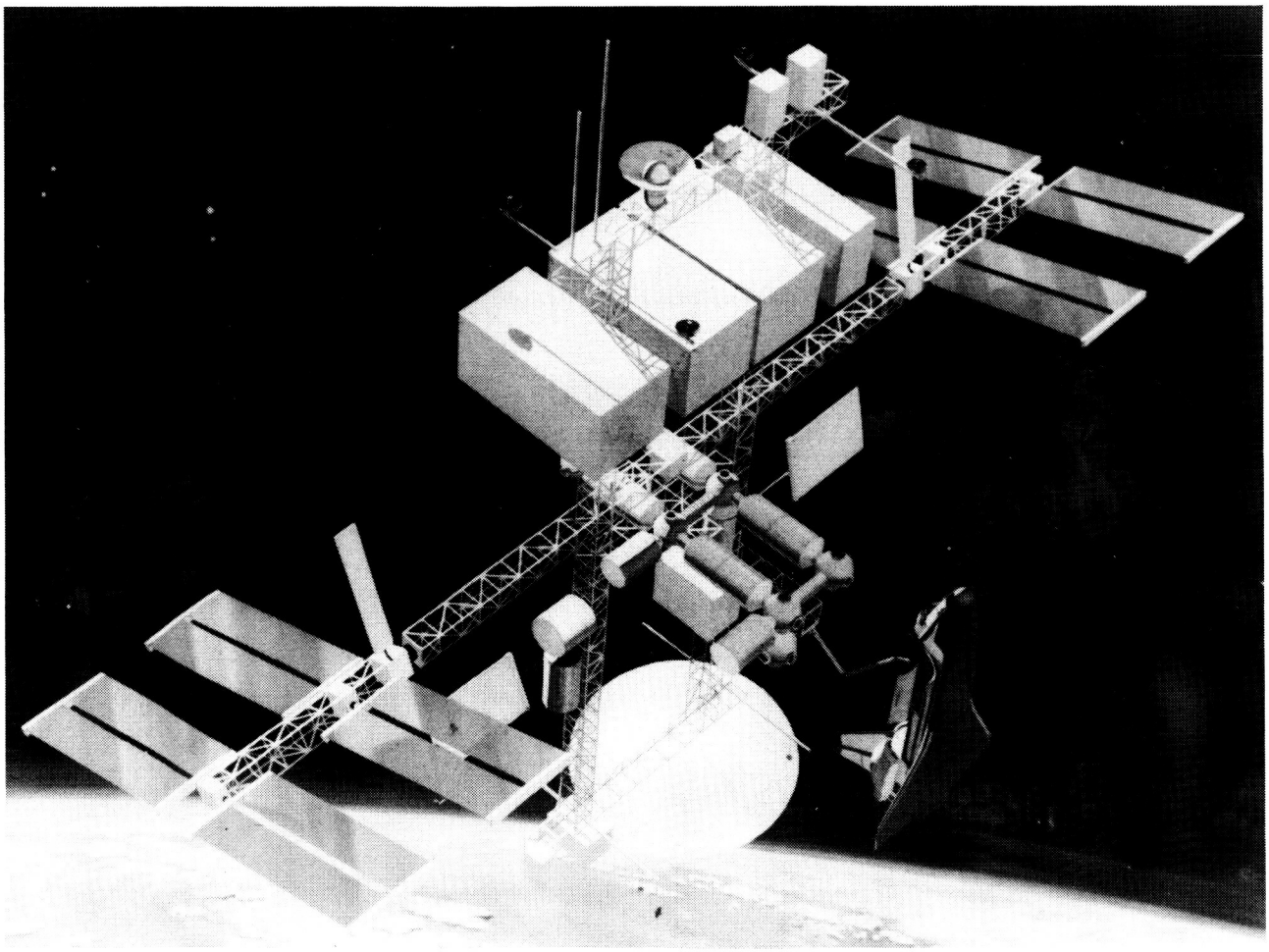
COFS I - Beam Dynamics and Control Technology Overview

