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FLIGHT DYNAMICS LABORATORY OVERVIEW

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Divisions of the Flight Dynamics Laboratory

The Flight Dynamics Laboratory (FDL) is one of four Air Force Wright Aeronautical Laboratories (AFWAL) and part of the Aeronautical Systems Division located at Wright-Patterson AFB, Ohio. The FDL is responsible for the planning and execution of research and development programs in the areas of structures and dynamics, flight controls, vehicle equipment/ subsystems, and aeromechanics. Some of the areas being researched in the four FDL divisions are as follows: large space structures (LSS) materials and controls; advanced cockpit designs; bird-strike-tolerant windshields; and hypersonic interceptor system studies. Two of the FDL divisions are actively involved in programs that deal directly with LSS control/structures interaction: the Flight Controls Division and the Structures and Dynamics Division.

Flight Controls Division Areas of Research

The Flight Controls Division has several programs that address control/ structures interaction technology for large space structures. These programs include pointing and shape control studies for large (100-meter) radar systems and robust control systems development. Research is performed in advanced controls/fighter technology integration, attitude and trajectory control for hypersonic vehicles, advanced cockpit designs, and flight simulator technology.

Structures and Dynamics Division Areas of Research

Some of the technology areas being developed in the Structures and Dynamics Division are advanced composite aircraft and spacecraft structures, cast aluminum structures technology, stores/aircraft flutter testing, and structures/dynamics/controls interaction. Programs have also been developed to research LSS control hardware, passive and active vibration control, suspension systems, and design optimization.

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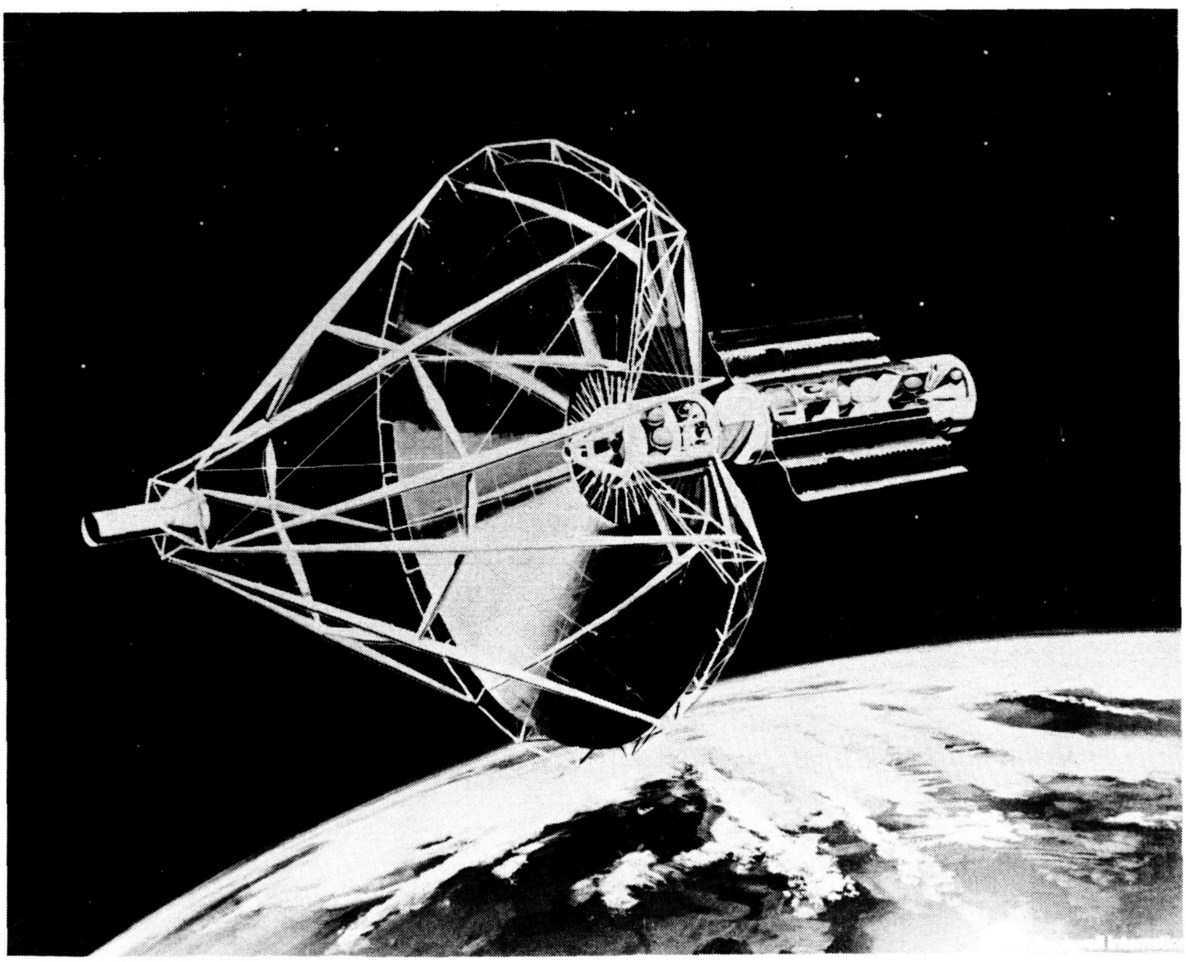
Large Space Structure Concept

Many defense systems have been proposed that incorporate space based structures an order of magnitude larger than those in orbit today. With the tremendous size and adverse environment associated with these systems come many challenges to the design and test engineers. Weight limitations imposed on LSS designs have made them much less rigid. This high flexibility combined with low damping results in structures very sensitive to disturbance forces. The structural precision required by many proposed missions creates the need for passive and active control systems. In the figure below is a space-based laser system concept whose flexibility, required precision, and size (approx. 15-m dia.) necessitate the use of combined passive and active control systems and specialized ground test procedures.



Technology Drivers

Development of large space structure control systems is hampered by the difficulty of the necessary performance validation ground tests. While some systems are too large for full-scale testing and/or do not lend themselves well to scaling techniques, the dynamics of a system on the ground may be radically changed when placed in orbit. The microgravity, low atmospheric pressure, thermal cycling environment of earth orbit produce material property changes and unique structural loads that may degrade control system performance. What is needed are technologies that allow earth-bound development and testing of LSS control systems to ensure reliable on-orbit system performance. The figure below illustrates some of the LSS technology drivers.

