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CONTROL OF FLEXIBLE STRUCTURES AND THE RESEARCH COMMUNITY

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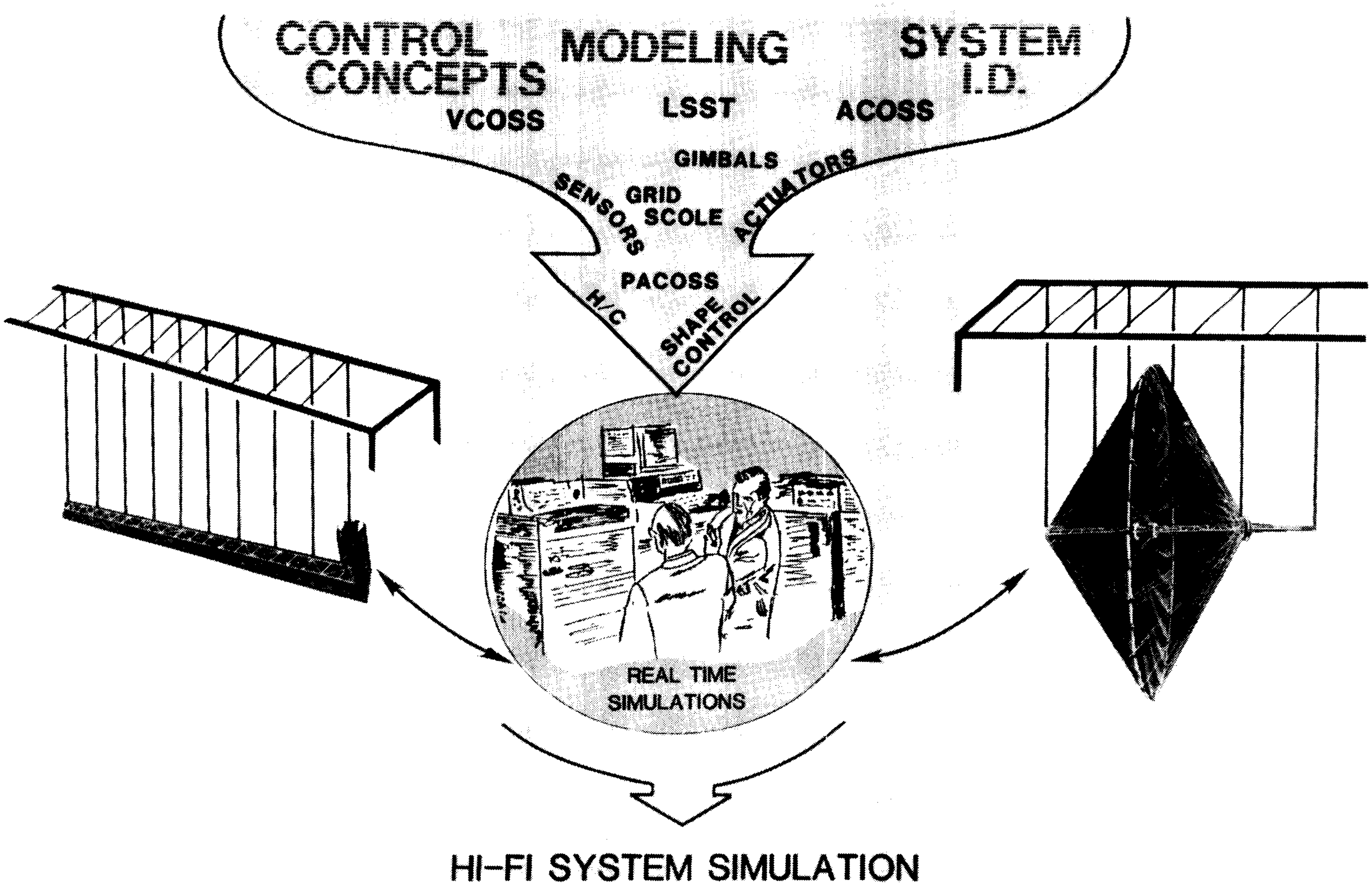
INTRODUCTION

A major new NASA activity has been initiated to develop the technologies required for understanding the control and structures interaction effects for large, flexible spacecraft structures. This activity, called the Control of Flexible Structures (COFS) program has been separated into three projects: COFS I, the development of ground and flight test hardware for validating the controls and structures interaction effects on a beam structure mounted in the Space Shuttle bay; COFS II, the natural extension of the simple beam testing through the construction of a three-dimensional test bed which will be utilized to validate the methodologies involved in modeling and controlling large, flexible structures in a space environment; and COFS III, the development of the ground test methodologies for multi-body configurations such as the space station concept. The goal of these COFS projects are to generate a technology data base that will provide the designer with alternatives for the improvement of spacecraft performance.

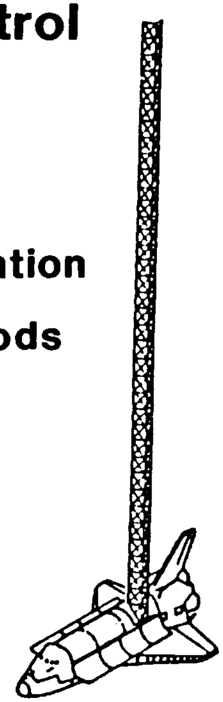
COFS II HYBRID TEST CONCEPT



CONTROL OF FLEXIBLE STRUCTURES

COFS I

Beam Dynamics & Control

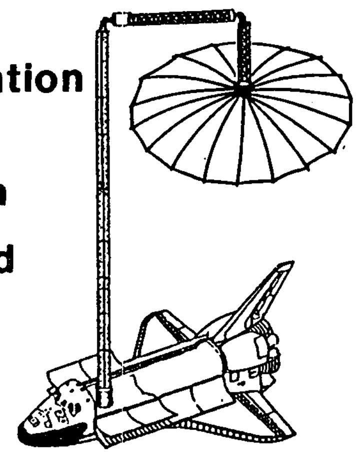


- Systems Identification
- Test Methods
- Distributed Controls

COFS II

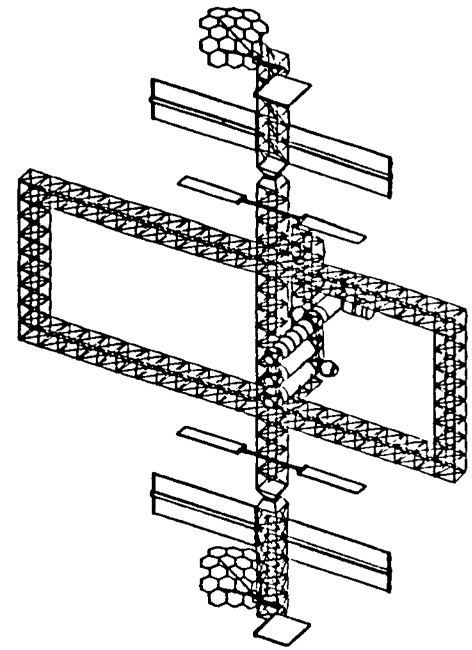
Three-Dimensional Dynamics & Control

- Systems Identification
- Shape Definition
- Distributed Controls
- Adaptive Controls



COFS III

Multi-Body Dynamics & Control



- Test Methods
- Systems Identification
- Model Sensitivities
- Analysis Validation
- Space Station Supporting Technology

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COFS II PROJECT OBJECTIVES

The COFS II project objectives are to develop and evaluate the control/structures interaction technologies needed for effective control of large, flexible, three-dimensional space structures. These functional capabilities are to be developed using sensor and actuator components physically distributed over the flexible flight test structure. The project test hardware will provide a point of focus for the development and evaluation of these functional technologies. Their development requires three types of technical activities; (1) Open-loop Modeling, the prediction of the on-orbit open-loop dynamics and performance using ground-based analytical and experimental methods with validation by orbital testing; (2) Control System Development, the development of control system algorithms and control components to establish the desired functional capabilities; and (3) Closed-loop Modeling, the prediction of the on-orbit closed loop dynamics and performance using ground-based analytical, empirical, and hybrid testing with validation by orbital testing.

CONTROL OF FLEXIBLE STRUCTURES

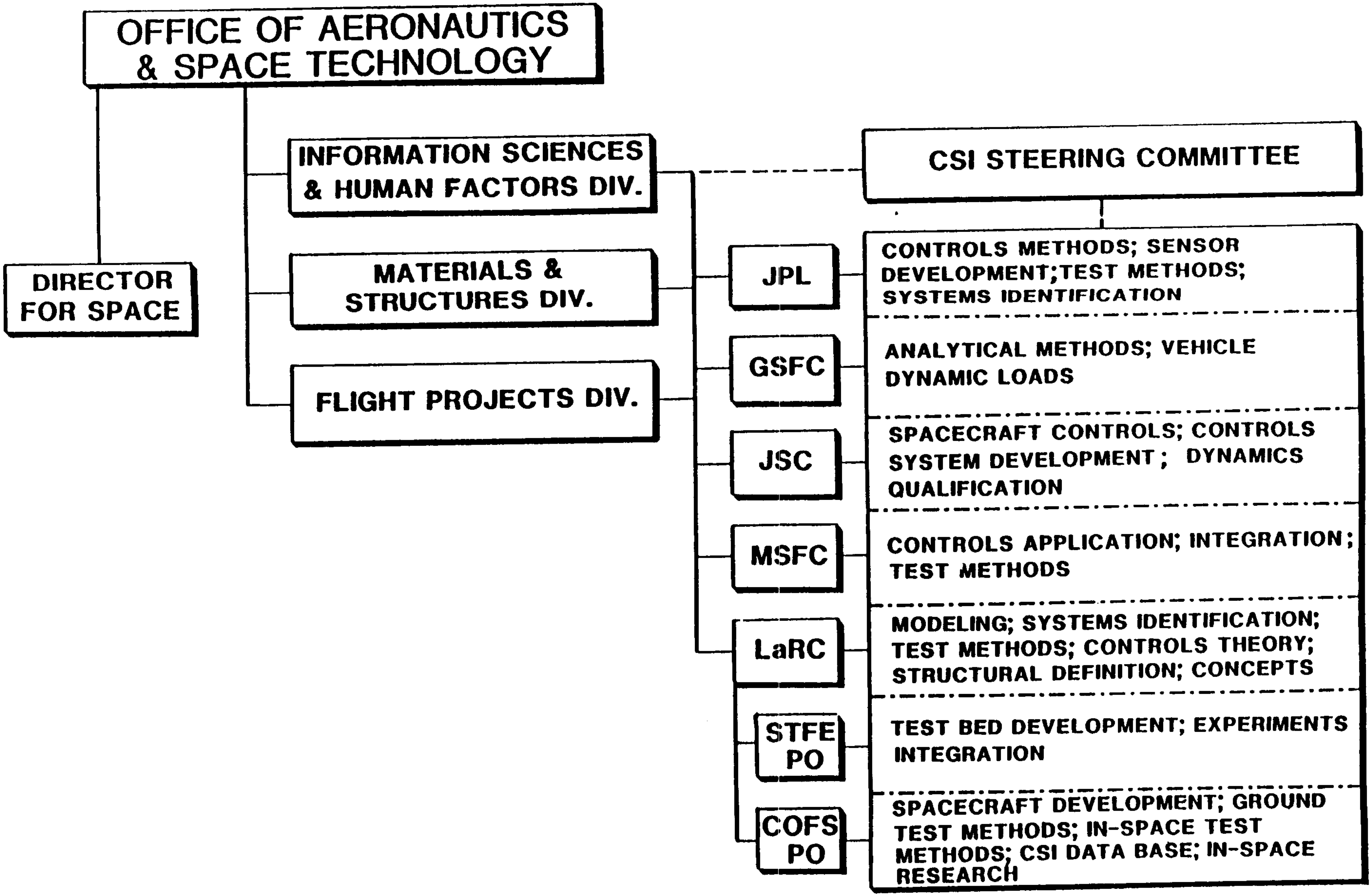
COFS II Project Objectives

- DEVELOPMENT AND EVALUATE THE METHODOLOGIES INVOLVED IN MODELING AND CONTROLLING LARGE, FLEXIBLE, 3-D STRUCTURES IN SPACE

