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# COFS I RESEARCH OVERVIEW

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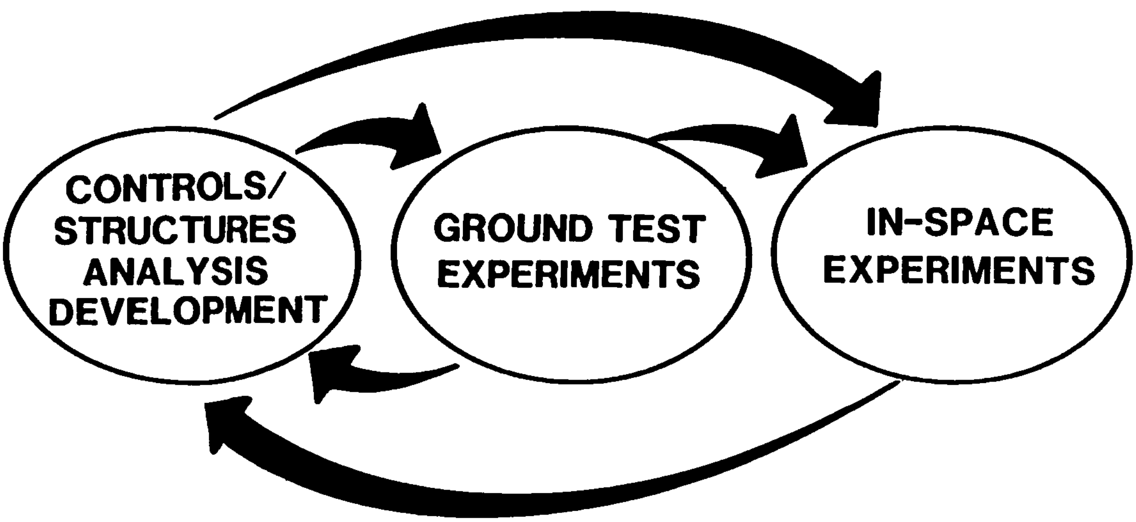
Control of Flexible Structures
Program Approach

The Control of Flexible Structures (COFS) program is divided into three areas of research. These three areas are controls/structures analysis development, ground test experiments, and in-space experiments.

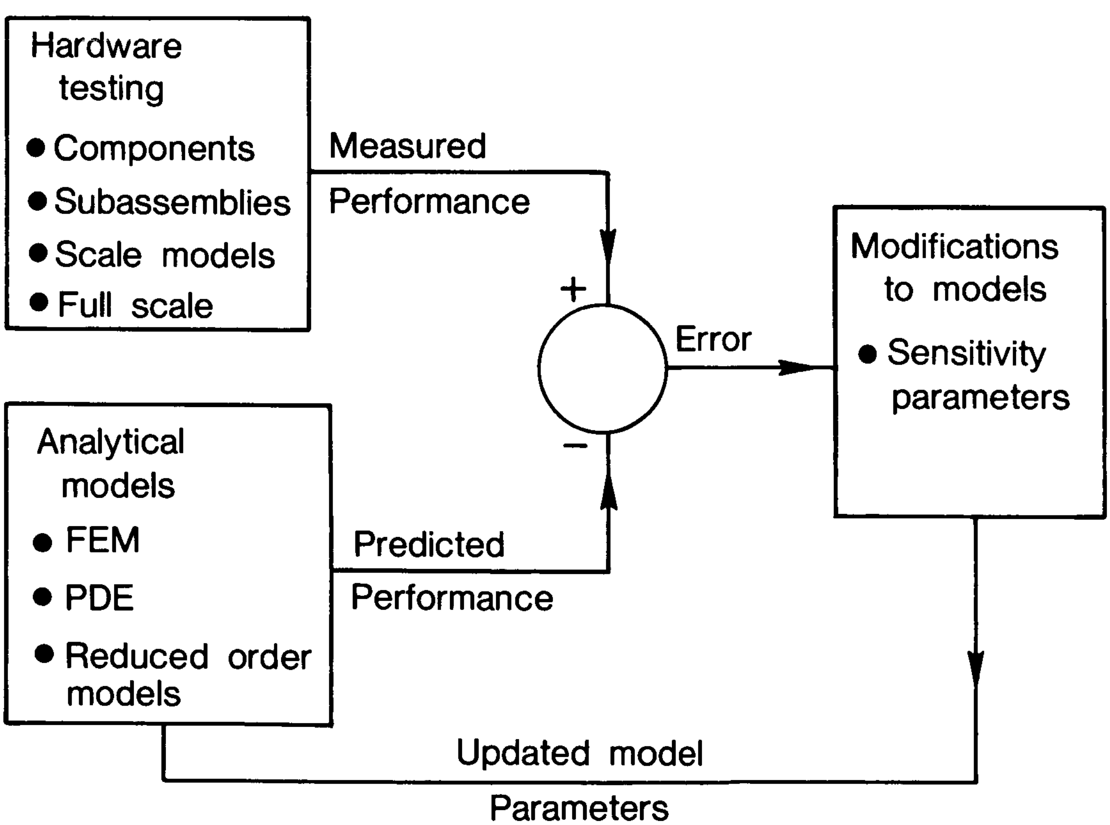
The ground test experiments are intented to validate analyses and to confirm through hardware tests our technical readiness to successfully fly the Mast hardware. There is this close relation to the results of ground tests and analytical predictions that must be understood before flight experiments may be attempted.