LARGE SIZE

- SCALING LAWS
- GROUND TEST TECHNIQUES

FLEXIBILITY

- ACTIVE & PASSIVE CONTROL

HIGH PERFORMANCE

- CONTROL / STRUCTURE OPTIMIZATION

ENVIRONMENT

- ADVANCED MATERIALS
- UNIQUE CONTROL HARDWARE
- GROUND TEST FACILITIES

Technical Issues Addressed by Flight Dynamics Laboratory

The Flight Dynamics Laboratory has developed several programs that address the challenging dynamics issues presented above. In the figure below is a chart illustrating the application of FDL programs to the development of the required technology areas.

PROGRAMS / ISSUES	BASIC RESEARCH	POINTING & SHAPE CONTROL	ROBUST CONTROL	LSS ACTIVE VIBRATION CONTROL	VIBRATION CONTROL OF SPACE STRUC	ACTIVE CONTROL EVALUATION FOR SPACECRAFT	LSS TECHNOLOGY PROGRAM	PASSIVE & ACTIVE CONT OF SPACE STRUCTURES	PRECISION STRUCTURAL JOINTS
THEORETICAL CONTROLS DEVELOPMENT	X		X						
OPTIMIZATION	X	X							
SCALE MODELING				X				X	
ACTIVE CONTROL IMPLEMENTATION						X	X	X	
PASSIVE DAMPING				X			X	X	
GROUND TEST TECHNIQUES				X	X	X	X		
HARDWARE					X		X		X

Basic Research Objectives

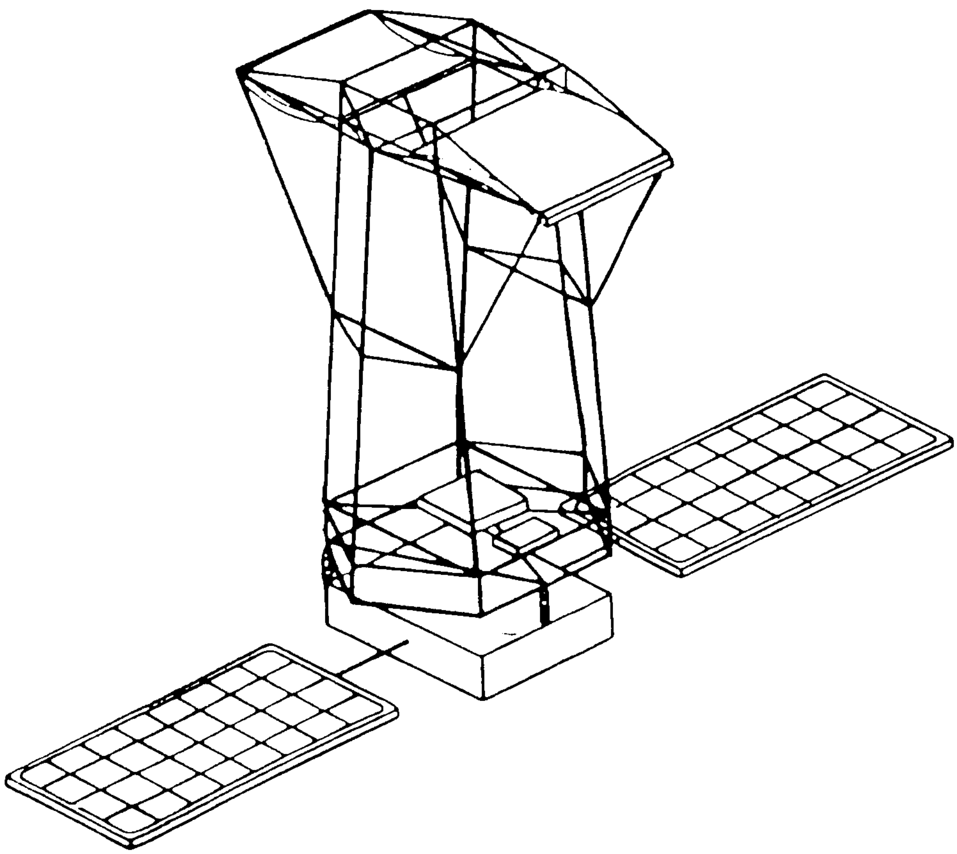
Several basic research programs are underway in the areas of optimization, analysis, and control algorithm development. Optimal control and estimation methods for discrete structural systems and modeling errors and their effect on the robustness of control/structures interaction are being studied and the structural dynamics and controls disciplines are being integrated for optimum structures in the space environment. Algorithms for structural optimization, precision pointing, shape control, and vibration suppression are being developed as well. The figure below summarizes the objectives for these programs.

OBJECTIVES

- DEVELOP OPTIMAL CONTROL METHODS
- ESTIMATE MODELING ERRORS AND THEIR EFFECTS
- INTEGRATE DYNAMICS AND CONTROLS

Basic Research Spacecraft Model

Many analytical spacecraft models have been used in the basic research programs. Shown in the figure below is one such model, the Draper Model #2. This model was developed for the Defense Advanced Research Projects Agency (DARPA) Active Control of Space Structures (ACOSS) program. In this model a flexible metering truss, approximately 22 x 20 meters, supports primary, secondary, and tertiary mirrors and the focal plane array. Attached to this structure is an equipment platform with solar arrays. The primary objective was to meet stringent line-of-sight and jitter control requirements by applying modern control techniques and state-of-the art hardware concepts.



Large Spacecraft Pointing and Shape Control

The objective of the Large Spacecraft Pointing and Shape Control program is to develop an integrated control system for a realistic large (100-meter) space antenna for controlling slewing, pointing, shaping, and vibration of the structure. General Dynamics, Convair Division, has defined mission drivers and environmental factors, performed control trade-off studies, and developed control algorithms for a realistic large flexible space antenna. The figure below summarizes the objective, approach, and payoffs of this program.

OBJECTIVE:

- DEVELOP INTEGRATED CONTROL SYSTEM FOR REALISTIC SPACE ANTENNA CONTROL SLEWING, POINTING, SHAPING AND VIBRATION

APPROACH:

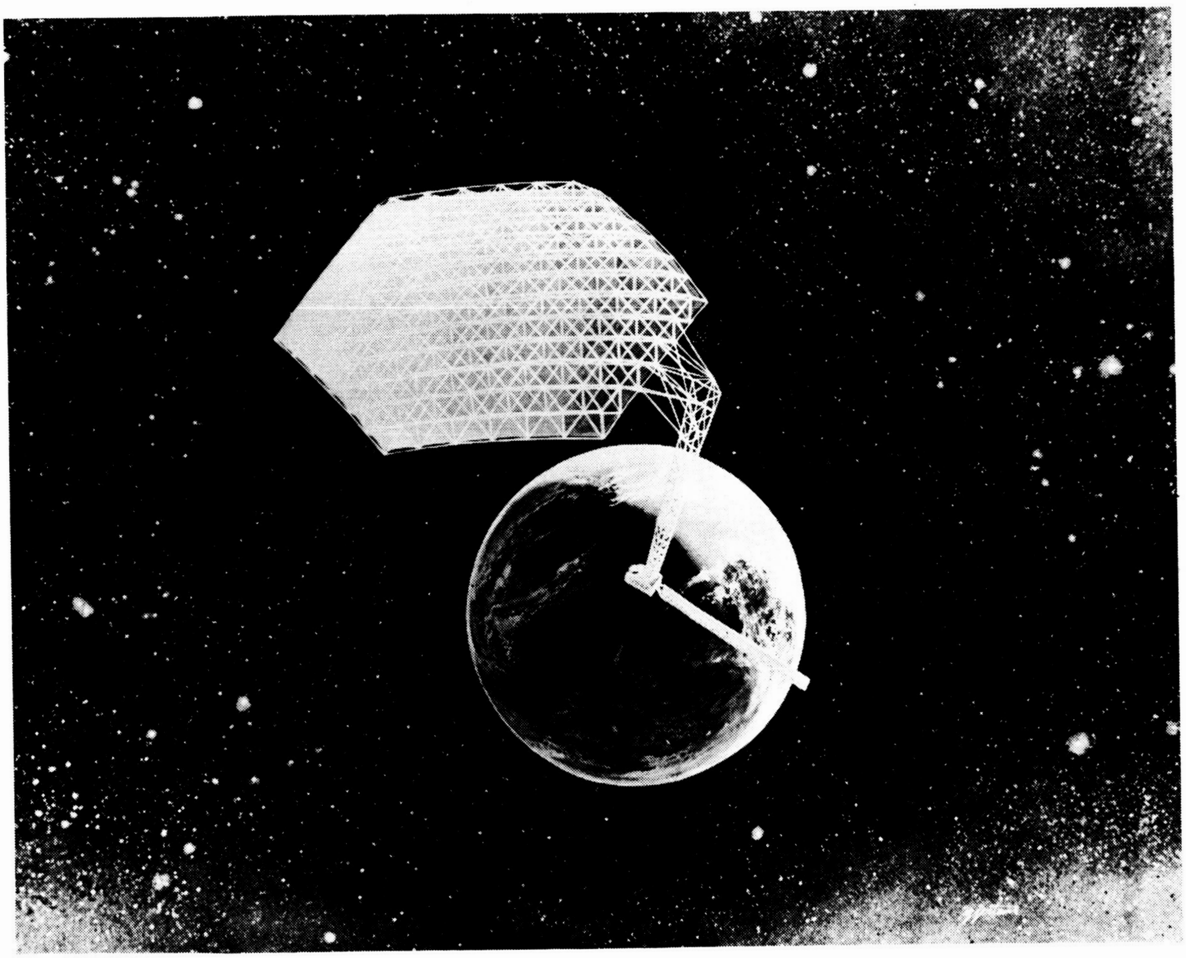
- MODEL REALISTIC ANTENNA AND ACTUATOR / SENSORS
  - STRUCTURE-LIMITED ANTENNA MODEL
- DEVELOP CONTROL ALGORITHMS
- PERFORM CONTROL TRADE-OFFS

PAYOFF:

- SHAPE CONTROL OF ANTENNA VERIFIED
- OPTIMIZED SUPPORTING TRUSS

Antenna Configuration

The figure below shows the configuration of the antenna model used in the Large Spacecraft Pointing and Shape Control program. The antenna dish is over 100 meters in diameter with a 110 meter support mast. Lengthy trade studies were performed to determine the optimal mix of the system parameters.



Robust Control for Large Space Antennas

Robust Control for Large Space Antennas is a two-year effort contracted to Honeywell Systems Research Center to assess the benefits of robust control design for pointing and shape control of large space antennas for both structured and unstructured uncertainty. Using the 100-meter geodetic truss reflector developed in the Large Spacecraft Pointing and Shape Control program as the baseline antenna configuration, performance/robustness measures were developed. A Linear Quadratic Gaussian/Loop Transfer Recovery (LQG/LTR) control algorithm was designed and the performance/robustness was analytically verified. The figure below gives a brief description of the objectives, approach, and payoffs of this program.

OBJECTIVES:

- ASSESS BENEFITS OF ROBUST CONTROL DESIGN
- EVALUATE CONTROLLER PERFORMANCE

APPROACH:

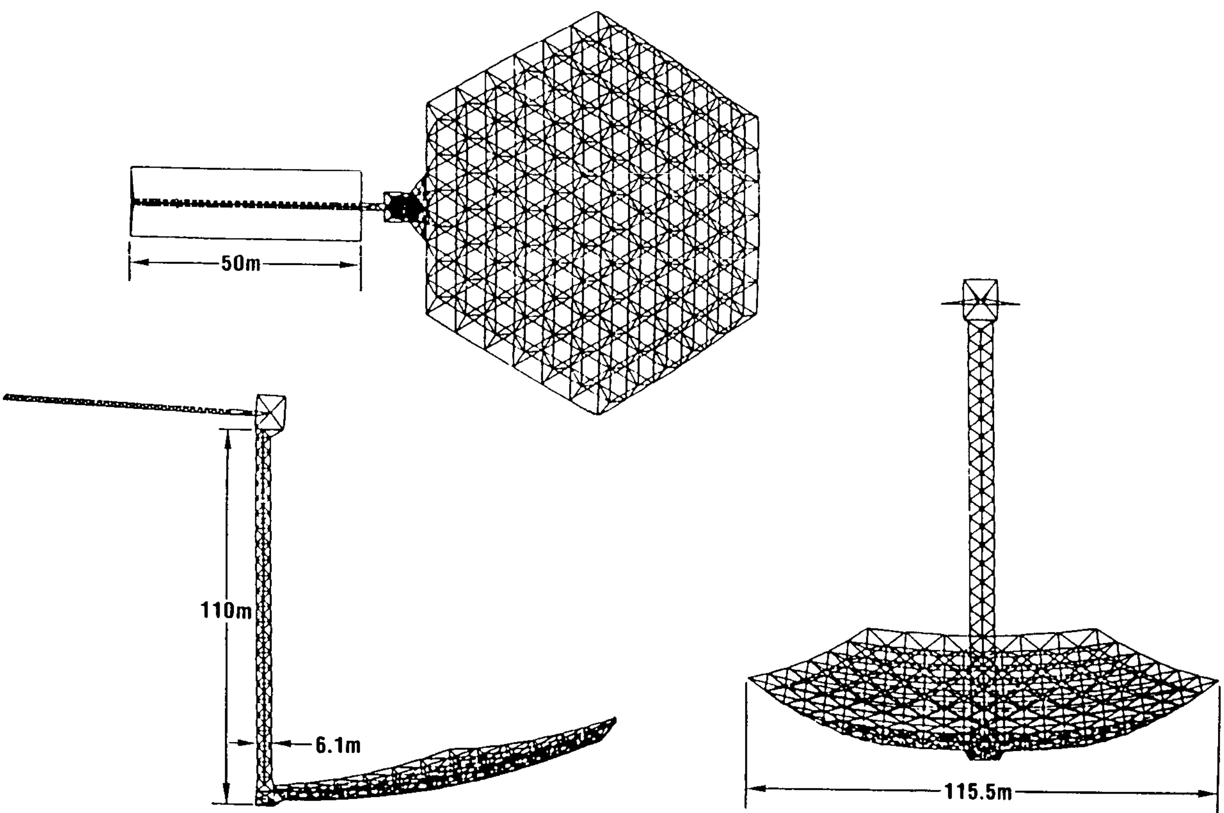
- USE REALISTIC SPACE ANTENNA DESIGN
- DEVELOP PERFORMANCE / ROBUSTNESS MEASURES