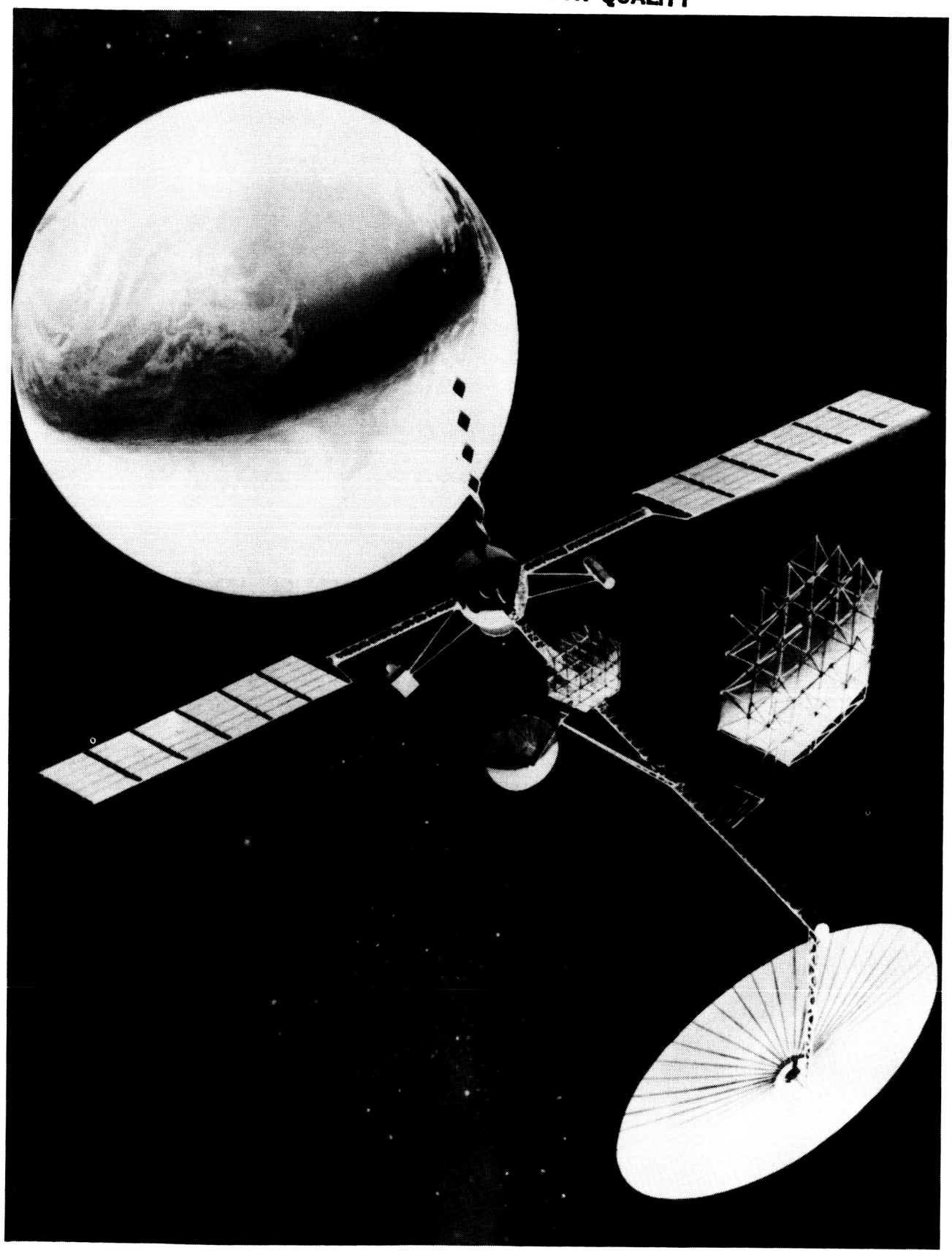
John L. Allen
NASA Langley Research Center
Hampton, VA 23665

First NASA/DOD CSI Technology Conference
Norfolk, Virginia
November 18-21, 1986

INTRODUCTION

NASA and other Government agencies have been exploring the unique characteristics of large space systems, from large orbital antennas to manned space stations, and have initiated the development of technologies required to assure the successful performance of these next-generation spacecraft. The COFS I Project provides the invaluable opportunity to test, validate, and measure the effectiveness of theories, structural concepts, control systems, and flight certification processes for future missions through a research program focusing on multiple issues in large flexible structures, dynamics, and controls. The COFS I Project consists of a series of ground and flight activities building progressively from modeling and dynamic characterization of large space systems to the more complex issues of flexible-body control. The COFS I Project also involves the space structures and controls research community from universities, industry, and Government through a formal Guest Investigator Program in which researchers are selected to participate in all program activity phases.