Model Validation Process

At every step of the ground test program each hardware test will be complemented by an equivalent analysis. That is, all components, subassemblies, scale models, and full scale assemblies will be tested in some fashion and the output of these tests is called measured performance. The equivalent result from the analytical models is called predicted performance. Next, the measured performance is compared to the predicted performance and the difference is an error measure.

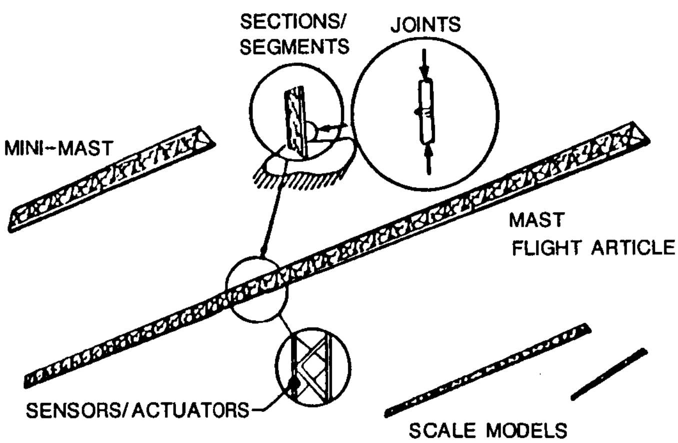
The purpose of this process is to have a validated analytical model. Using sensitivity parameters, adjustments to the analytical model are made such that the predicted performance better predicts the measured performance.



Control of Flexible Structures
Ground Test Program

The objectives of the ground test program are the development of ground test methods, evaluation of control instruments, validation of control/structure analyses, evaluation of scaling methods, evaluation of joint/damping effects, and evaluation of distributed control techniques. These tests will be conducted on components, scale models, mini-Mast, and Mast.

Ground test hardware

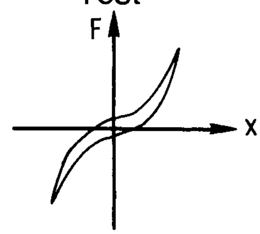
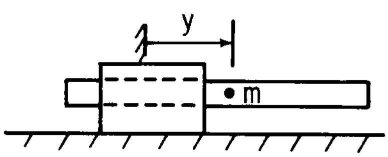
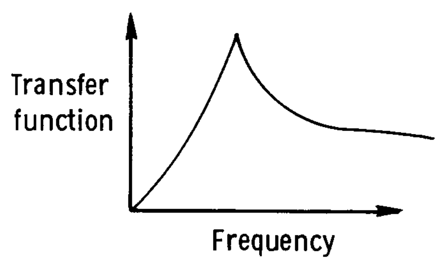



Objectives

- DEVELOP GROUND TEST METHODS AND CAPABLITY
- EVALUATE CONTROLS INSTRUMENTS
- VALIDATE CONTROL STRUCTURES ANALYSES
- EVALUATE SCALING METHODS
- EVALUATE JOINTS/DAMPING EFFECTS
- EVALUATE DISTRIBUTED CONTROL TECHNIQUES

## Ground Test/Analysis Program

Examples of components that will be tested are joints that will be loaded in tension and compression to determine the joint properties such as stiffness and damping. Also, actuators will be bench tested to determine the dynamic characteristics.

| Analysis | Component | Test |
|---|---|---|
| $F = k_1 x + k_2 x^3 + \text{H.O.T.}$ |  |  |
| $\Sigma F = m\ddot{y}$ |  |  |