PAYOFFS:

- IMPROVED POINTING AND SHAPE CONTROL
- GUIDELINES FOR ACHIEVING PERFORMANCE / STABILITY ROBUSTNESS

Antenna Design

The figure below illustrates the antenna design used in the Robust Control for Large Space Antennas program. Given in the figure are some of the major dimensions.



Large Space Structures Technology Program

The Large Space Structures Technology Program (LSSTP) was created to address many of the LSS control challenges and develop an in-house capability for LSS test and analysis. The objectives, approach, and payoff of the LSSTP are given in the figure below.

OBJECTIVES:

- DEVELOP TEST AND ANALYSIS CAPABILITY

APPROACH:

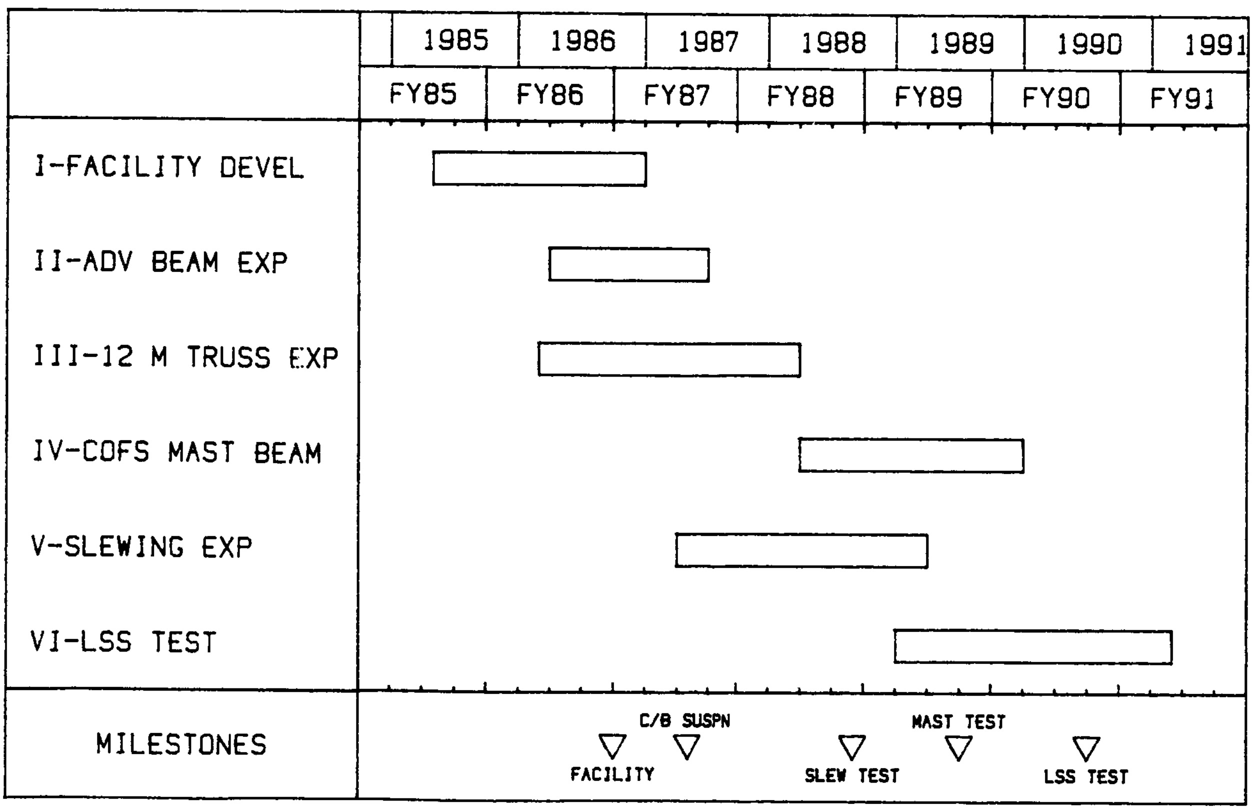
- CONTROLS-DESIGNED STRUCTURES TESTS
  - PASSIVE DAMPING STUDIES
  - ACTIVE VIBRATION CONTROL TESTS
- HARDWARE DEVELOPMENT
  - LIGHTWEIGHT PROOF MASS ACTUATORS
  - NONINTERFERING SENSORS

PAYOFFS:

- VERIFY ANALYTICAL ALGORITHMS
- VERIFY GROUND TEST TECHNIQUES
- EVALUATION OF ACTUATORS AND SENSORS

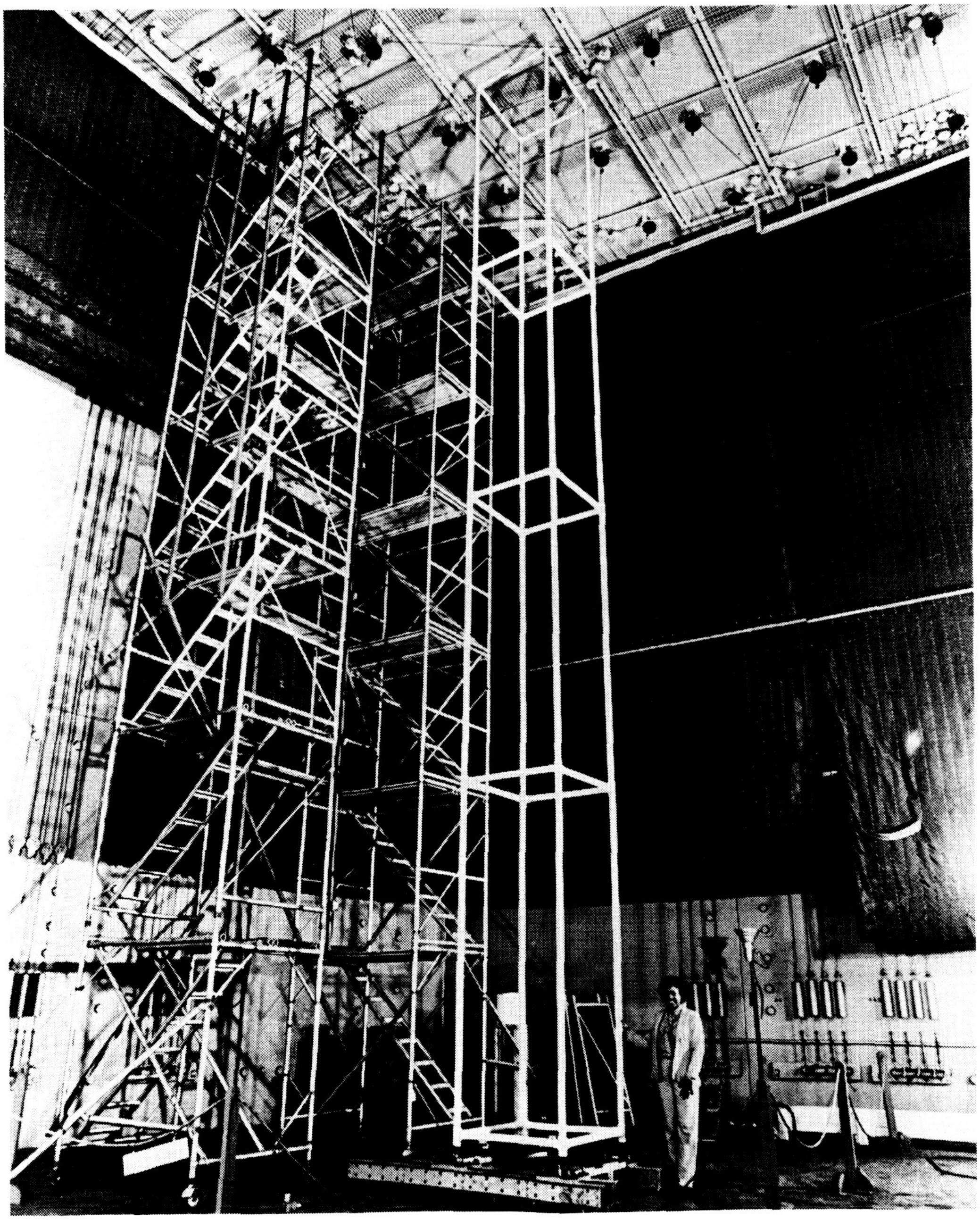
Program Schedule

The figure below illustrates the time schedule for the various activities associated with the Large Space Structures Technology Program beginning with the facility development started in FY 85. Within the program are subtasks to develop the LSS testing capabilities of the facility, develop low-restraint suspension systems, and perform controls experiments on a set of structures that progress in complexity. Tests of active vibration control have been completed for a simple cantilever beam and will progress to a more complex and realistic large space structure test article. Intermediate complexity test articles are now being tested which include a cantilever beam with rotary inertia and a set of two 12-meter damped and undamped truss structures. Fifth-scale models of the NASA-Langley Control of Flexible Structures program (COFS) 60-meter Mast beam will also be tested.



Dynamics Testbed Structure

The figure below shows a forty-foot truss structure fabricated from PVC tubing used in the facility development portion of the LSSTP. The structure was used to test and develop sensing, actuation, and data analysis equipment and methods. The 40-foot truss testbed is shown located in the large chamber of the Flight Dynamics Laboratory Sonic Fatigue Facility. Designed for the vibration and acoustic testing of large aircraft and missiles, the chamber is over 12 meters high, 17 meters wide, and 21 meters long. With its large size and excellent data gathering and analysis equipment, the facility is ideal for large space structures testing.



Large Space Structures Active Vibration Control

The objectives of Large Space Structures Active Vibration Control program are to verify and extend the results of laboratory control tests. Through ground tests of a fifth-scale version of the NASA-Langley Control of Flexible Structures (COFS) 60-meter deployable beam, one-g test procedures will be developed and verified. Active and passive control techniques will be tested on the scale beam in the AFWAL test facilities and the results will be validated with data from the shuttle flight tests of the full-scale hardware. The figure below summarizes the objectives, approach, and payoffs of this program.

OBJECTIVE:

- VERIFY AND EXTEND LABORATORY CONTROL TESTS

APPROACH:

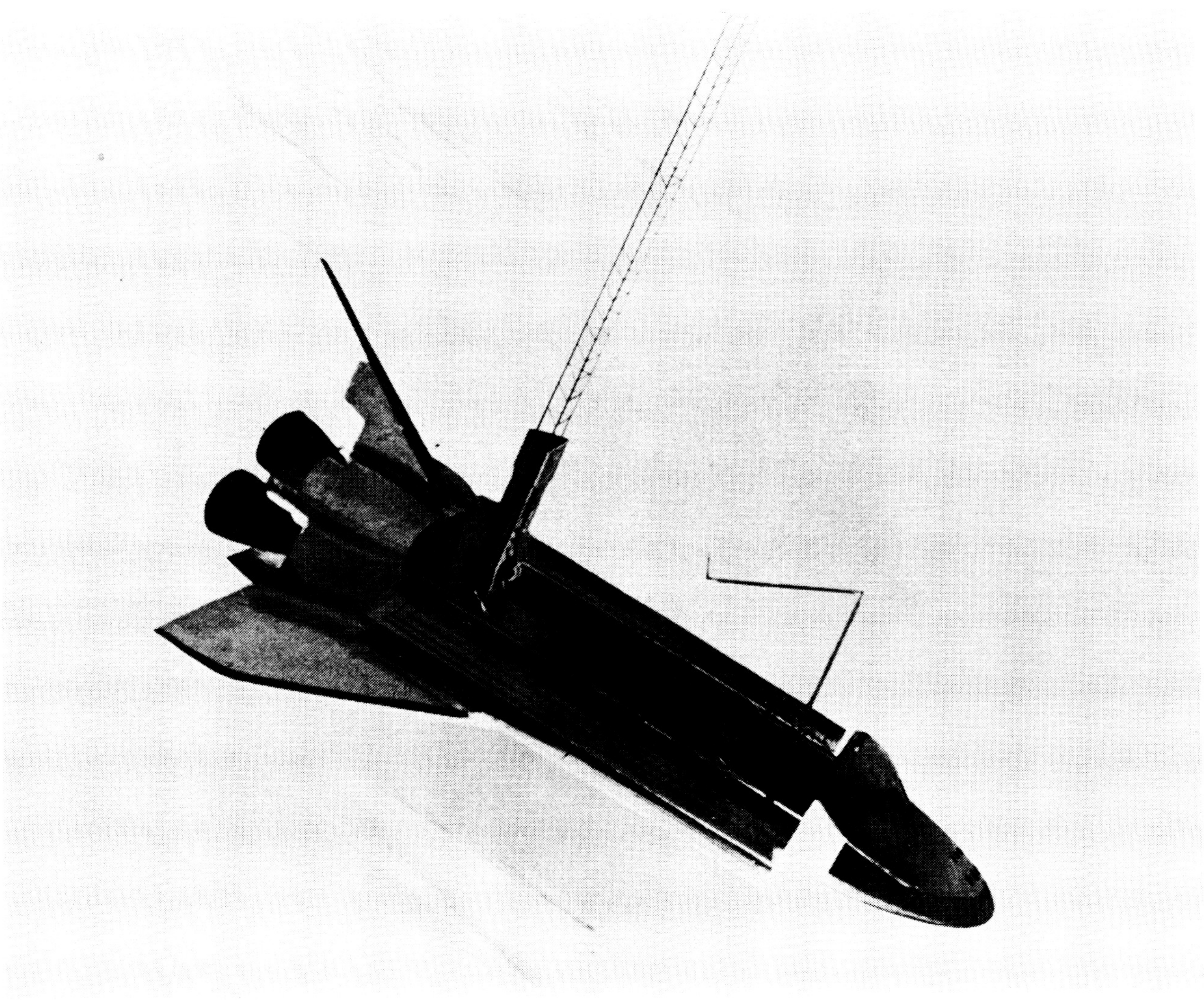
- COOPERATIVE EFFORT WITH NASA-LANGLEY SPACE TEST PROGRAM
  1/5-SCALE MAST MODEL TESTED IN AFWAL LABORATORY