SPACECRAFT CONTROLS/STRUCTURES INTERACTION (CSI) TECHNOLOGY PROGRAM

The Control of Flexible Structures (COFS) program was developed based on recommendations of the Controls/Structures Interaction (CSI) subcommittee of the Space Systems Technology Advisory Committee (SSTAC) as well as NASA/OAST and the NASA field Centers. The program funds for the conduct of the CSI projects are under the direction of the OAST Director for Space. A steering committee consisting of the NASA/OAST Division Chiefs for Information Sciences and Human Factors, Materials and Structures, and Flight Projects was formed to provide guidance in the development of the CSI technologies and to assure that these results are communicated between the NASA Research Centers and the CSI community. The CSI Technology Program figure indicates representative research efforts being conducted within each of the NASA spacecraft oriented centers and the related NASA Langley Shuttle Technology Experiments Pallet (STEP) and Control of Flexible Structures (COFS) programs.

SPACECRAFT CONTROLS/STRUCTURES INTERACTION (CSI) TECHNOLOGY PROGRAM

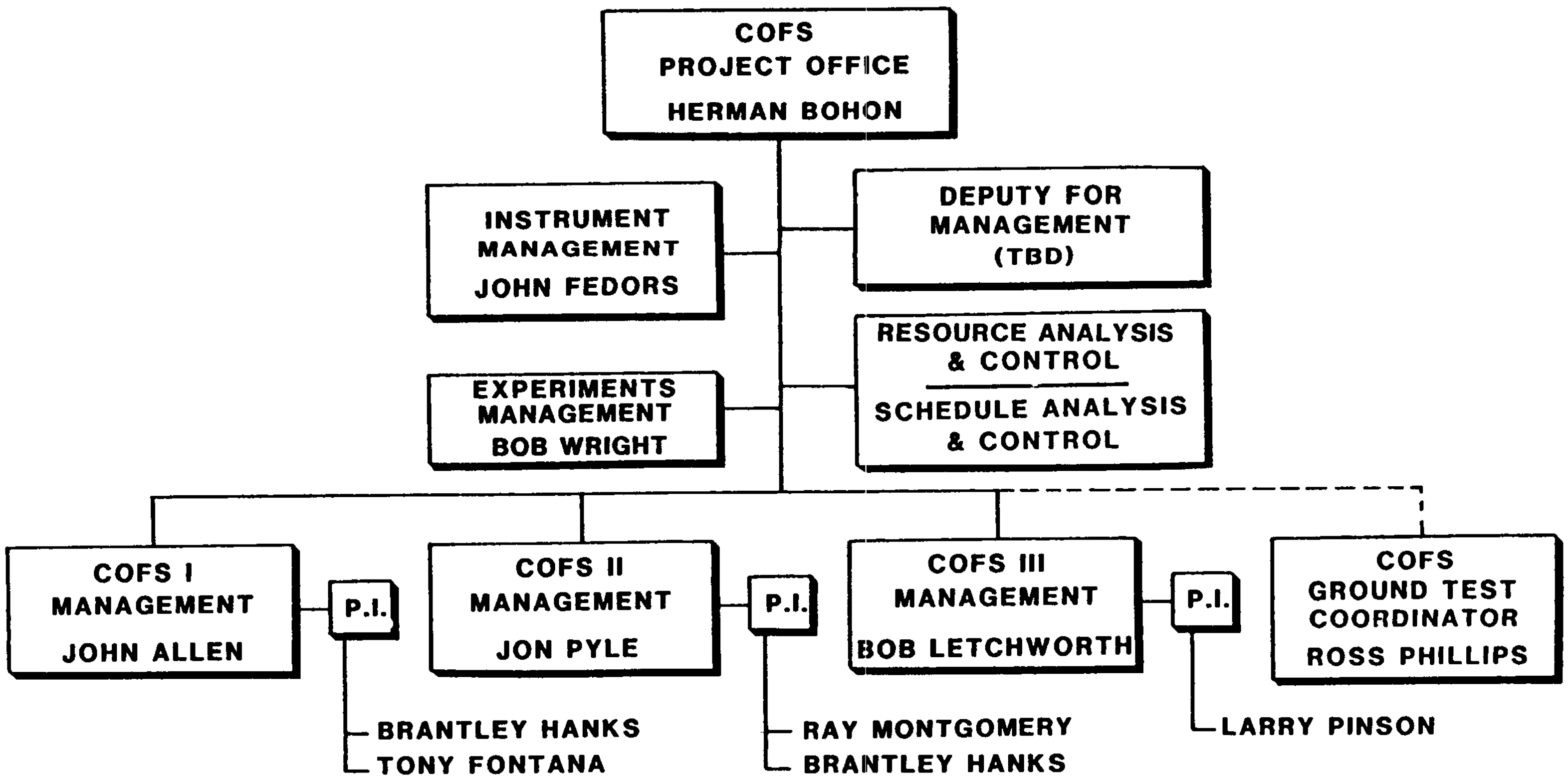


NASA LANGLEY COFS ORGANIZATION

The COFS Project Office is located within the Electronics Directorate at NASA Langley Research Center. This office has the responsibility for implementing the project requirements, goals, and objectives defined by the Langley Structures and Flight Systems Directorates into ground and flight experiments for the development and validation of Controls/Structures Interaction technologies for large, flexible structures. The Project Office is responsible for advocacy of the COFS projects within the CSI community, NASA/OAST and the associated NASA Centers, and for assuring that the COFS projects stay within the costs and schedules accepted by the CSI Steering Committee. In addition, the Project Office is responsible for managing the Guest Investigator contracts and to assure that their experiments are incorporated into each of the COFS projects.

The Project Office is separated into three projects to develop beam dynamics and controls (COFS I), three-dimensional structural dynamics and controls (COFS II), and multi-body structural dynamics and controls (COFS III). Each of these projects have Principal Investigators identified from the Structures and Flight Systems Directorates to guide the project in the development and validation of the technologies. Since a large portion of the experimental effort will be concerned with the ground testing of various scale models of the project hardware, a ground test coordinator has been identified to best utilize the facilities and resources available to the COFS project.

NASA LANGLEY COFS ORGANIZATION



COFS WORKSHOP RESULTS

A Controls/Structures Interaction (CSI) workshop was held at NASA Langley Research Center on August 27-28, 1985. The purpose of the workshop was to review the objectives and hardware proposed for the COFS I project; define the critical technology needs and identify test configurations to develop the critical technologies for large, three-dimensional, flexible structures (COFS II); and to define methods for CSI community participation in the proposed COFS ground and flight tests.

Six discipline panels consisting of approximately ten (10) members each from the CSI community and two members each from NASA LaRC were asked to review the proposed Mast dynamics and controls project and determine the technology needs requiring development in the next generation project. Nine major technology needs were identified requiring the utilization of a three-dimensional configuration as a follow-on to the simple beam experiments of the COFS I project.

After completion of the discipline panel meetings, six configuration panels were organized from members of each of the discipline panels to define viable three-dimensional flight configurations for the COFS II project. Most panels agreed that the configuration should include secondary boom attached by gimbals to a "realistic antenna" and to the Mast beam developed and validated during the COFS I project. Other configurations identified consisted of simpler gimballed booms with masses; however, these configurations did not fully satisfy the development of all the critical technologies.

COFS WORKSHOP RESULTS

August 1985, NASA Langley Research Center

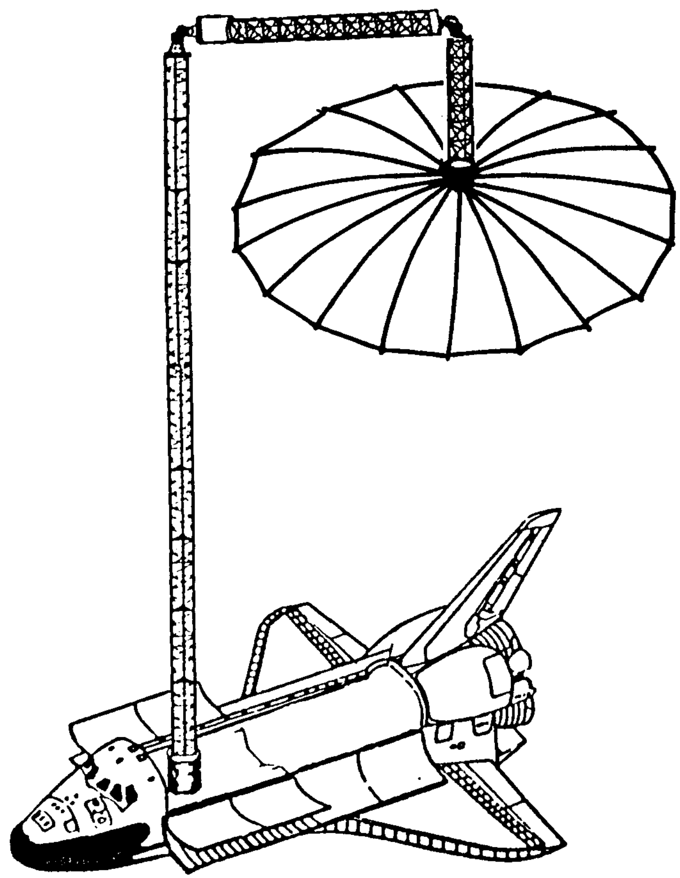
- DEFINED CRITICAL CONTROLS AND STRUCTURES TECHNOLOGY REQUIREMENTS FOR 3-D SPACE EXPERIMENTS
- IDENTIFIED 3-D CONFIGURATION FOR GROUND AND ON-ORBIT TESTING

COFS II WORKSHOP CONFIGURATION TECHNOLOGIES

The COFS II workshop configuration and the critical technologies recommended for development and validation during ground and flight tests are identified in the attached figure. The vertical beam structure shown is the Mast beam which will be extensively ground and flight tested during the COFS I project. Two gimbal assemblies providing a minimum of two (2) degrees of freedom (DOF) each are utilized to connect a secondary deployable boom to the tip of the Mast beam and the boom to the antenna. This secondary boom provides adequate separation between the Mast and an antenna to allow full articulation of the antenna. The secondary boom modal characteristics should be capable of combining with the structural modes of the Mast to provide additional modal characteristics of research interest. The antenna should be realistic in the sense that the technologies developed will have generic application to the industry as a whole rather than to one specific design. The antenna should have a mesh surface with adequate controllability to permit quasi-static changes (long period) in the local surface shape. This controllability will permit validation of control techniques to correct contour errors in the antenna shape caused by over-stretching of the mesh during deployment, thermal distortion or deterioration of the mesh fabric.