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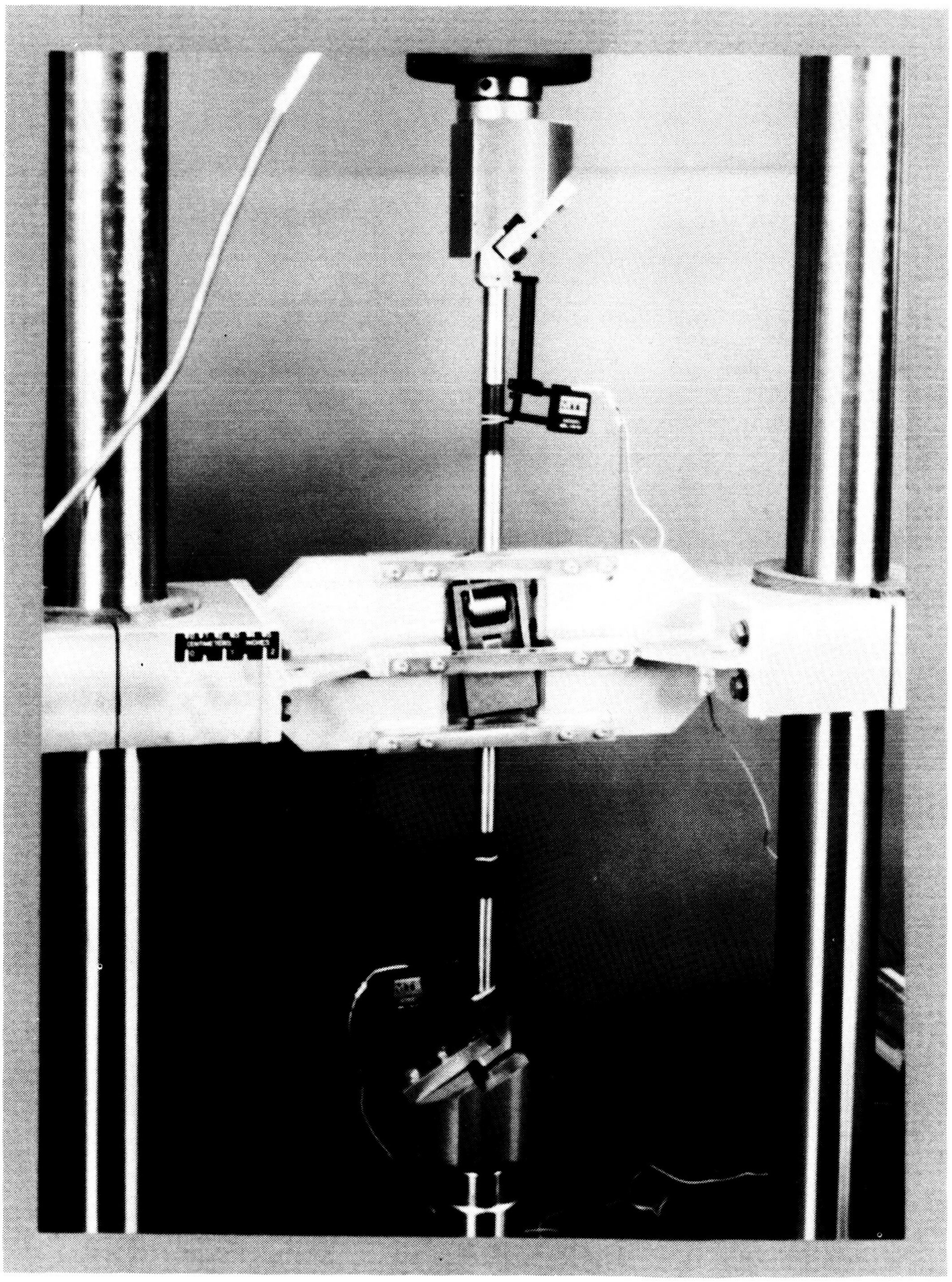
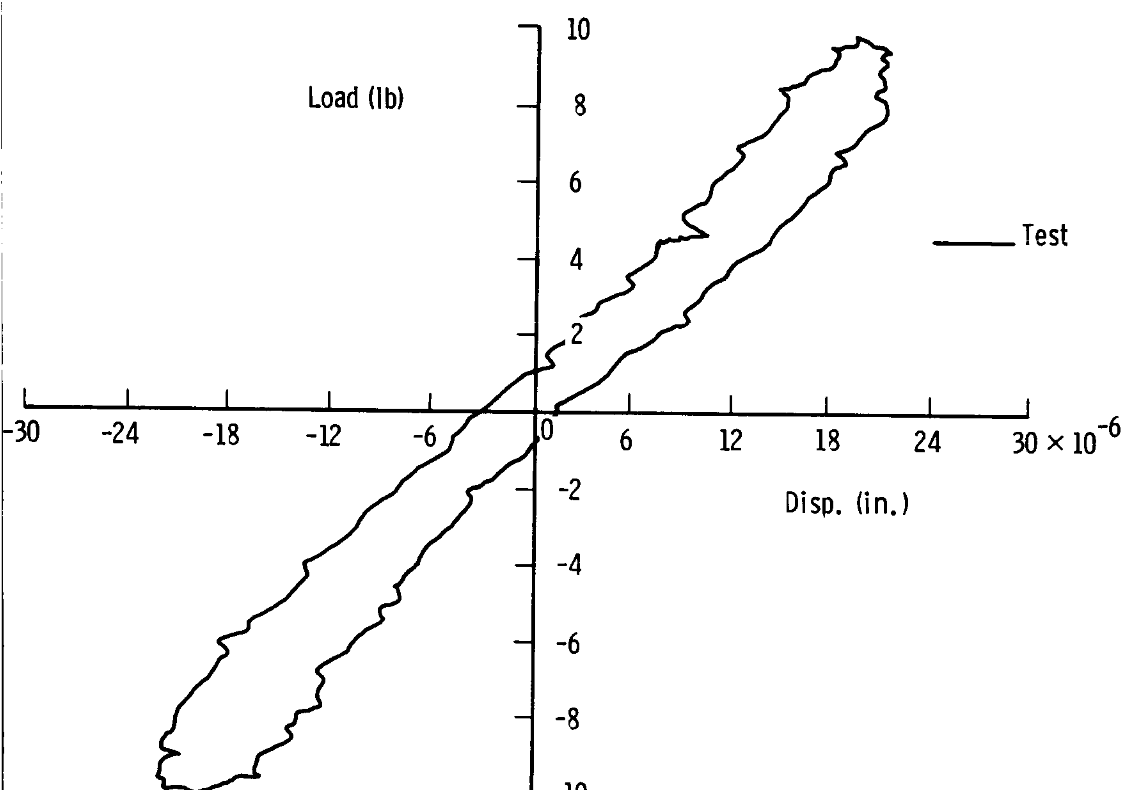
Diagonal Hinge Joint

This is a picture of a diagonal hinge joint for mini-Mast. It is shown in a test machine with a fixture to capture the joint if it should start to open.