COFS I TECHNOLOGY GOALS

COFS I is the initiation of a planned series of configurations and tests that are required to achieve the overall long-range goals of the COFS program. Advanced techniques will be used to quantify the benefits and limitations of full-scale ground testing; to correlate scale model results to full-scale performance, both ground and space based; to verify robust control system design methodologies; and to identify the applicability of ground tests necessary to support future programs requiring on-orbit dynamic characterization and robust control.

- **VALIDATE GROUND TEST METHODS**
- **DEVELOP & VALIDATE IN-SPACE TEST METHODS**
- **VERIFY CSI ANALYTICAL TOOLS**
- **ASSESS SCALING EFFECTS**
- **EVALUATE DISTRIBUTED CONTROLS METHODS**

COFS I SPECIFIC OBJECTIVES

Specifically selected research objectives are tailored to attainment of COFS I technology goals and are a major constituent of the overall goals of the Control of Flexible Structures Program.

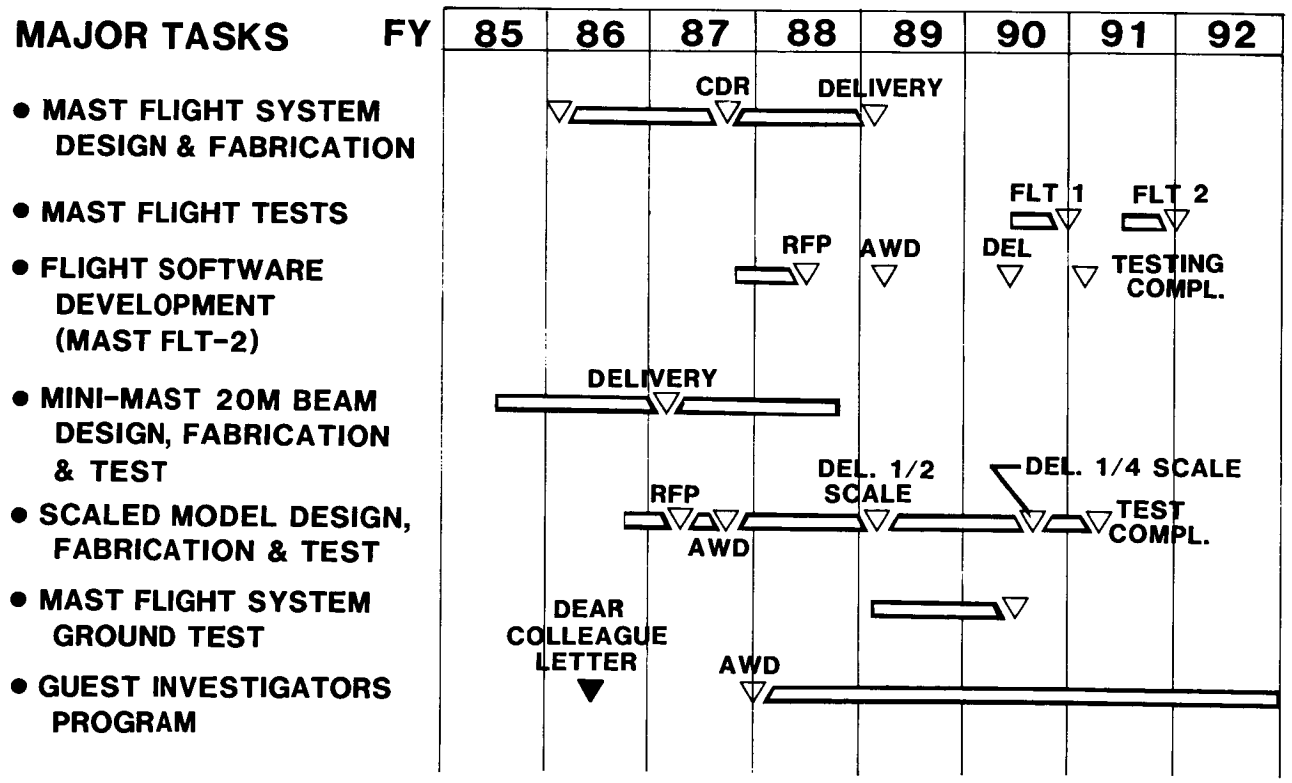
- **DETERMINE DEGREE TO WHICH THEORY AND GROUND TESTING CAN PREDICT FLIGHT PERFORMANCE OF NEXT-GENERATION LOW-FREQUENCY STRUCTURES.**
- **EVALUATE STRUCTURAL FIDELITY OF REPRESENTATIVE NEXT-GENERATION LARGE DEPLOYABLE PRECISION STRUCTURE.**
- **ASSESS MATH MODELING REQUIREMENTS FOR LARGE LIGHTWEIGHT COMPLEX SYSTEMS ON WHICH GROUND TEST RESULTS ARE QUESTIONABLE.**
- **DETERMINE DEGREE TO WHICH SCALE MODEL ANALYSIS AND TESTS CAN BE CORRELATED TO FULL-SCALE PERFORMANCE.**
- **EVALUATE SYSTEM IDENTIFICATION AND STATE ESTIMATION ALGORITHMS ON COMPLEX LIGHTWEIGHT STRUCTURES IN THE SPACE ENVIRONMENT; COMPARE ON-LINE AND OFF-LINE METHODS.**
- **EVALUATE AND VERIFY CONTROLS/STRUCTURES MODELING CAPABILITY.**
- **EVALUATE CONTROL LAWS AND CONTROL SYSTEMS.**
- **EVALUATE DAMPING EFFECTS IN MICRO-G ENVIRONMENT.**

