MODAL IDENTIFICATION EXPERIMENT

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ABSTRACT

The Modal Identification Experiment (MIE) is a proposed on-orbit experiment being developed by NASA's Office of Aeronautics and Space Technology wherein a series of vibration measurements would be made on various configurations of Space Station Freedom (SSF) during its on-orbit assembly phase. The experiment is to be conducted in conjunction with station reboost operations and consists of measuring the dynamic responses of the spacecraft produced by station-based attitude control system and reboost thrusters, recording and transmitting the data, and processing the data on the ground to identify the natural frequencies, damping factors, and shapes of significant vibratory modes. The experiment would likely be a part of the Space Station on-orbit verification.

Basic research objectives of MIE are to evaluate and improve methods for analytically modeling large space structures, to develop techniques for performing in-space modal testing, and to validate candidate techniques for in-space modal identification. From an engineering point of view, MIE will provide the first opportunity to obtain vibration data for the fully-assembled structure because SSF is too large and too flexible to be tested as a single unit on the ground. Such full-system data is essential for validating the analytical model of SSF which would be used in any engineering efforts associated with structural or control system changes that might be made to the station as missions and uses evolve over time.

Extensive analytical simulations of on-orbit tests, as well exploratory laboratory simulations using small-scale models, have been conducted in-house and under contract to develop a measurement plan and evaluate its potential performance. In particular, performance trade and parametric studies conducted as part of these simulations were used to resolve issues related to the number and location of the measurements, the type of excitation, data acquisition and data processing, effects of noise and nonlinearities, selection of target vibration modes, and the appropriate type of data analysis scheme.

The purpose of this talk is to provide an executive-summary-type overview of the modal identification experiment which has emerged from the conceptual design studies conducted to-date. Emphasis throughout is on those aspects of the experiment which should be of interest to those attending the subject utilization conference. The presentation begins with some preparatory remarks to provide background and motivation for the experiment, describe the experiment in general terms, and cite the specific technical objectives. This is followed by a summary of the major results of the conceptual design studies conducted to define the baseline experiment. The baseline experiment which has resulted from the studies is then described.
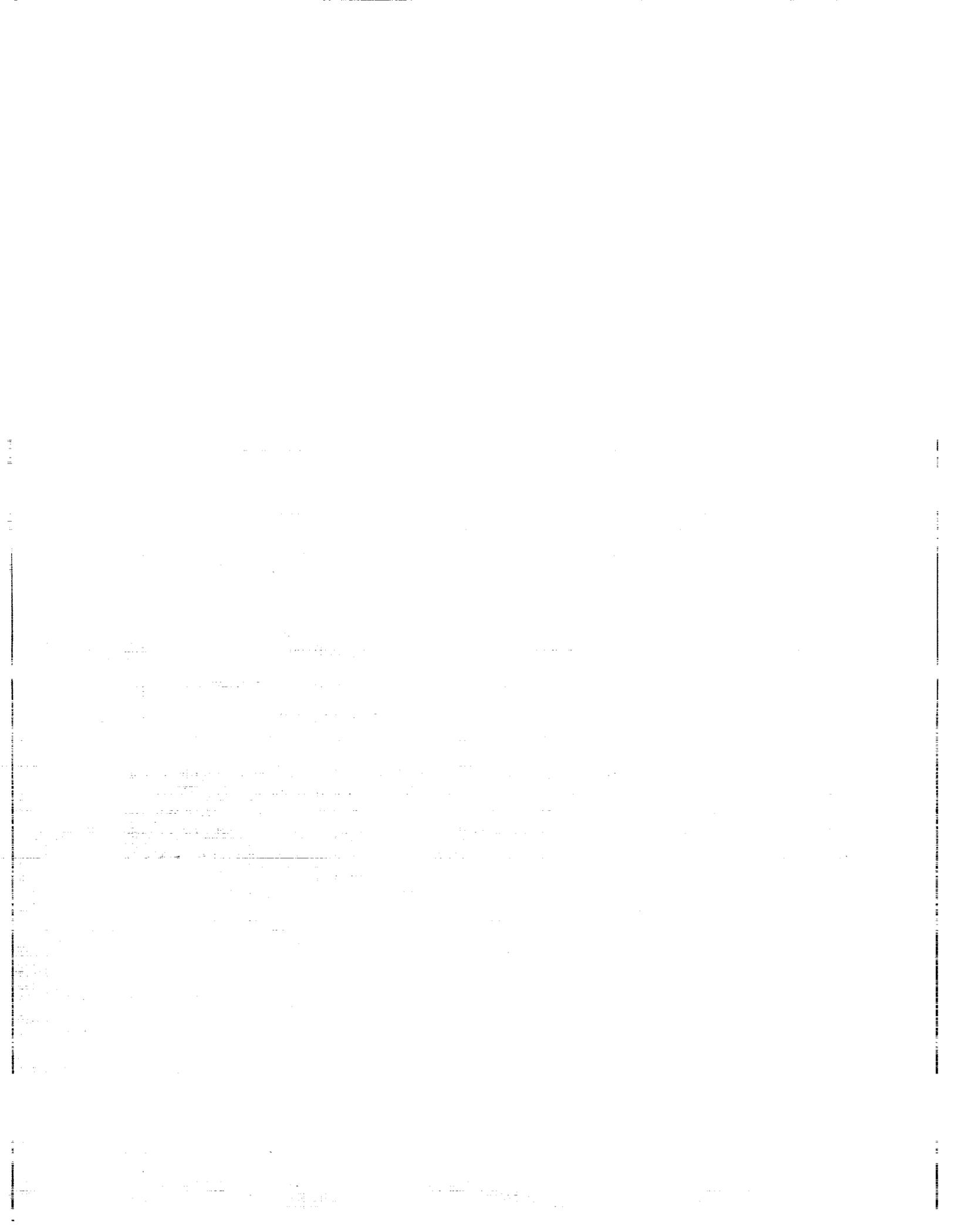
MODAL IDENTIFICATION EXPERIMENT