Load Deflection Data

Here are results of a joint test where the load is applied at the rate of one cycle per second which is in the vicinity of frequencies for mini-Mast. The slope of the curve is the stiffness and the area inside the curve is a measure of the damping.



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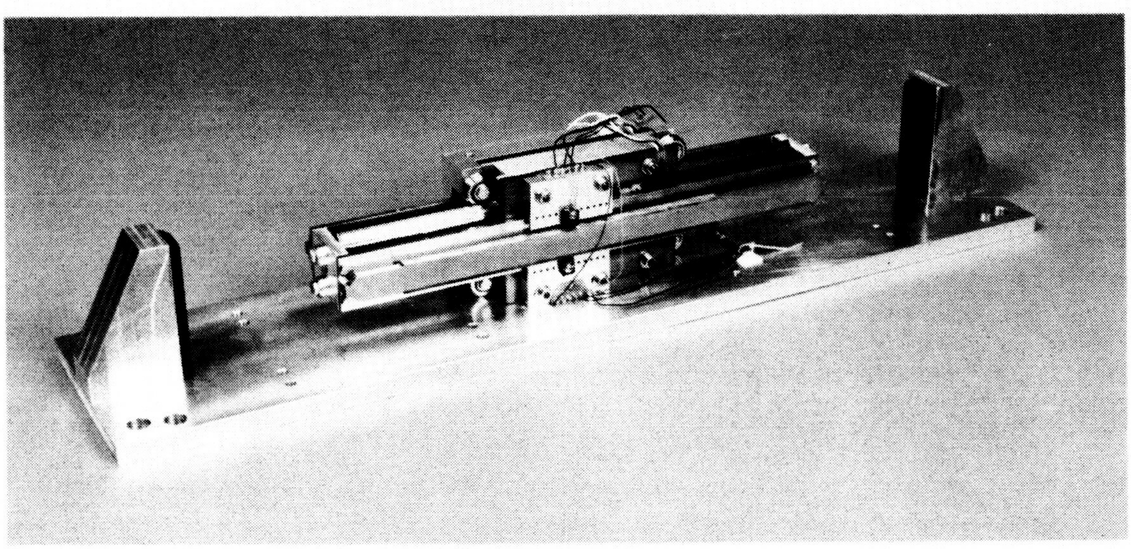
Linear DC Motor (LDCM)

This is a picture of the Harris prototype LDCM that will be tested and characterized. There will be ten actuators on the Mast flight and these actuators are the devices which apply forces to the Mast truss structure.



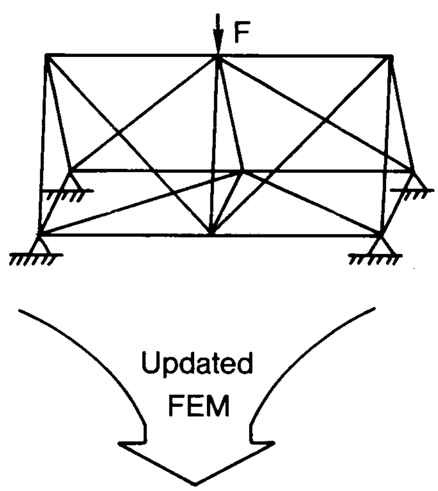
## Ground Test/Analysis Program

The ground test program will progress from testing components to testing subassemblies such as the two-bay truss model shown. It is planned to static test a mini-Mast two-bay model. This is a calibration test which will be used in the model validation process to obtain a validated FEM of a two-bay model. Different test configurations, such as various loads and different boundary conditions, are planned.

Analysis

- Two-bay FEM
  $Kx = F$
- Equivalent PDE models

Subassemblies



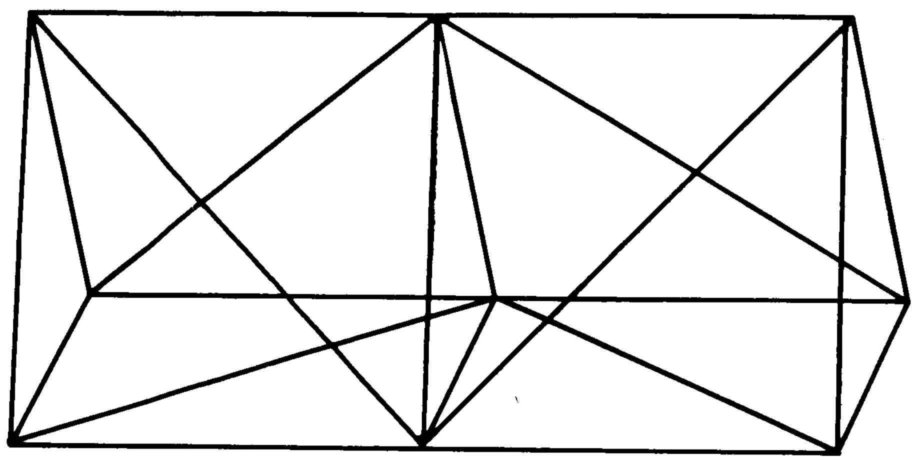

Test

Static load vs deflection

- various load points
- different boundary conditions

## Mini-Mast/Mast Baseline Configuration

The baseline configuration consists of three longerons, three battens, and three diagonal elements per bay.