COFS I - BEAM DYNAMICS AND CONTROLS TECHNOLOGY

The schedule shown above depicts major milestones for the significant activity areas which constitute the COFS I program. Each of these activity areas will be addressed briefly in the remainder of this presentation and the follow-on COFS I papers will provide full details of salient programmatic developments.

The Mast Flight System is being developed by Harris Corporation and is the centerpiece of the COFS I ground and flight test activities. This system, as well as the mini-Mast prototypical beam-truss and sub-scale Mast structural models, will experience extensive ground testing and correlative analysis.

A Guest Investigator Program has been established to involve all sectors of the nation's science and technology community in the COFS I research activity. Flight coding of guest investigator algorithms will be accomplished through a separate Government software contract.



MAST FLIGHT EXPERIMENT

The approach, which has been adopted for COFS I research, centers on a flight/test structure with selected generic characteristics of large space structures. This centerpiece of the COFS I Project, the Mast flight system, contains a large (60-meters long) deployable/restowable "next-generation" truss beam attached in a cantilever fashion to its carrier (the STEP) which is, in turn, attached within the Space Transportation System (STS) Orbiter payload bay. Actuators, instrumentation, and avionics necessary for excitation, measurement, and control of the low-frequency modes of this structure are an integral part of the flight system. The beam truss also contains a Parameter Modification Subsystem (PMS) which provides the capability to change flight system physical properties, thereby altering frequency spacing and cross axis coupling between modes. The Mast flight system will be used to support two flight research missions from the STS Orbiter.

COFS I FLIGHT TESTS

The Mast Flight System, bridging the gap between ground modal verification, on-orbit modal verification, and validation of control methodologies, makes use of the same flight structure for both the ground tests and the two flight tests. As structural characteristics are identical, ground modal testing and on-orbit modal testing can be compared and evaluated. Also, as no hardware modifications are required for flight two, the structural characteristics will be the same for the distributed flex-body control experiment of that flight and the systems identification experiment of the first flight; i.e., the control algorithm will work against a system model that has been previously characterized, both on the ground and on-orbit.

Mast I. - The first flight (Mast I) of the two mission scenario basically addresses the aspects of large flexible structures and structural dynamics with rudimentary research tasks in structural damping. The Mast I experiment is dynamically excited by the subsystems of the Mast experiment at various lengths of extension, with and without modal alteration by the Parameter Modification Subsystem (PMS), and response data collected. At the conclusion of the flight test sequence, which should occupy three or four days of activity, the flight system will be restowed for the descent and landing phase. Upon return of the flight data, systems identification techniques and ground-based analyses will be conducted to structurally and dynamically characterize the beam-truss in the space environment and to establish and improve the validity of preflight ground test data and analytical models.