PAYOFFS:

- OBTAIN LOW-COST SPACE TEST EXPERIENCE AND DATA
- VERIFY 1-g, 1 ATMOSPHERE LABORATORY TEST RESULTS

Deployable Space Beam

The figure below shows a truss structure being deployed from the space shuttle cargo bay as will the 60-meter Mast beam in the NASA-Langley Control of Flexible Structures program. The Large Space Structures Active Vibration Control Program will perform ground tests of active and passive control of damped and undamped fifth-scale Mast beams and validate the tests through comparison with the space test data.



Vibration Control of Space Structures (VCOSS II)

Vibration Control of Space Structures (VCOSS II) is a cooperative program between the Structures and Dynamics Division and the NASA Marshall Space Flight Center to develop and demonstrate actuator and sensor hardware for flexible-mode control of a space structure in the presence of dynamic disturbances. In this 28-month contract, TRW developed a set of linear proof-mass actuators and optical position sensors to control a 45-foot Astromast space structure suspended vertically in the NASA-Marshall Ground Test Verification Facility. The Astromast is a spare magnetometer boom identical to the ones used on the Voyager and Mariner spacecraft. The objectives, approach, and payoffs of the VCOSS II program are listed in the figure below.

OBJECTIVES:

- DEVELOP LAB HARDWARE TEST TECHNIQUES
- OPTIMIZE CONTROLS / STRUCTURE INTERACTION

APPROACH:

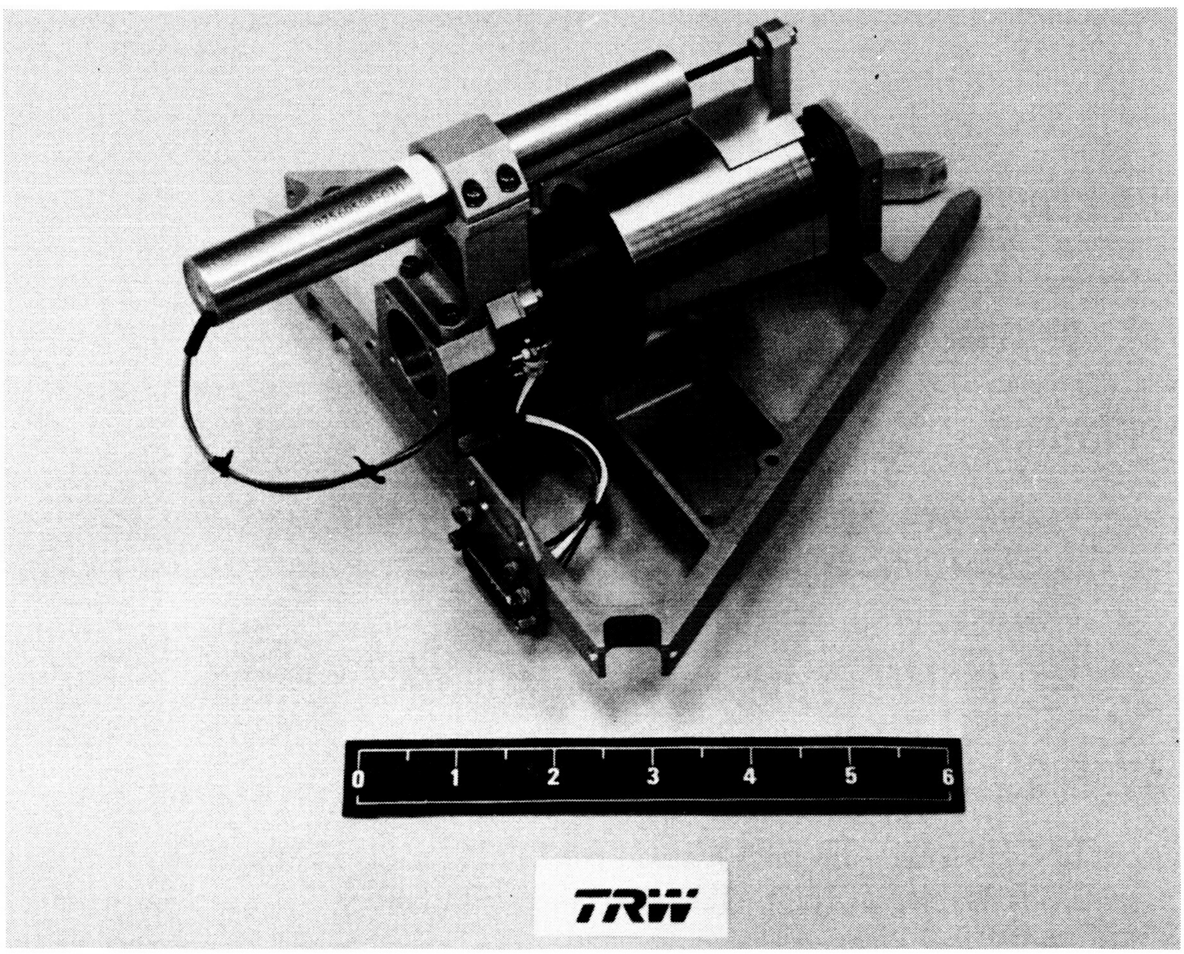
- DESIGN AND BUILD IMPROVED SENSORS AND ACTUATORS
  - 2.1 POUND FORCE PROOF-ACTUATORS
  - LASER-OPTIC SENSOR SYSTEM
- TEST CONTROL SYSTEM ON 40-FOOT ASTROMAST STRUCTURE