2 Bays

## Scale Models

The objective of the scale model program is to study the validity of using scale models to simulate flight structures. The approach will be to procure and test four replica models. The scales of the four models are 1/2, 1/4, and 1/5. There are two 1/5 scale models planned. Also, similar ground tests and analyses programs as in mini-Mast and Mast are planned.

Objective: Study validity of scale models for simulating flight structure

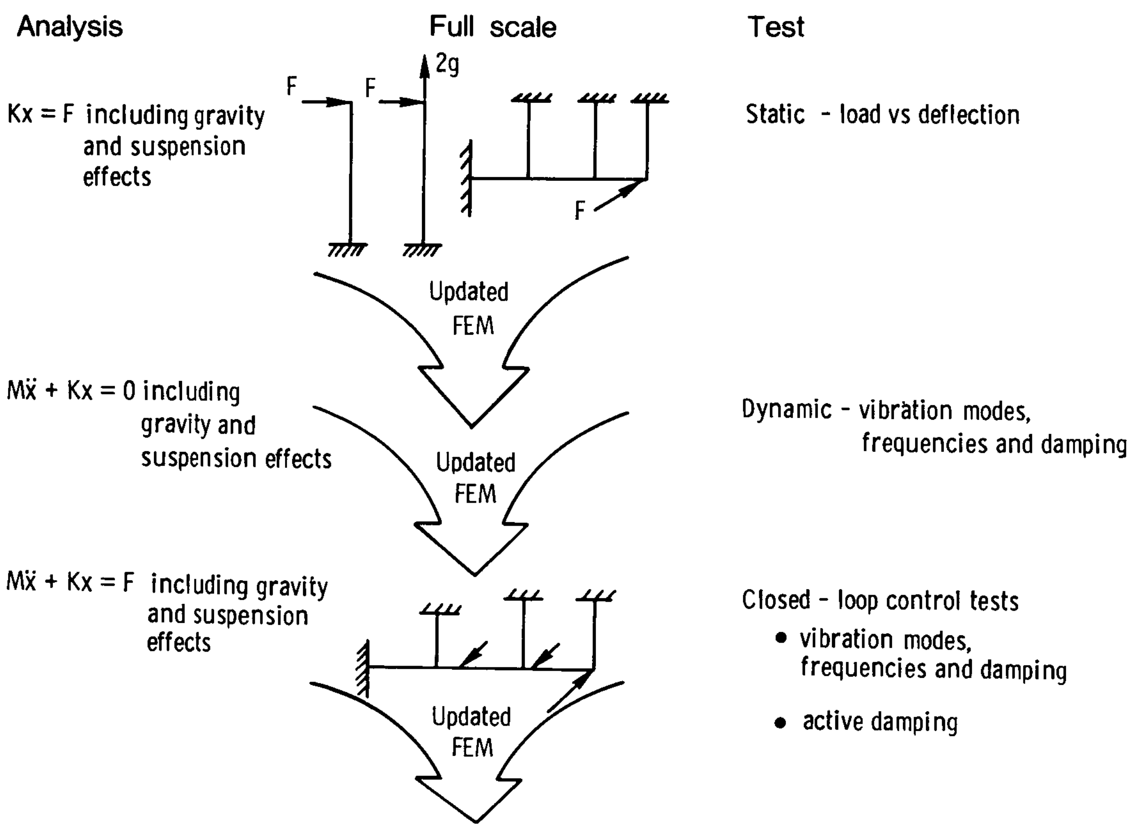
Approach:
- Four replica models planned -1/2, 1/4, 1/5 (2) scale
- Similar tests and analysis programs as in mini-Mast and Mast

## Ground Test/Analysis Program

The full scale testing of the mini-Mast will initially take place in the Structural Dynamics Research Laboratory. The test orientation is vertical and cantilevered from the base. In this orientation the joints should all be loaded in one direction and static as well as dynamic tests will be run. Next, the truss will be loaded in tension at the free end to load the joints in the opposite direction. The same tests will be repeated. The results of each test are run through the model validation process. It is anticipated that static test results will be used to update the stiffness matrix of the FEM and dynamics test results used to update the mass matrix.

The mini-Mast tests will be repeated with the longitudinal axis in the horizonal direction. Cables will be used to support part of the weight of the structure.