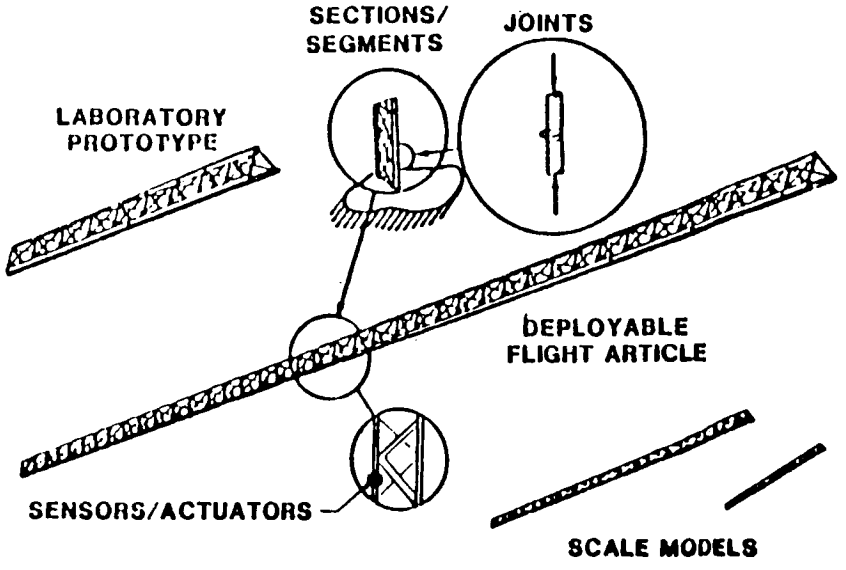
Mast II. - In the second flight experiment of the COFS I Project, the Mast test article will be reflown without modification of its hardware complement. During the Mast II flight, the beam structure will be excited, response data collected, and the modal characteristics determined by ground-based systems identification to verify that the structure is modally identical to that flown on the first flight. Experiments in distributed control will be conducted to evaluate performance of flex-body control algorithms operating in conjunction with a structure that has been modally characterized after launch.

GROUND-BASED TECHNOLOGY

Prior to flight mission activities, there is an extensive ground-based program to be conducted in-house to prepare for the flight phase. These activities include: (1) Utilization of prototypic full scale 20-meter truss beam segment ("mini-mast") to aid in development of structural modeling methodologies and as a preliminary test bed for examining Mast full scale dynamic characterization techniques and to evaluate flex-body control algorithms for a distributed control system, and (2) Development of one-quarter and one-half scale structural models of the Mast beam truss; complete ground-based characterization of these systems will be accomplished through modeling, testing, and analysis of the scaled components and assemblies. Prediction of Mast full scale characteristics will be developed from sub-scale model results, and correlation of these predictions with results of Mast flight system testing, ground and space-based, will be accomplished.