PAYOFFS:

- DEVELOPMENT OF IMPROVED ACTUATOR / SENSOR HARDWARE
- LIGHTWEIGHT ACTIVELY CONTROLLED STRUCTURES

Linear Proof-Mass Actuators

Linear proof-mass actuators and optical sensors were developed in the Vibration Control of Space Structures program. Shown in the figure below is one of the linear proof-mass actuators with attached mounting bracket and LVDT compensation sensor.



Active Control Evaluation for Spacecraft (ACES)

Active Control Evaluation for Spacecraft (ACES) is a DOD and NASA funded, cooperative AFWAL/Air Force Weapons Laboratory and Marshall Space Flight Center program to assess leading techniques for LSS flexible mode control. The control testing will be performed in the NASA-Marshall test facility using the Astromast structure and the VCOSS II actuator and sensor hardware. The control techniques to be tested are Harris' Maximum Entropy/Optimal Projection (ME/OP), Lockheed's High Authority/Low Authority Control (HAC/LAC), and TRW's Positivity. Below are the program objective, approach, and payoff.

OBJECTIVE:

- ASSESS LEADING TECHNIQUES FOR FLEXIBLE MODE CONTROL

APPROACH:

- USE VCOSS II DEVELOPED CONTROL HARDWARE
- IMPLEMENT AND TEST ON SPACECRAFT ANTENNA AND FEED MAST

PAYOFF:

- SELECTION OF OPTIMAL CONTROL TECHNIQUE

Modified Astromast Structure

The flexible spacecraft model used in the Active Control Evaluation for Spacecraft program is the Astromast structure used in the VCOSS II program with added offset antenna dish and feed. An artist's rendering of the test structure is shown in the figure below.

Development of Precision Structural Joints for Large Space Structures

Development of Precision Structural Joints for Large Space Structures is a program contracted to General Dynamics Convair Division for the development of design data on dimensionally stable, zero free-play, enhanced high energy laser survivable joints for large space structures. Innovative designs of low thermal response materials (composites) will be developed and joint strength/stiffness, free-play, thermal response, and dimensional precision will be validated. The objective, approach, and payoff of this program are shown in the figure below.

OBJECTIVE:

- DEMONSTRATE LIGHTWEIGHT, THERMALLY STABLE JOINTS

APPROACH:

- HARDWARE DESIGN
  - 2 JOINT DESIGNS
  - 2 MATERIAL COMBINATIONS
  - MULTIPLE MEMBER JOINTS
- HARDWARE TESTS
  - LOADS
  - THERMAL STABILITY
  - FREE PLAY

PAYOFF:

- DESIGN CRITERIA DEVELOPED FOR SPACE STRUCTURE JOINTS

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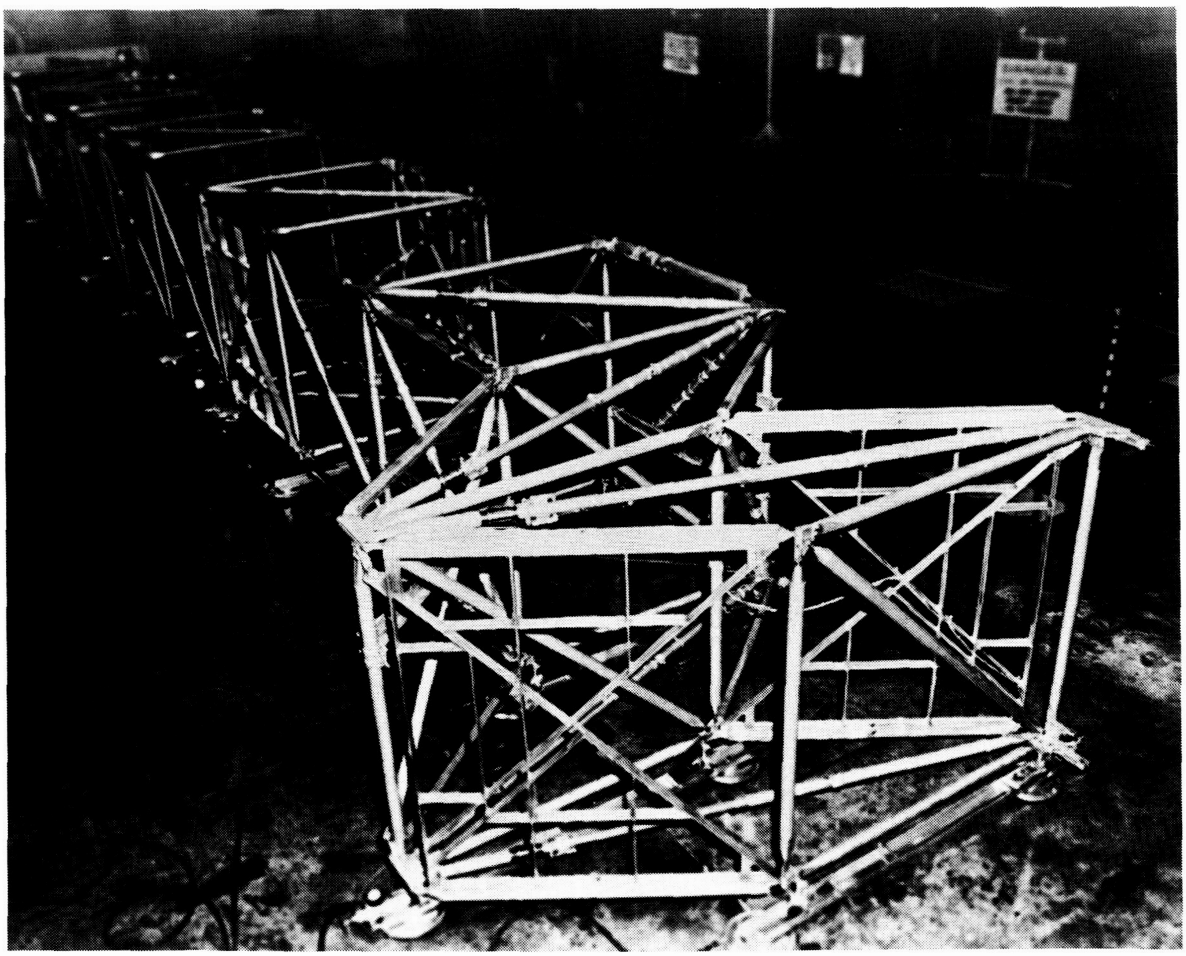
Joint Installed on SADE Beam

Development of Precision Structural Joints for Large Space Structures program baselines for joint design development are the contractor's GEO-truss antenna fitting and three joints from the NASA Marshall Structural Assembly Demonstration Experiment (SADE) linear beam. Two designs, a graphite/aluminum GEO-truss antenna fitting and a carbon-carbon nodal fitting from the SADE beam, were selected for fabrication. The SADE beam is shown deployed in the figure below. In the left foreground is one of the joints developed in this program.