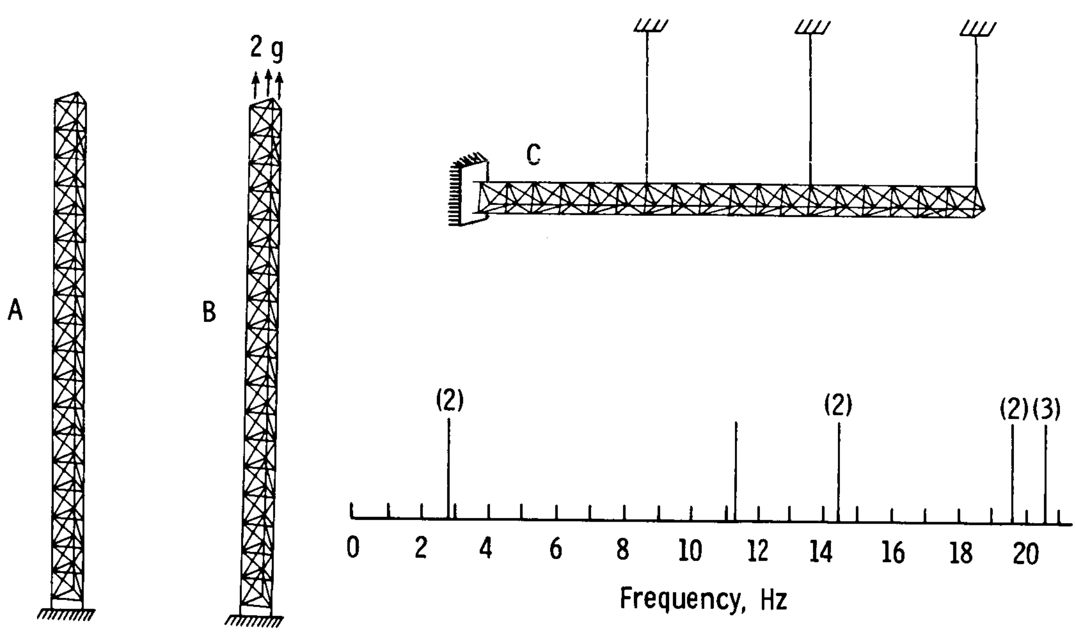
Finally, control research testing is planned for both the vertical and horizonal orientations.



## Mini-Mast Test Configurations

Test configurations A and B are the vertical orientations which will be located in the tower in building 1293B at the Langley Research Center (LaRC). Test configuration C is the horizontal orientation which will be in the hanger annex of building 1244 at the LaRC.

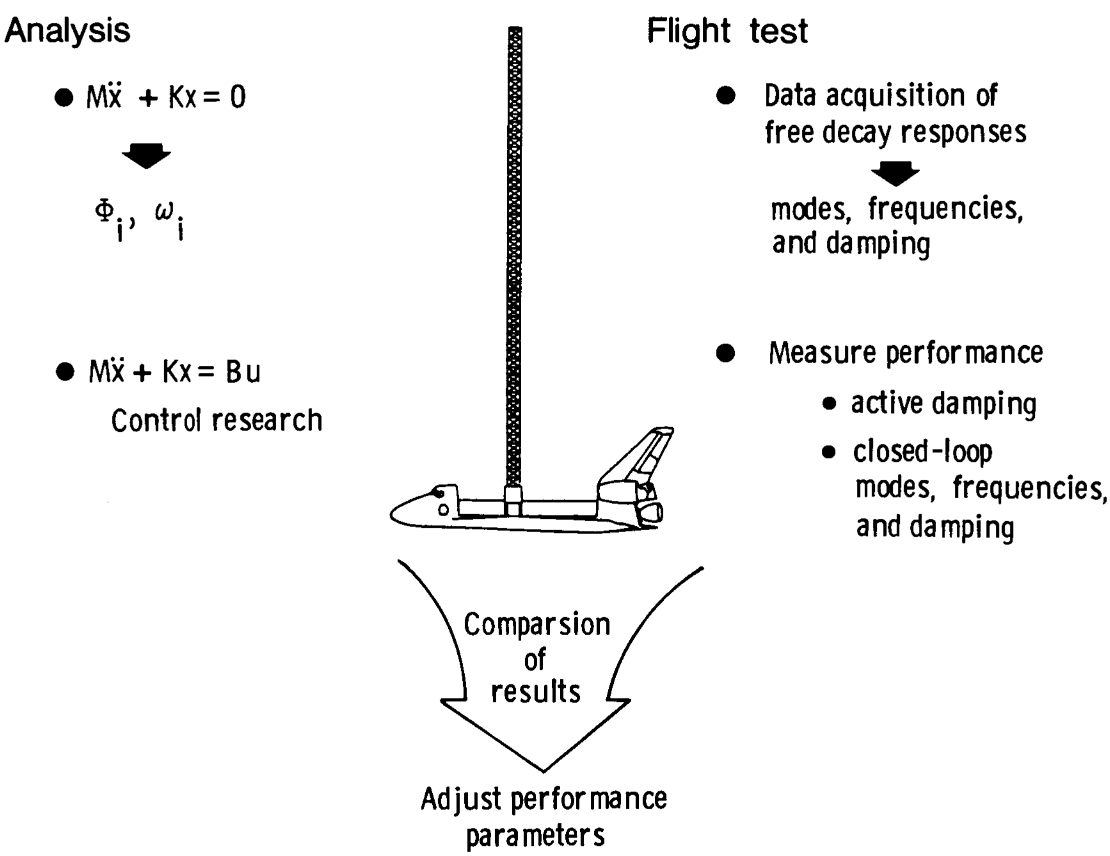
For test configuration A the vibration frequency spectrum from 0 to 21 Hertz is given. The lowest frequency is the first transverse bending frequency at 2.8 Hertz. The next frequency is the first torsional frequency at 11.3 Hertz.