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OUTLINE

- **Introductory Remarks**

- **Experiment Definition Studies**

- **Baseline Experiment Design**

- **Summary and Concluding Remarks**

INTRODUCTORY REMARKS

MOTIVATION

- Dynamic characteristics of spacecraft traditionally verified by ground vibration tests

- Emerging space structures (such as Space Station Freedom) too large/flexible to test as complete systems on ground

- Complete reliance on math models to verify dynamic behavior

- Math models must be validated to establish accuracy

- Vibration mode shapes for fully-assembled structure essential for validating/updating dynamic models

- Required data can only be obtained on-orbit

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BACKGROUND

- Modal Identification Experiment (MIE) utilizing Space Station Freedom (SSF) proposed in 1984

- Element of NASA's space technology program
    - Sponsor is Office of Aeronautics and Space Technology
    - Object is in-space research and technology

- Not element of Space Station program

ESSENCE OF PROPOSED EXPERIMENT

- Collect vibration measurements on various configurations of SSF during its on-orbit assembly phase

- Conduct experiment in conjunction with station reboost operations

- Key Steps:
    - Excite structure
    - Measure dynamic responses
    - Record and transmit data
    - Apply system identification techniques to data

- Identify significant vibratory modes

ON-ORBIT ASSEMBLY OF SPACE STATION
PERMITS UNIQUE RESEARCH OPPORTUNITY

SC-2

SC-7
(MTC+)

SC-17
(PMC)
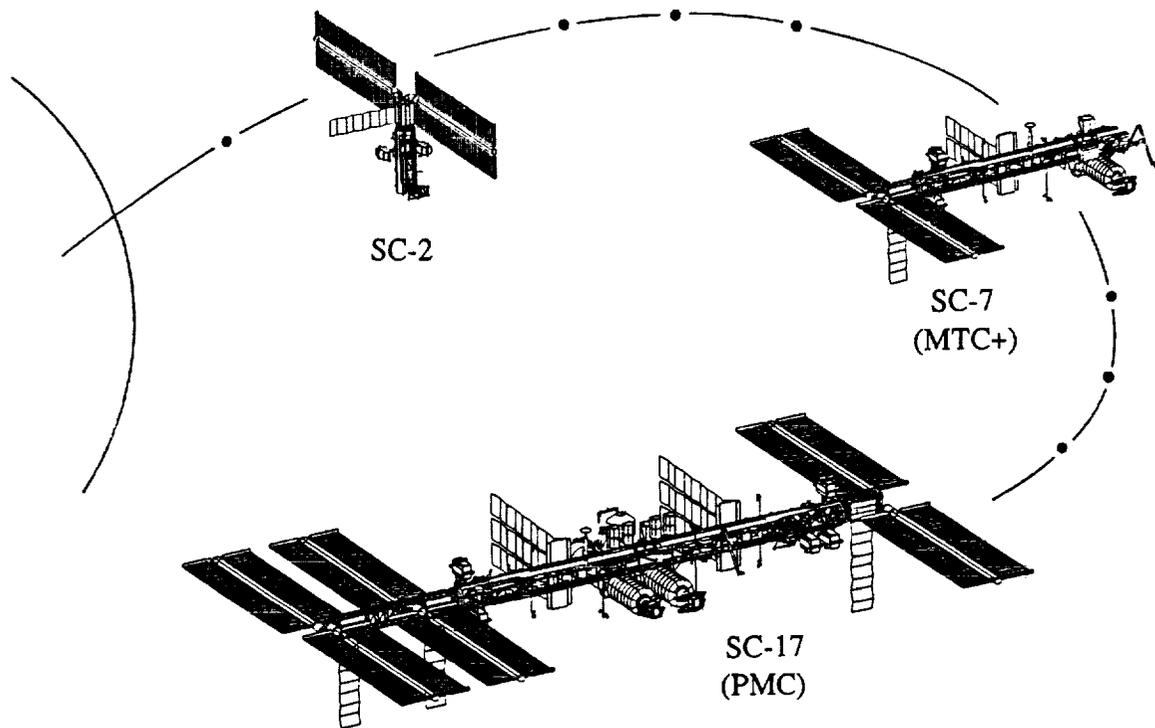
SPECIFIC TECHNICAL OBJECTIVES