The primary technology needs for the three-dimensional configuration are centered around understanding the control of large, flexible structures during repositioning. Therefore, the understanding and development of control techniques for maneuvering, articulation, slewing, pointing or aiming, of the appended bodies, with some degree of precision, and the controllability of the antenna surface shape to assure maximum transmission/reception efficiency are of primary interest. In order to effectively control the secondary boom and antenna, an understanding of the structural characteristics of the three-dimensional configuration is required including the deployment dynamics, system identification/structural evaluation, structural dynamics and vibration characteristics. The successful development and validation of these primary technologies will then permit the further development of adaptive control technologies for this complex configuration.

COFS II
WORKSHOP CONFIGURATION/TECHNOLOGIES



CRITICAL TECHNOLOGY NEEDS

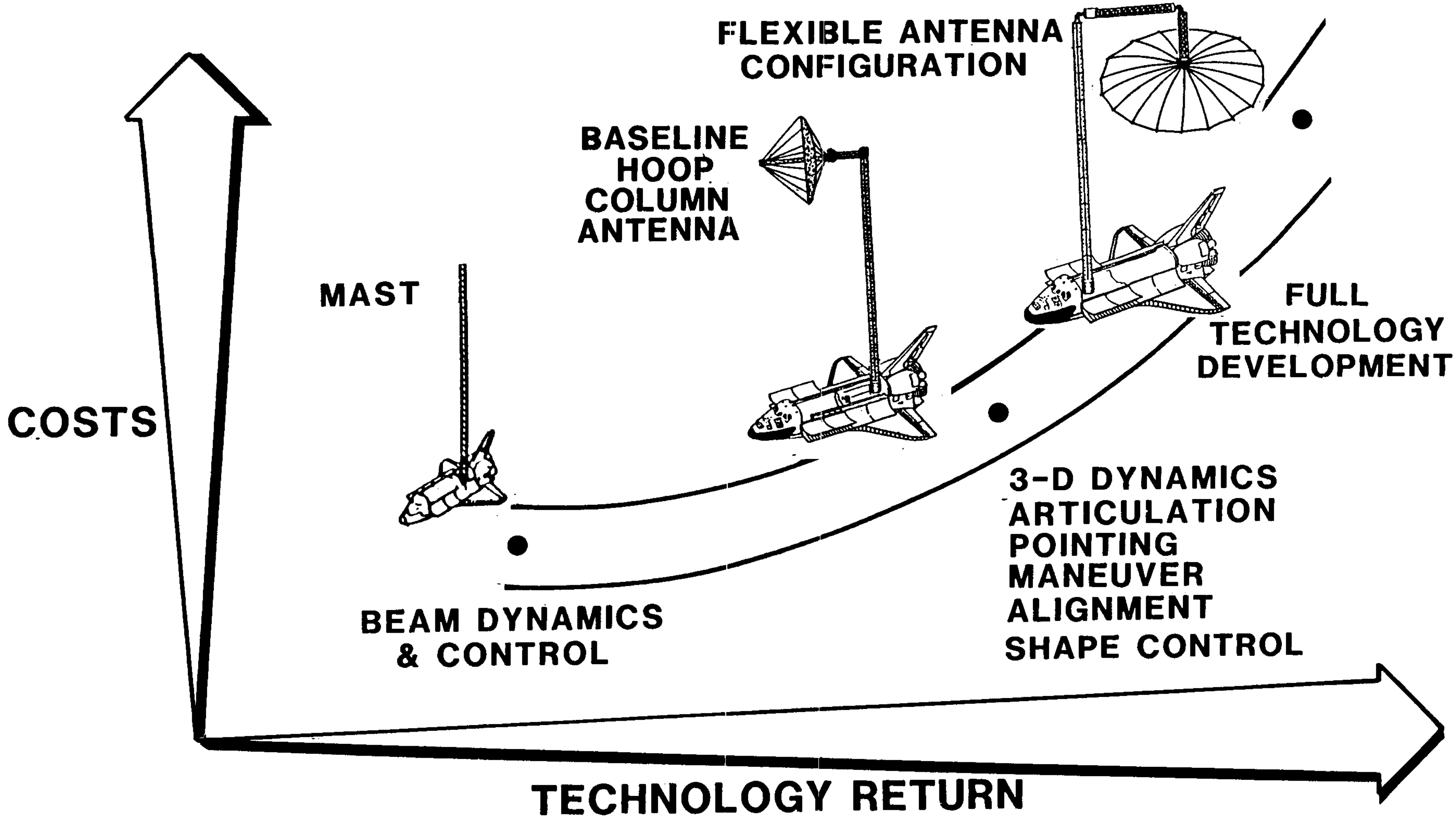
- POINTING/AIMING
- ARTICULATION
- SLEWING
- SHAPE CONTROL
- MANEUVER LOAD
- ALIGNMENT
- SYSTEMS IDENTIFICATION
- STRUCTURAL EVALUATION
- DEPLOYMENT CHARACTERIZATION
- VIBRATION CONTROL
- ADAPTIVE CONTROL

COFS II CONFIGURATION COST OPTIONS

A project cost estimate was completed for various types of large, flexible, three-dimensional configurations which would satisfy the critical technology recommendation of the workshop. The results of this exercise is shown on the figure with increasing project costs as the vertical axis and increasing technology return as the horizontal axis. The COFS I project, Beam Dynamics and Control, was shown as a bench mark of the relative project development costs. Obviously, as the number of technologies and the complexity of the configuration increases, the project costs also increase. Many of the technologies defined at the Langley workshop can be partially developed and validated through the testing of a simplified version of the workshop configuration. However, to achieve full technology development and validation of all the workshop technologies, the configuration recommended by the workshop attendees would probably be required.

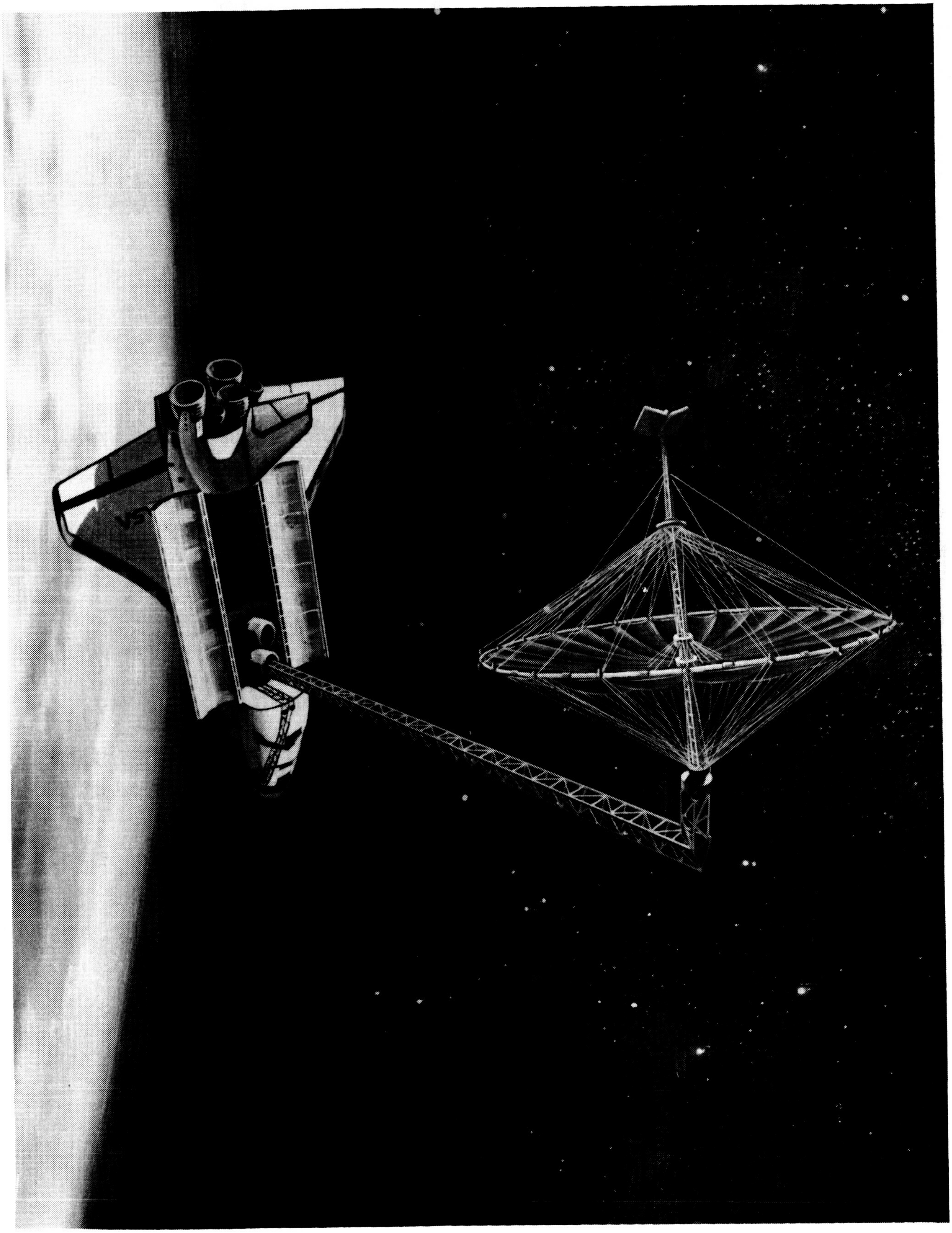
CONTROL OF FLEXIBLE STRUCTURES
COFS

COFS II CONFIGURATION COST OPTIONS



ARTIST CONCEPT OF COFS II STUDY CONFIGURATION

The artist rendition of the COFS II configuration shows the Langley designed and developed Hoop/Column antenna attached to the tip of the Mast by means of a two (2) degree of freedom gimbal assembly. This concept, with exception of the feed unit, was utilized as the study configuration for an in-house engineering analysis to determine the feasibility of attaching a realistic antenna to the Mast and developing control and structures technologies. The Hoop/Column antenna has extensive ground testing background plus currently planned development of a quasi-static surface control system for one antenna quadrant (one-fourth of the mesh surface) and is owned by NASA. This configuration will allow partial development of all the critical technologies defined by the COFS Workshop. The canisters will be connected by means of the gimbal assembly and a short (2.5 meters) structural adaptor. During deployment, the Mast will extend to any desired length (up to 60 meters) carrying the undeployed Hoop/Column antenna. The antenna can be fully deployed and then articulated by means of the two degree-of-freedom gimbal assembly. Technology development, evaluation and validation can then be initiated. Upon completion of the flight tests, the antenna and the Mast will be restowed into their respective canisters for the landing phase of the mission.