Test configuration A

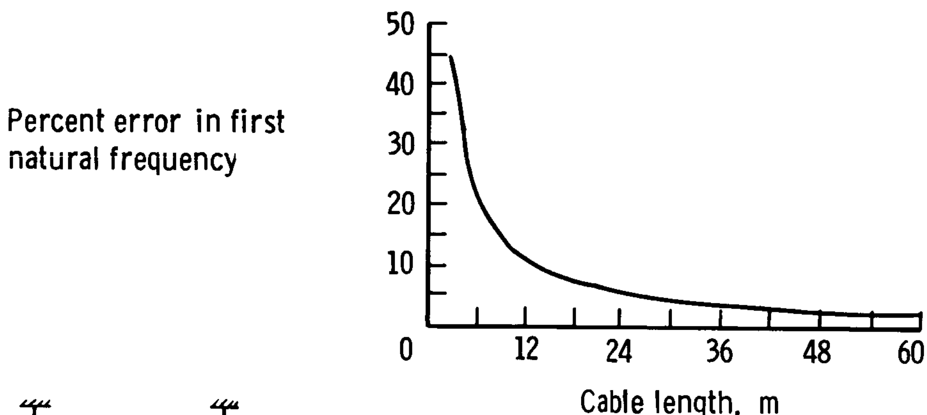
## Flight Test/Analysis Program

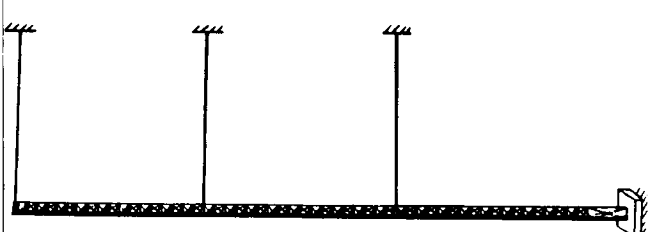
The flight test of the Mast flight system will be conducted after extensive ground testing has concluded. The result of the ground tests should be a verified mathematical model of the Mast flight system. Initial flight tests will confirm the validity of these math models. If necessary, which is likely to be the case, flight test data will be used to update and improve these math models. Both open-loop dynamics tests and closed-loop controls tests are planned.



## Cable Suspension Effect Study

A study of the effect of cables on the vibration frequencies and mode shapes of the cantilevered Mast truss is shown below. The major conclusions of this study are that only the first natural frequency is affected by cables. It was also concluded that cables do not affect the first mode shape and the first natural frequency is not affected by the cable arrangement.



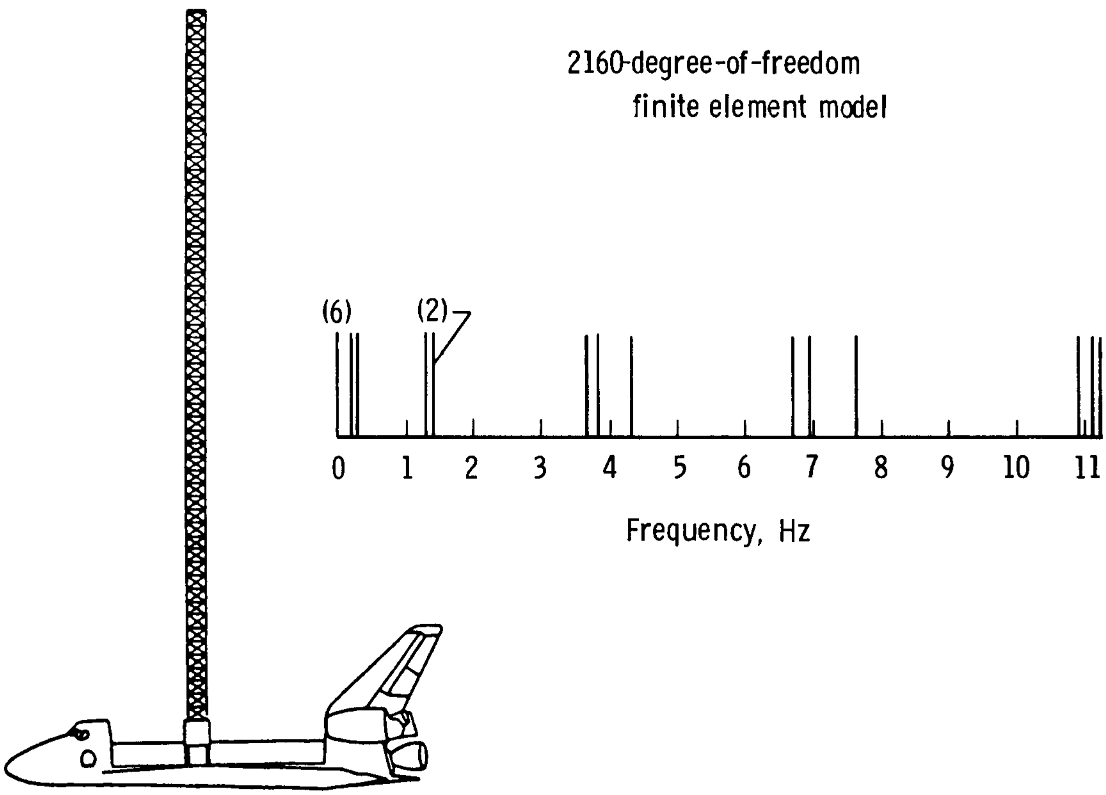



- Only first natural frequency is affected
- Cables do not affect first mode shape
- First natural frequency is not affected by number of cables.