GROUND TEST APPROACH

GROUND TEST HARDWARE

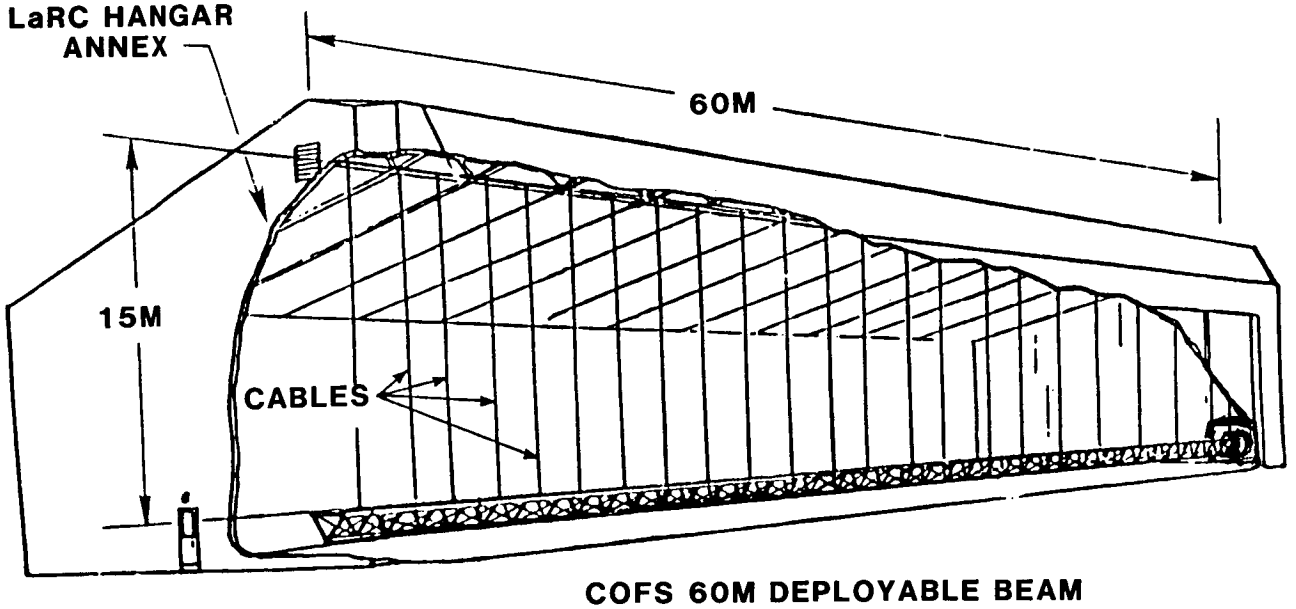


OBJECTIVES

- DEVELOP GROUND TEST METHODS AND CAPABILITY
- EVALUATE CONTROLS INSTRUMENTS
- VALIDATE CONTROL STRUCTURES ANALYSES
- EVALUATE SCALING METHODS
- EVALUATE JOINTS/ DAMPING EFFECTS
- DEVELOP STRUCTURAL DEFINITION OF FLIGHT ARTICLE

MAST FLIGHT SYSTEM GROUND TEST

The ground-based testing of the 60-meter Mast flight system will be accomplished by suspending the beam horizontally and measuring modes and frequencies to provide ground-based data by which predictions of space-based system responses may be developed. Response instrumentation and control parameters will be thoroughly evaluated. Flight performance predictions, derived from ground-based testing and advanced modeling and analytical techniques, will be assessed and ultimately correlated with zero-g Mast system flight performance data, thereby providing a quantitative measure of the ability to predict zero-g system dynamics utilizing ground-based certification methodologies.



COFS 60M DEPLOYABLE BEAM

GUEST INVESTIGATOR PROGRAM

A Guest Investigator Program is being established to create a partnership with NASA, other Government laboratories, universities, and industry for direct participation in the science activities for each Mast flight and in the ground-based program. Research proposals have been solicited and received from the above community and are presently being evaluated; this process will ultimately lead to a selection of experiments by the Office of Aeronautics and Space Technology (OAST) for inclusion in the Control of Flexible Structures COFS I research program.

OBJECTIVE:

TO PROVIDE OPPORTUNITIES FOR AND PROMOTION OF GENERIC RESEARCH BOTH GROUND AND IN-SPACE AMONG INDUSTRY/ UNIVERSITY AND GOVERNMENT FOR THE DEVELOPMENT OF CONTROLS/STRUCTURES INTERACTION TECHNOLOGY

APPROACH:

ESTABLISH GROUND AND IN-SPACE FACILITIES WHICH PROVIDE FOR INDIVIDUAL AND/OR COMPANY EXPERIMENTS AT MINIMUM COST

PAYOFF:

- **BROAD BASE FOR ADVANCED CSI METHODOLOGIES**
- **DISSEMINATION OF PROGRAM DATA & FINDINGS WITHIN CSI COMMUNITY**
- **IN-SPACE RESEARCH AWARENESS**

COFS I SUMMARY

- Mast Flight System development contract has been underway for a year with delivery scheduled for late 1988.
- Ground test preparations are moving forward; the 20 meter mini-Mast test program to start soon. RFP for Scale Model Structures to be released early next year.
- Guest Investigator (GI) research proposals have been received and selection process underway leading to selection and award of GI contracts/grants in 1987.
- COFS I first flight (Mast I) tentatively scheduled for October 1990 with second flight (Mast II) a year later.