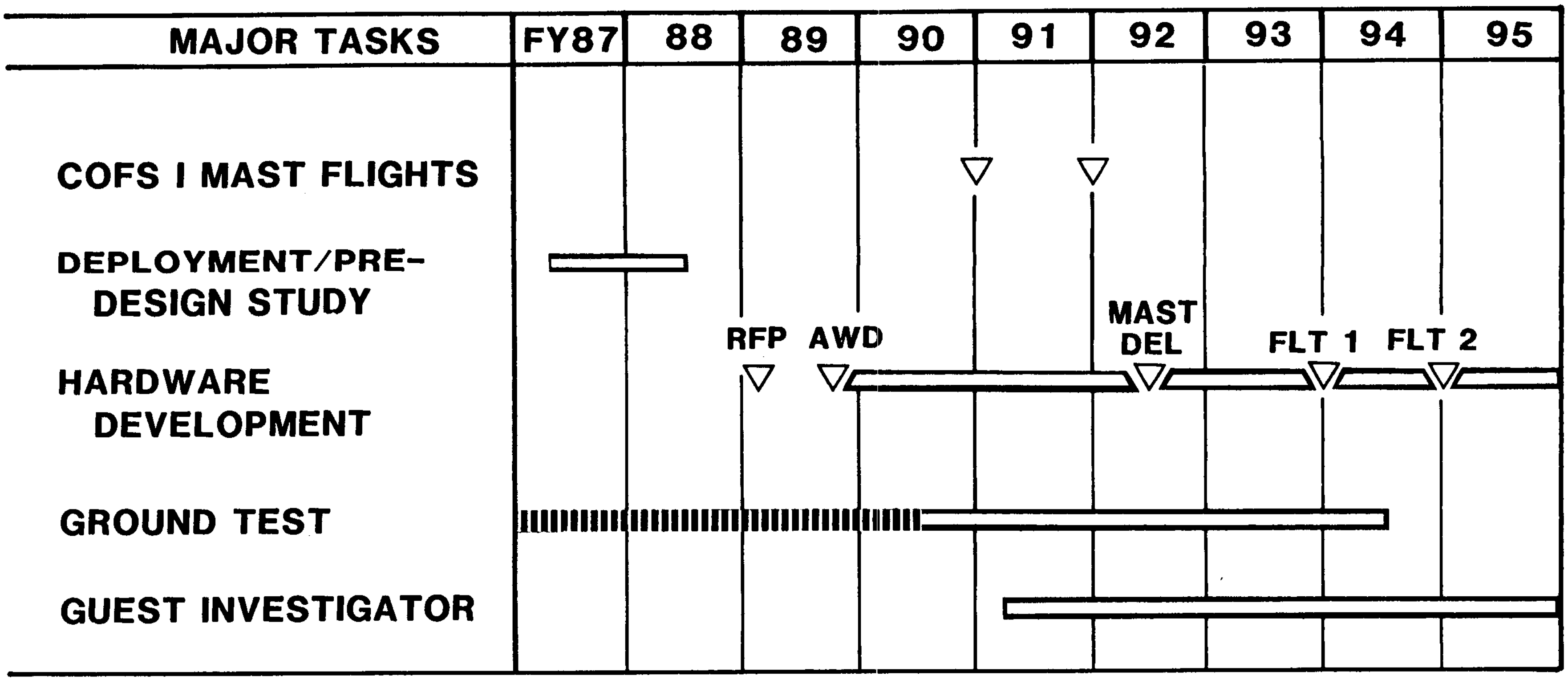
COFS II PROJECT SCHEDULE

The anticipated delay caused by the loss of the Space Shuttle vehicle in January 1986, may slip the expected flight dates for the COFS I project to October 1990 and October 1991. Since the COFS II configuration utilizes the Mast beam developed and validated during the COFS I flight tests, the earliest expected flight date for the COFS II project phase is October 1993. The 18 months identified between the test flight delivery of the Mast and the first COFS II mission will be used for refurbishing the Mast, adding wiring and power, integrating and testing the COFS II hardware, and preparing the COFS II payload for Shuttle integration. The initiation of the hardware development contract in FY 1989 should allow adequate time for the development and verification of the COFS II unique hardware (such as the gimbals and antenna) prior to the required delivery date of the Mast beam for integration. The deployment and pre-design study identified for the FY 1987 through FY 1988 period should provide preliminary solutions to current concerns and issues identified for the COFS II concept.

The ground test schedule is shown as a dashed line representing non-project sponsored basic research development and testing being conducted on related structures which will have a direct input to the COFS II configuration. These tests include work being accomplished through the Air Force with Marshall, development and verification of sensors/actuators at JPL, MSFC and LaRC, and in-house Langley research on the Grid Test Fixture and, SCOLE, as well as the structural surveys and surface controllability efforts on the Hoop/Column antenna. This background information will be utilized in the development of a HYBRID GROUND TEST CONCEPT which will pave the way for understanding and establishing the techniques necessary for ground testing very large flexible structures.

In conjunction with the development of the COFS II hardware and the hybrid ground testing, a guest investigator program will be initiated to encourage participation by industry, universities, and government in the development and validation of the COFS II technologies. Individuals with specific scientific experiments will be invited to support the ground and flight experiments.

COFS II PROJECT SCHEDULE



GUEST INVESTIGATOR OPPORTUNITIES

Opportunities for participation by the Controls/Structures Interaction community in the analysis, ground and flight testing of the COFS II configuration can be realized through several research areas. These areas were characterized in the "Guidelines for Participation in the Control Of Flexible Structures (COFS I) Guest Investigator Program" as: (1) STRUCTURES, such as deployment kinematics and beam static precision; (2) STRUCTURAL DYNAMICS, such as dynamic math modeling (partial or complete configuration), systems identification/structural evaluation, damping prediction, ground test methodology, and on-orbit test methods; and (3) CONTROL OF FLEXIBLE STRUCTURES, such as vibration suppression, sensor and actuator dynamic modeling, articulation control, slewing control, pointing and aiming control, maneuver load control, alignment control, antenna surface shape control, adaptive control and failure detection identification, and re-configuration. The COFS II project may provide the opportunity of allowing the integration of unique hardware (sensors, actuators, structures, etc.) into the ground and/or flight test configuration for development and validation. These examples should in no way be construed as preferential and, in fact, innovative and unique experiments are encouraged.

Within the broad technology areas listed above, research may be subdivided into analysis, development of software, and development of hardware. Each of these subdivisions may apply to either ground research or flight research. The "analysis" subdivision involves the development of control algorithms and modeling techniques as well as the use of ground and/or flight test data in a research investigation, e.g., computation of beam damping for joint test data. The "development of software" subdivision involves development of algorithms to be executed by the experiment computer during ground and/or flight tests, e.g., adaptive control law design. The "development of hardware" subdivision involves development of unique hardware that becomes part of the ground and/or flight test article.

GUEST INVESTIGATOR OPPORTUNITIES

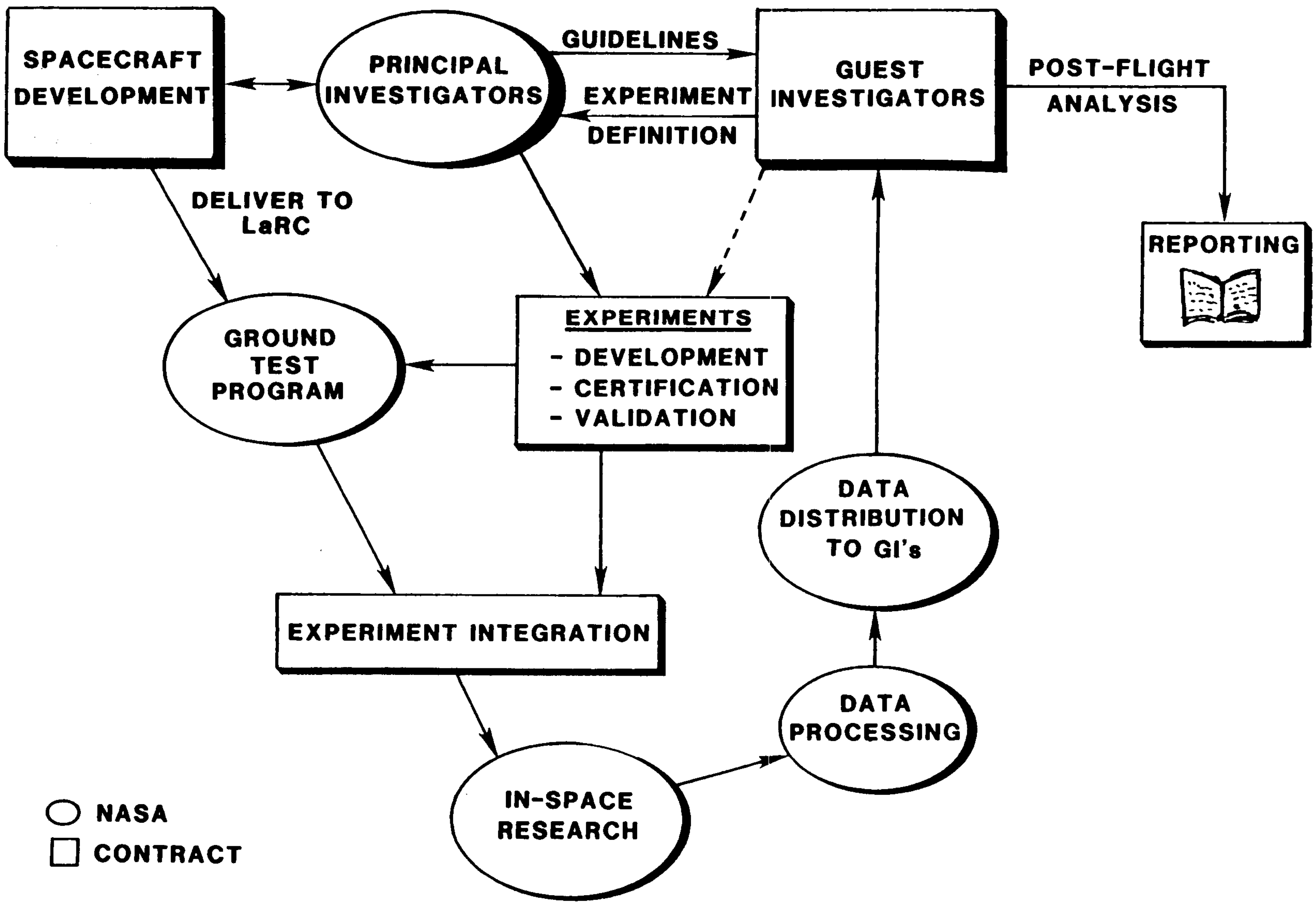
(TYPICAL)

- STRUCTURAL DYNAMICS
- FLEX-BODY CONTROL ALGORITHMS
- SYSTEM IDENTIFICATION ALGORITHMS
- FLIGHT & GROUND TEST METHODS
- MATH MODELLING
- VIBRATION SUPPRESSION
- ANALYSIS OF GROUND & IN-SPACE TEST DATA
- FLIGHT TESTING OF UNIQUE HARDWARE

GUEST INVESTIGATOR TECHNOLOGY TRANSFER

The interaction between NASA and the Guest Investigators (GI's), during conduct of the COFS II project, is shown on the COFS TECHNOLOGY TRANSFER figure. The circles represent those project tasks which will be accomplished within NASA and the squares indicate those tasks to be accomplished by contract (either Hardware Developer or Guest Investigator). The GI's will respond to experiment guidelines generated by the COFS II Principal Investigators and define experiments to be conducted during the ground and flight tests. The experiments will be developed and certified in conjunction with the hardware contractor and the COFS II project office and then validated during the ground and/or flight testing. The data obtained from the testing will be processed through the NASA Data Processing system and distributed to both the GI's and the Principal Investigators. The GI's will have prime responsibility for analyzing the data and reporting the results.

