS
- ADDRESS THERMAL/MATERIAL PROBLEMS

FIGURE 7 - STRUCTURAL MATERIALS

ISSUES:

- SPS DESIGN AND DEVELOPMENT WILL DEPEND STRONGLY ON ANALYSIS AND MODELING
- MATERIAL PERFORMANCE/LIFE REQUIRES DATA

RECOMENDATIONS:

- DEVELOP EXPRIMENTAL APPROACHES FOR VERIFICATION OF ANALYSIS AND MODELING (GROUND AND FLIGHT)
- CHARACTERIZE LIMITATIONS OF GROUND TESTING AND FLIGHT SCALE TESTING (CAN LEO TEST VERIFY FULL SCALE SYSTEM STABILITY?)
- DEVELOP SIMULATION CAPABILITY FOR APPLICATION TO EXPERIMENTS
- PLAN SCALE PROOF OF PRINCIPLE TESTING WHICH IS TECHNICALLY TRACEABLE TO FULL SCALE
- DEVELOP MATERIALS EXPERIMENTS

FIGURE 8 - EXPERIMENTS