Passive and Active Control of Space Structures (PACOSS)

Passive and Active Control of Space Structures (PACOSS) is an advanced development program being conducted by Martin Marietta Denver Aerospace under sponsorship by the Flight Dynamics Laboratory and the Strategic Defense Initiative Organization. The program approach is to determine the dynamic challenges of future large precision space systems, develop structural concepts which incorporate and integrate passive damping with the active control system, and fabricate and test a dynamic test article which incorporates the damping technology. The PACOSS objectives and goals are to demonstrate the benefits of passive structural damping technology to the dynamic performance of large precision space structures, achieve 50% reduction in settling time following retargeting, 90% reduction in line of sight jitter, and significant reduction in cost and complexity of active vibration control systems. The figure below summarizes the program objective, approach, and payoffs.

OBJECTIVE:

- DIMENSIONAL PRECISION THROUGH PASSIVE DAMPING

APPROACH:

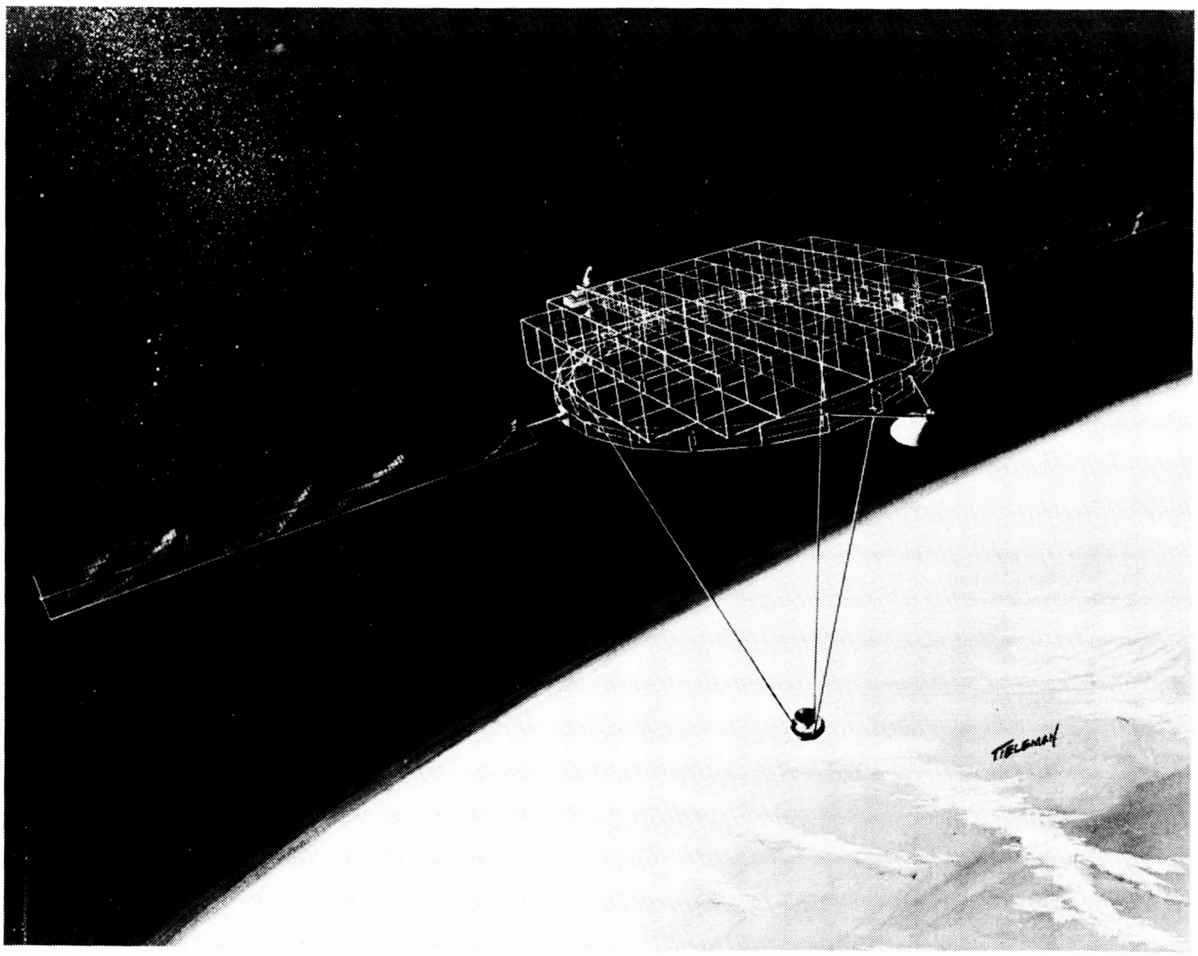
- DESIGN, FABRICATE AND TEST A REPRESENTATIVE SPACE STRUCTURE

PAYOFFS:

- 90% REDUCTION IN LINE-OF-SIGHT JITTER
- 50% REDUCTION IN SETTLING TIME AFTER MANEUVER
- SYNERGISTIC EFFECT ON ACTIVE CONTROL SYSTEM

Dynamic Test Article

One of the PACOSS dynamic test articles consists of a large box and ring truss with attached solar arrays and tripod secondary support which represent structural components from a variety of proposed large space structures. This structure is shown in the artist's concept in the figure below.



Technology Needs

Experience in applying active control to large flexible space structures has indicated that there are several technology needs that must be addressed. Listed in the figure below, these needs are high force low mass actuators; lightweight, high sensitivity sensors; efficient, robust controllers; lightweight structures; and space test experience. Future developmental programs should be focused on these issues.

- HIGH FORCE / LOW MASS ACTUATORS
- LIGHTWEIGHT, WIDEBAND SENSORS
- EFFICIENT, ROBUST CONTROLLERS
- LIGHTWEIGHT STRUCTURES
- SPACE TEST EXPERIENCE