COFS TECHNOLOGY TRANSFER



COFS II FLIGHT EXPERIMENT OBJECTIVES

The objectives of the COFS II flight experiment encompass not only the inflight validation of control techniques and methodologies, or the characterization of the large flexible test article, but also the verification of the design approaches applied during the course of the program evolution. These include correlation of flight test results with ground test and analytical predictions to determine the viability of assumptions and modeling decisions made in the development of the system design. In addition, the flight results will be used to establish the viability of the hybrid testing techniques used in predicting on-orbit performance of a large, flexible, and complex structure. Validation of this testing method for large complex systems, as well as verification of the design approaches will be instrumental in the success of future large spacecraft missions.

CONTROL OF FLEXIBLE STRUCTURES

COFS II Flight Experiment Objectives

- DEVELOP AND VALIDATE ADVANCED CONTROL METHODOLOGIES ON A LARGE, 3-D FLEXIBLE STRUCTURE IN A ZERO-G ENVIRONMENT
- IDENTIFY AND CHARACTERIZE THE PLANT DYNAMICS OF A LARGE, 3-D FLEXIBLE STRUCTURE IN A ZERO-G ENVIRONMENT
- CORRELATE FLIGHT TEST RESULTS WITH GROUND TEST AND ANALYTICAL PREDICTION
- ESTABLISH VIABILITY OF HYBRID TESTING TECHNIQUES FOR PREDICTING ON-ORBIT PERFORMANCE OF LARGE, FLEXIBLE, AND COMPLEX SYSTEMS

COFS II TECHNICAL GOALS

The technical goals associated with the COFS II flight experiment program are illustrated in this figure. As can be noted, these goals address issues associated with modeling as well as control of large flexible structures. In the modeling area, it is desired to assess the accuracy of the various models generated for the system configuration, and to evaluate the ability and desirability of utilizing a synergistic combination of analytical, ground and flight test data to develop the high fidelity model of the large flexible structure. Specifically, prediction of the modal frequencies, mode shapes and slopes within five percent, and modal damping within 20 percent for the first ten modes is desired. For the controls discipline, it is deemed essential to establish control synthesis techniques for future missions by comparing the predicted and on-orbit performance of the system incorporated in the COFS flight article. In addition, evaluation of the performance improvements which can be realized from real time, in-situ systems identification must be assessed along with the robustness of the control configuration used on this flight system. Finally, critical technologies in the areas of shape control, articulation, pointing, and failure detection for large, flexible, complex systems must be examined. Specific technical goals for each of these individual tasks are identified on the right hand column of the figure and include goals on stability margins and damping augmentation, bandwidth, impact of modeling uncertainties, and failure detection thresholds.

CONTROL OF FLEXIBLE STRUCTURES

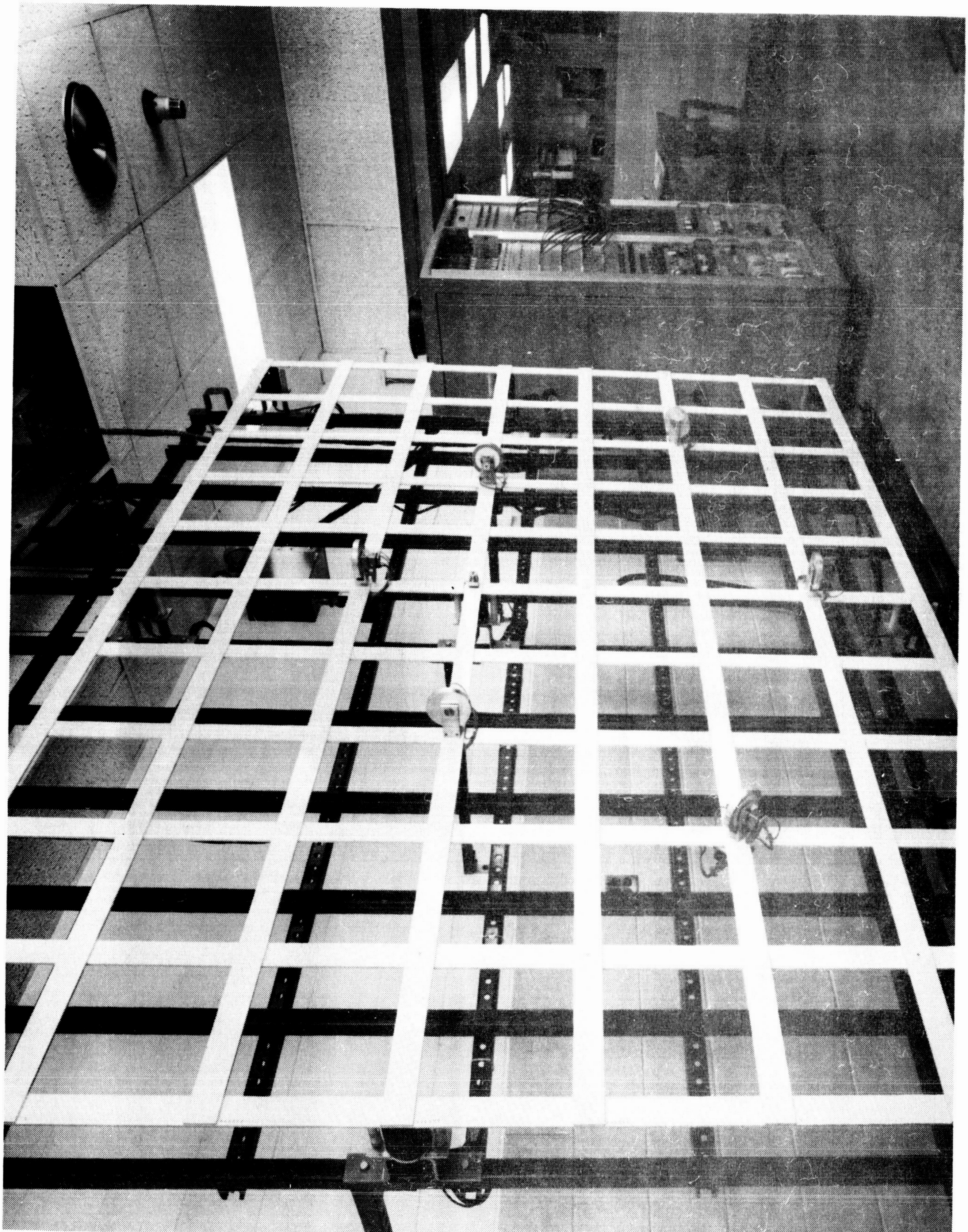
COFS II TECHNICAL GOALS

CONTROL	SPECIFIC GOALS
ASSESS CONTROL SYNTHESIS TECHNIQUES BY COMPARING PREDICTED AND ON-ORBIT SYSTEM PERFORMANCE	• STABILITY MARGINS WITHIN 25% AUGMENT DAMPING TO 5% .... FOR FIRST FIVE MODES
DEMONSTRATE PERFORMANCE IMPROVEMENTS ARISING FROM ON-ORBIT SYSTEMS IDENTIFICATION	• INCREASE BANDWIDTH BY 100% SAME STABILITY MARGINS
EVALUATE SYSTEM ROBUSTNESS	• MODAL FREQUENCIES UP TO 15% MODAL DAMPING UP TO 100% MODE SHAPES AND SLOPES UP TO 20% .... ALL MODES
VALIDATE SHAPE CONTROL, ARTICULATION, POINTING, AND FAILURE DETECTION TECHNIQUES	• SHAPE WITHIN 1 MILLIMETER DETECT ANGULAR VELOCITY FAILURE AT 1 DEG/SEC DETECT ACCELERATION FAILURE AT 0.2 M/SEC^2

MODELING	SPECIFIC GOALS
ASSESS ACCURACY OF MODELS OF 3-D, JOINT DOMINATED STRUCTURE AT ZERO-G	• MODAL FREQUENCIES WITHIN 5% MODAL DAMPING WITHIN 20% MODE SHAPES & SLOPES WITHIN 5% .... FOR FIRST TEN MODES
EVALUATE PROCEDURE OF MODELING VIA COMBINING ANALYTICAL, GROUND & FLIGHT TESTS RESULTS	• MODAL FREQUENCIES WITHIN 2% MODAL DAMPING WITHIN 5% MODE SHAPES & SLOPES WITHIN 2% .... FOR FIRST TEN MODES

LANGLEY GRID TEST FIXTURE

Complementary test programs are being conducted at Langley as part of the base R&T program. A typical example is shown by this view of the Langley grid test fixture. This test article consists of a number of aluminum bars joined at their intersections. The article is suspended from the ceiling by two thin cables, and exhibits a lowest natural structural frequency of approximately 0.5Hz. Typical control actuators and sensors, such as reaction wheels and rate gyros, are attached to the grid. Test programs conducted on this device include control law evaluations on-site and from remote locations, system identification studies, and failure accommodations developments.