## Mast/Orbiter Vibration Frequency

A 2160-degree-of-freedom finite element model of Mast with the orbiter has been modeled in NASTRAN and EAL. The vibration frequency spectrum from 0 to 21 Hertz is shown.

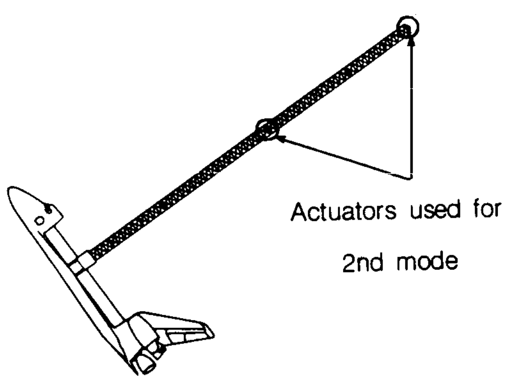
The first six frequencies are the rigid body frequencies. The next two frequencies are the first bending frequencies in the fore and aft direction and the side-to-side or port-starboard direction. The next group of three frequencies consists of two second bending frequencies and the first torsion. One second bending and the first torsional frequency are at the same frequency which is one of the requirements of the structural design.



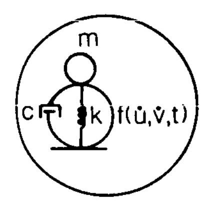
## Closed-Loop Simulation Of COFS-I Flight Test

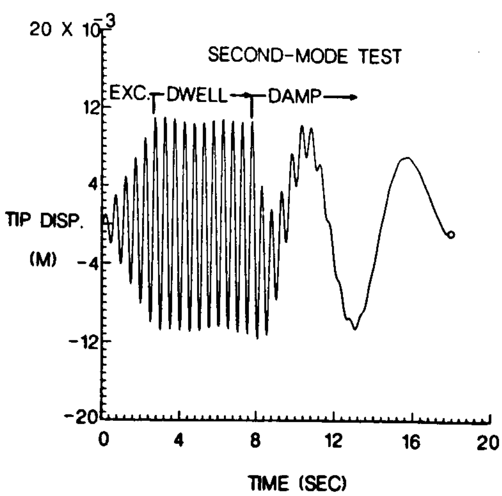
Closed-loop simulations of the Mast flight test have been conducted. The actuators have been modeled as ideal linear devices in the simulation. The curve on the left shows excitation, free vibration, and damping of the second mode. The curve on the right is only excitation of the second mode but without a spring or relative position control between the proof mass of the actuator and the structure. The results of this study indicate the need for relative position control.

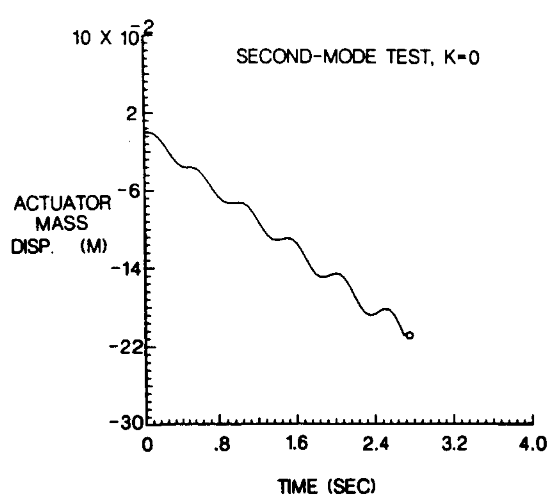
COFS-I




ACTUATOR MODEL



## Directly Related Base R&T

The related base research and technology programs consist of analysis and scaling of joints, suspension methods for ground tests, math modeling of structures using exact element analyses and partial differential equation representations, system identification methods, and control algorithm development and tests.

- Analysis and scaling of joints
- Suspension methods for ground tests
- Exact element and PDE math modeling
- System identification methods
- Control algorithm development and tests

## Research Program - Status

The mini-Mast diagonal hinge joint has been tested and results are being analysed. Mini-Mast actuators are being developed. Finite element models of both the mini-Mast and Mast have been developed. A simulation of the Mast flight tests is operational. The procurement of scale models is in preparation. Mini-Mast tests are to be conducted in 1987 with all of the above activities being supported by the base research and technology effort.

- Mini-Mast diagonal hinge joint tested
- Finite element models developed
  - Mini-Mast (1908 DOF)
  - Mast (2160 DOF)
- Mast simulation operational
- Mini-Mast actuators being developed
- Scale models procurement in preparation
- Mini-Mast tests to be conducted in 1987.
- Supported by base R&T effort.