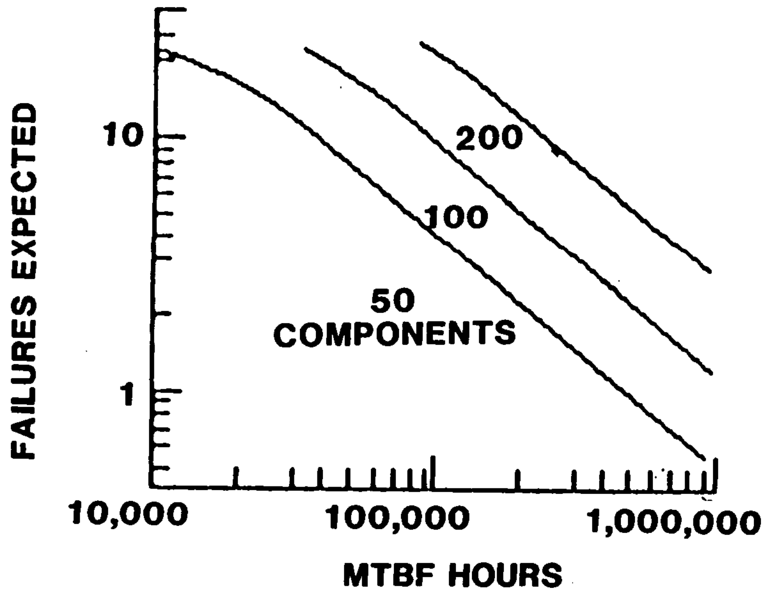
FAILURE ACCOMMODATION

Typical results from failure accommodation studies are examplified in this figure. It can be readily determined that failures can either be anticipated and redundancy provided for that eventuality, or the system design accounts for eventual failures in its original development. For example, if components are known to exhibit a certain Mean Time Between Failures (MTBF) history, and the number of components in the system are known, then it is possible to predict how many of these elements can be expected to fail during the course of the mission. Knowing the predicted failure frequency, it is then possible to develop a cost function which can then be employed in the determination of which control system configuration best accommodates contemplated failures over the postulated mission life. In this figure, two typical system configurations are examined. It is seen that for the long mission cycle, system 2 has the lower associated cost penalty and is thus preferable. Therefore, system design can incorporate contemplated system failure in its definition.

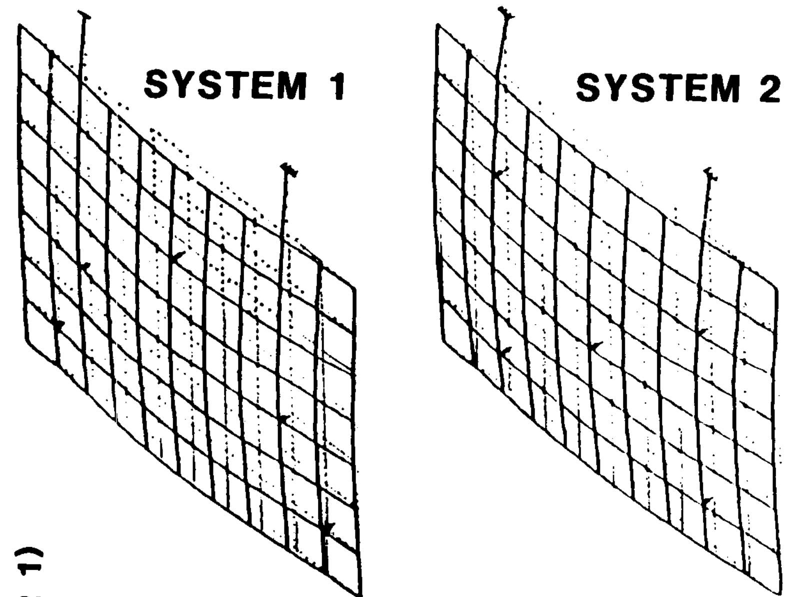
CONTROL OF FLEXIBLE STRUCTURES

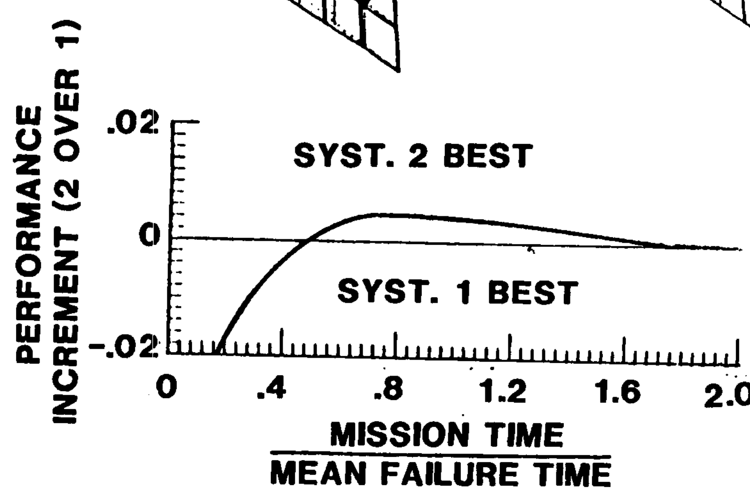
Failure Accommodation

SYSTEM RELIABILITY



SYSTEM CONFIGURATIONS





SPACECRAFT CONTROL LABORATORY EXPERIMENT

(SCOLE)

Another test article utilized in the development of control technology is the Spacecraft Control Laboratory Experiment (SCOLE). This system includes a simulated Shuttle vehicle to which is attached a generic reflector and a flexible mast. The shuttle representation is equipped with a set of double gimbal (CMQ's) to provide system control for maneuvering and reorientation. Twin reaction wheel assemblies are attached to the flexible beam for control of the system flexible modes. The reflector is also equipped with a reaction jet package for maneuver load alleviation, vibration suppression and control. Appropriate sensors, such as accelerometers and rate gyros, are also mounted on this test facility and used in system performance evaluation and loop closures. This test apparatus is being studied and used by a contingent of university and government researchers for modeling research, flexible body control and identification, etc.

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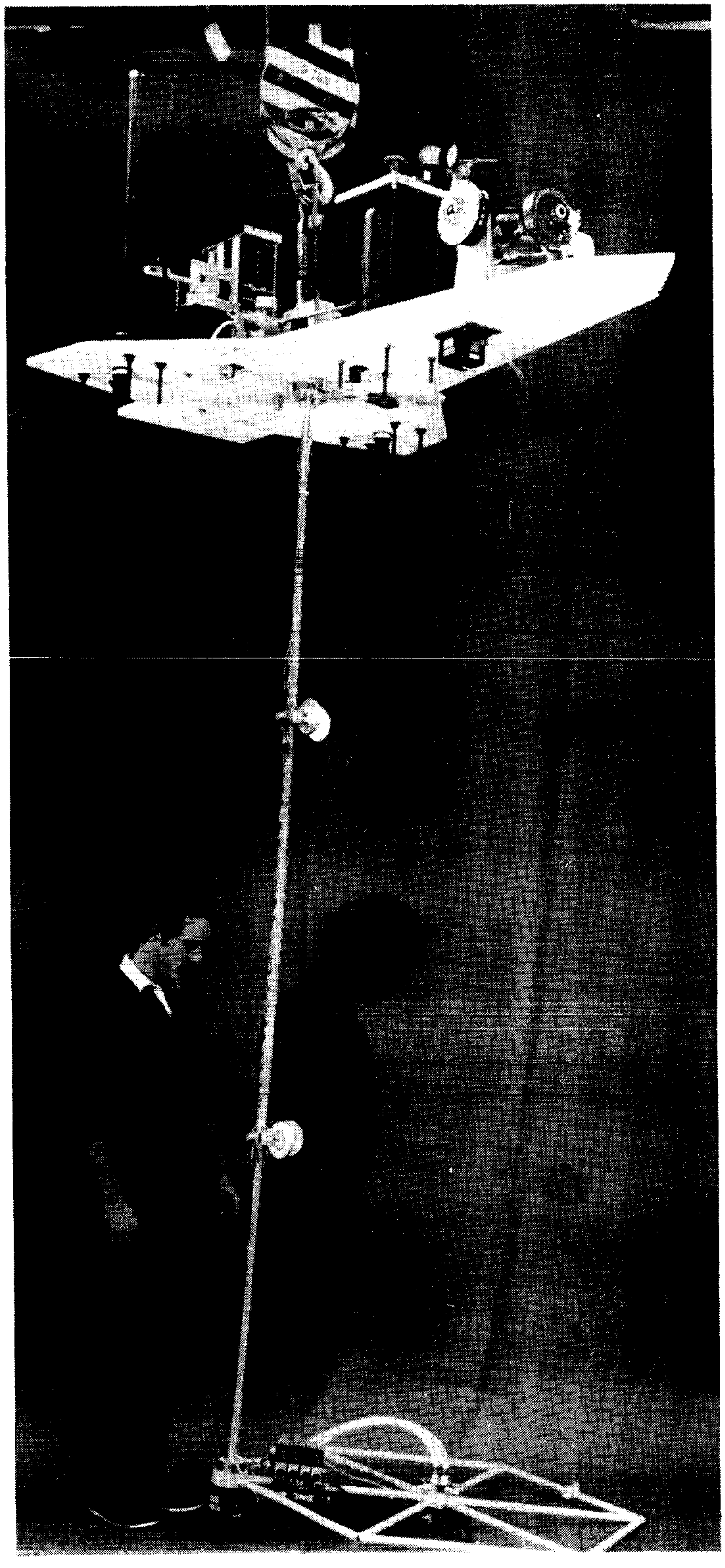
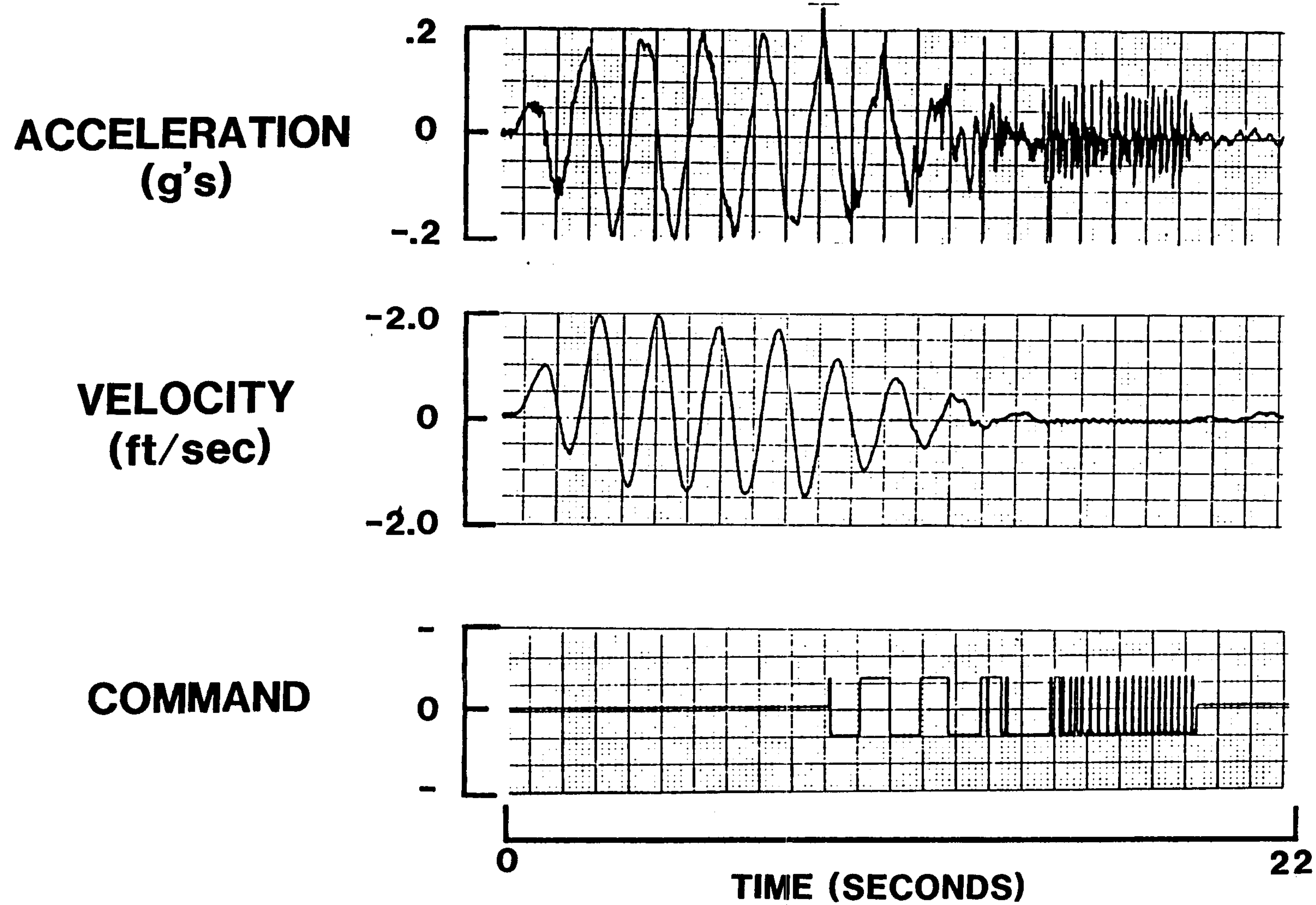


SCOLE VIBRATION SUPPRESSION TEST RESULTS

Representative test results from the SCOLE facility are shown in this figure. Suppression of the first vibrational mode of the cantilevered mast of the SCOLE configuration was performed using the reaction jets located at the hub of the reflector. As can be readily noted, the control method utilized in this test was highly effective in damping out the encountered distrubance.

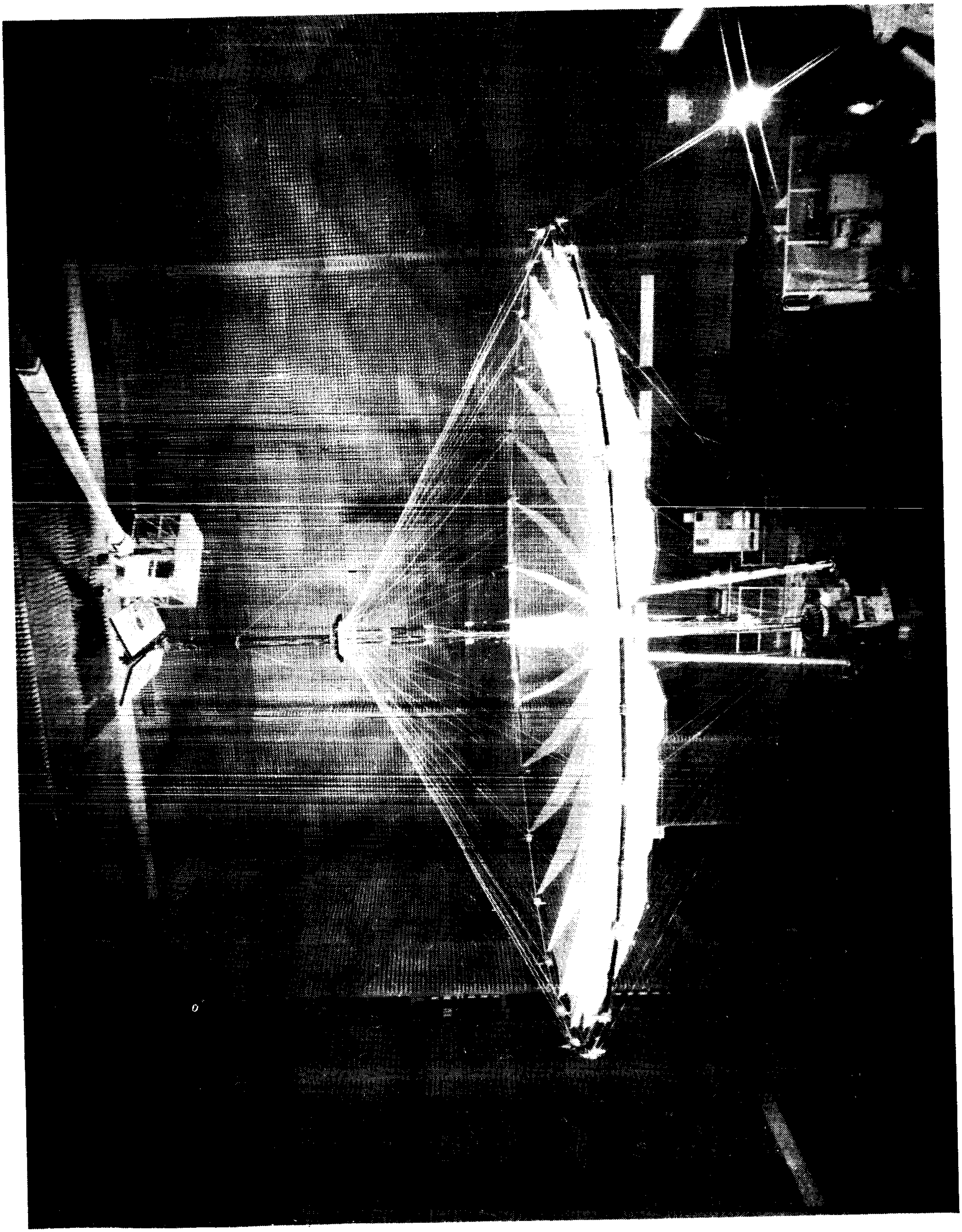
SCOLE VIBRATION SUPPRESSION USING ON-OFF THRUSTERS

Cantilevered Mast – First Mode



HOOP COLUMN ANTENNA

The Hoop-Column antenna depicted in this figure has been widely used by Langley in a variety of experimental programs dealing with antenna research in the areas of RF performance and structural dynamics evaluations. It is currently being prepared for evaluations of shape control techniques which are essential to providing the antenna efficiencies required by the user community. This article is fifteen (15) meters in diameter and consists of a graphite-epoxy hoop connected to a telescoping graphite-epoxy column via a number of control and alignment cables. The mesh stretched over the surface of the antenna provides four reflector surfaces thus resulting in an antenna with multiple apertures. Testing is expected to begin the summer of 1986.



HOOP COLUMN ANTENNA ANALYSIS AND TEST RESULTS

Analytical models of the Hoop-Column antenna were developed during the design phase of the antenna program. These models have been utilized to predict structural dynamics characteristics of this article. Following the fabrication and installation of the antenna at Langley, structural dynamics experiments were conducted to establish the characteristics of this antenna configuration and to evaluate the accuracy of the models and their development techniques. As can be seen from this figure, initial predictions were not unreasonable when compared to the actual physical characteristics. However, as in any program of this nature, some refinement is always needed to overcome the shortcomings of the assumptions made in the generation of the model. In addition, deviations from the hardware design occurring during the fabrication phase will impact the structural characteristics of the system thus requiring mathematical model refinement. It is to be noted that the refined model does subsequently provide very good agreement with the test results when all system anomalies are incorporated into the model. Such research efforts permit the establishment of improved modeling techniques which will be beneficial to the COFS and other programs.

HOOP COLUMN ANTENNA

Analysis and Test Results

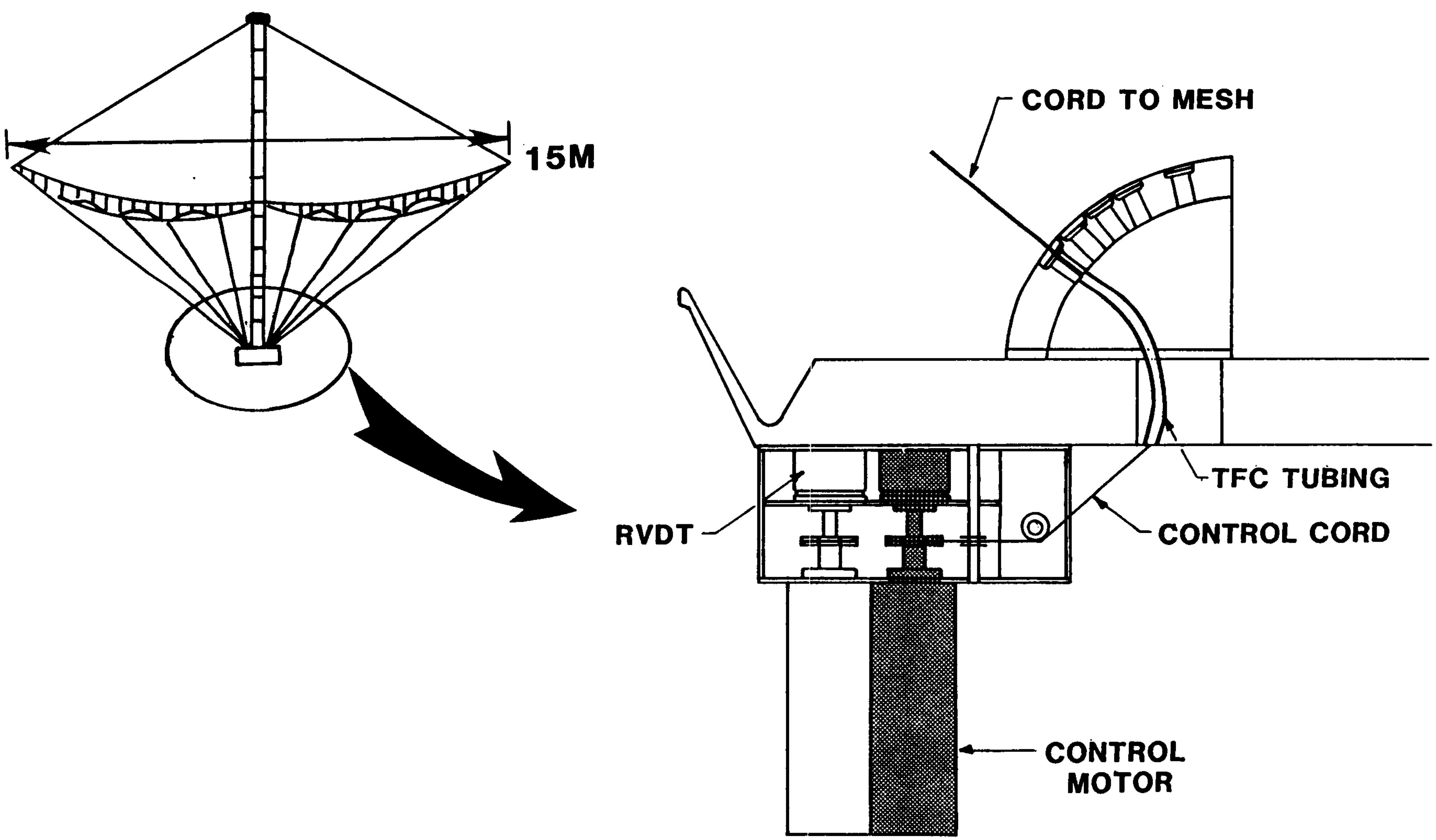
MODE	TEST				INITIAL ANALYSIS		REFINED ANALYSIS	
	W/O MESH		W MESH		FREQ	% ERROR	FREQ	% ERROR
	FREQ	DAMP	FREQ	DAMP				
HOOP TORSION	0.068	3.5	0.077	9.5	0.092	19	0.077	0
HOOP ROCKING	0.785	-	0.697	4.4	1.32	88	0.097	0
HOOP IN-PLANE	1.36	4.1	1.76	6.8	2.15	22	1.73	-2
LOWER COL. TORSION	3.13	2.6	3.18	2.6	3.20	5	3.18	4

SURFACE CONTROL CONCEPT

The design of the surface control system for the Hoop-Column antenna will permit active control of each mesh control cord. This is effected by providing a motor for each of four cords per gore to pull on the control cables to achieve the proper surface tension. Release of tension on the mesh, when desired is achieved by actuation of the appropriate motor and a spring mechanism incorporated in the control cord guide to pull the cable out toward the mesh. Since a single quadrant of the antenna will be evaluated, only twenty-eight motors and associated sensors will be required for the initial tests. Control of the hoop alignment and motion relative to the column is also being undertaken by incorporating an additional twenty-four motor and sensor assemblies distributed around the rim and pulling on the appropriate control cord. The actuator/sensor assemblies are to be located at the ends of the antenna mast under the control cord junction plate.

CONTROL OF FLEXIBLE STRUCTURES

Surface Control Concept



HYBRID TEST CONCEPT OBJECTIVES

Because of the increasing size of the flight configurations, it becomes necessary to establish some testing techniques which will permit the ground verification of the system design and prediction of its expected on-orbit performance with a high degree of confidence. As such, a hybrid testing concept is contemplated which provides an alternative to full-scale structures and controls ground testing. This concept consists of a combination of real-time simulations and hardware subsystems which are linked through programmed software/hardware interfaces to permit integrated system evaluations. The establishment of this testing technique through the COFS program will be highly instrumental in the ground validation and on-orbit success of future large spacecraft missions.

CONTROL OF FLEXIBLE STRUCTURES

Hybrid Test Concept Objectives

OBJECTIVE:

DEVELOP AND VALIDATE ADVANCED HYBRID TEST CONCEPTS FOR PREDICTING AND CONTROLLING THE DYNAMIC BEHAVIOR OF LARGE FLEXIBLE STRUCTURES

PURPOSE:

PROVIDE ALTERNATIVE TO FULL-SCALE STRUCTURES AND CONTROLS GROUND-BASED EVALUATIONS OF LARGE FLEXIBLE STRUCTURES

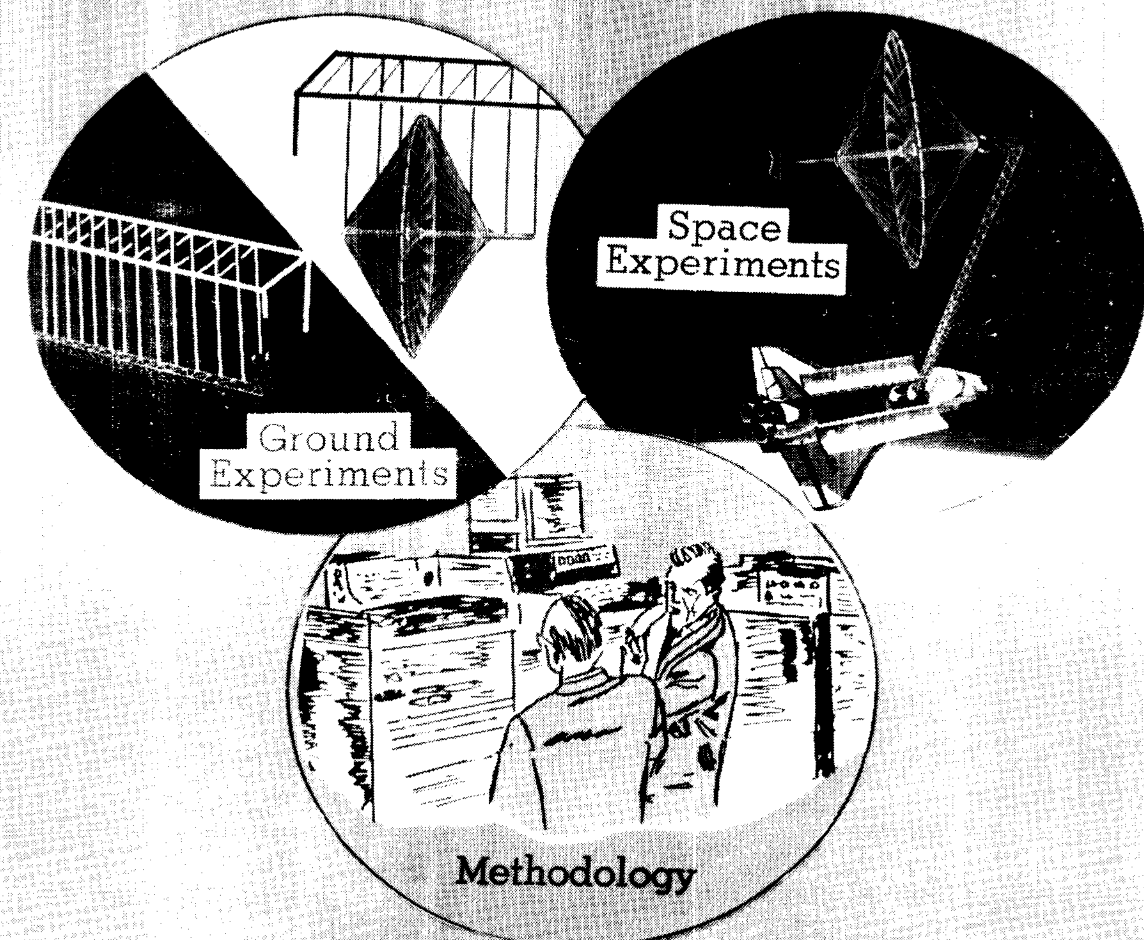
APPROACH:

COMBINE REAL-TIME SIMULATIONS AND HARDWARE SUBSYSTEMS THROUGH PROGRAMMED SOFTWARE/ HARDWARE INTERFACES TO PERMIT INTEGRATED SYSTEM EVALUATION

COFS II HYBRID TEST CONCEPT

Capitalizing on the legacy of previous programs in the areas of control concepts development, system modeling and identification, as well as in the large, flexible space structures arena such as LSST, VCOSS and ACOSS, synthesis and modeling techniques which proved successful in these programs will be utilized to initiate the COFS analyses and designs. These will be refined by the results obtained from experimental testing and component development efforts as examplified in the testing of flexible beams, grids, SCOLE, and various sensor/actuator components. Results from ongoing programs, such as the Hoop-Column antenna shape control developments and PACOSS, will be incorporated into the establishment of the high fidelity real-time simulations as they become available. Physical test articles, such as the Mini-Mast, and Hoop-Column antenna, will be combined with these real-time simulations to effect integrated system testing. Physical integration of large test articles is not always possible because of their respective sizes and the requirements they resultantly place on facilities, or because the preferred one-g orientation for one element of the configuration is incompatible with that required for the other elements. Therefore, the simulations will be used to provide the appropriate excitations at the subassembly interfaces, thus producing an integrated system test capability.

COFS II
CONTROL OF FLEXIBLE STRUCTURES



SURFACE SENSOR CHARACTERISTICS

To effect figure control of the antenna surface or the flexible supporting beam, an appropriate sensor is required. This sensor system must be capable of examining several targets simultaneously from a remote location. This tracking of numerous targets must be effected in real time at sampling rates sufficiently high to permit control loop closures. This can provide control of certain dynamic characteristics which could otherwise severely impair the performance of the antenna. A survey of typically available sensors which might be use for such an application, either singly or in multiple pairs, was accomplished and the candidate sensors are shown on this figure. As can be observed, the list is somewhat limited and represents mostly sensors which are still in the development stage. Some, such as the unit employed in the VCOSS program, have progressed to a laboratory operational phase. Further evaluation of these and other to be discovered candidates is continuing.

SPECIFIC SENSOR CHARACTERISTICS

	Number of Targets/Type	FOV	Focal Plane Technology	Sampling Rate	Accuracy
Ball	23/Passive	19°	Array CID	6Hz	2mm/30M • 1/15000
Barnes	12/Active	2°	Array CCD	20Hz	1mm/60M • 1/60000
Grumman	16/Active	35°	Linear Photodiode	200 Hz	.3mm/25M • 1/83000
JPL	1-Dynamic 14-Static / Passive	13°	Streak Tube / Array CCD	8Hz	.1mm/10M • 1/100000
Lockheed	1/Active	19°	Linear Photodiode	100Hz	1A.S/19° • 1/68000
TRW	6/Active	7.5°	Linear Photodiode	4000Hz	.04mm/21M • 1/525000

CONCLUDING REMARKS

As has been shown in this presentation, the COFS II program is a complex and ambitious undertaking which will address several critical technology areas. Among them are modeling, structural dynamics, controls, and ground testing issues which are not only germain to this effort, but to other large space structure programs being contemplated. This effort requires the early integration of controls and structural dynamics considerations in order to achieve mission success. Several technology advances must be achieved in the areas of system modeling, control synthesis and methodology, sensor/actuator development, and ground testing techniques for system evaluation and on-orbit performance prediction and verification. This program offers a unique opportunity for the integration of several disciplines to produce technology advances which will benefit many future programs. In addition, the opportunities available to participate in the various levels in the phases of this program, e.g., analytical development and modeling, ground testing, and flight testing, permit for the involvement of a significant number of interested researchers and organizations from government, universities and industry.

CONCLUDING REMARKS

- COFS II IS AMBITIOUS & COMPLEX EFFORT
- OPPORTUNITIES FOR RESEARCH IN MANY DISCIPLINES
- SYNERGISTIC COMBINATION OF ANALYTICAL, GROUND & FLIGHT EXPERIMENT DEVELOPMENTS
- UNIQUE OPPORTUNITY FOR GUEST INVESTIGATOR PARTICIPATION AT ALL LEVELS