- Engineering
  - Data essential for verifying dynamic math models of integrated system
  - Enhanced model for changes/growth studies

- Research
  - Technology for predicting dynamics of large space structures
  - Techniques for performing on-orbit modal testing
  - Spacecraft scale model ground vibration test technology
  - Techniques for in-space system identification
  - Improved dynamics modeling techniques

EXPERIMENT DEFINITION STUDIES

MAJOR PARTICIPANTS

- **McDonnell Douglas Space Systems Company**
  - Phase A Study - Determine feasibility
  - Phase B Study - Conceptual design definition
  - Delta Phase B Study - Assess impact of new SS design

- **Structural Dynamics Research Corporation**
  - Develop simulation and evaluation methods

- **University of Cincinnati**
  - Modal parameter estimation techniques

- **NASA Langley Research Center**
  - Analytical simulation
 - Dynamic scale model test simulation

SCHEDULE FOR STUDIES

FY / TASKS	88				89				90				91				92				93			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Phase A Concept Definition Study		▲	▲	▲																				
Phase B Selected Studies						▲▲	△																	
Phase B Concept Definition Study								▲	△	▲	▲	△												
Delta Phase B Concept Definition Study													△	▲	△									
Phase C Preliminary Design and Analysis																		△	△	△				
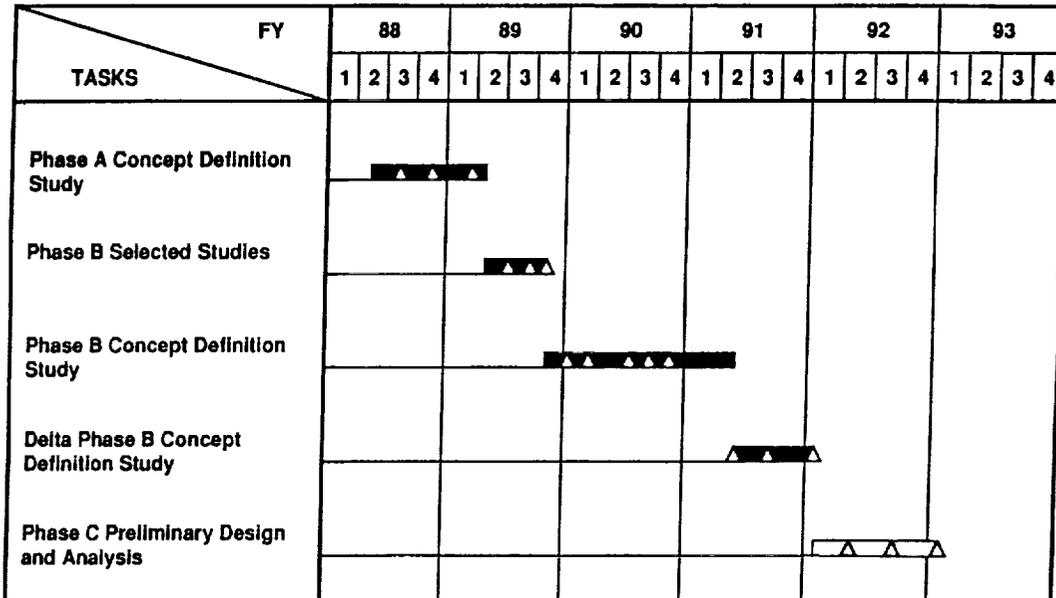
LABORATORY SIMULATION USING SCALE MODELS

MB-2 Configuration

Response History

Acceleration

Time

Modal Identification Algorithm

Modal Data

o Frequencies
o Mode Shapes
o Damping Ratios

Simulated On-Orbit Excitation

Force

Time

Load Cell

Shaker

+

−

Feedback Control

Experiment Design Performance Evaluation
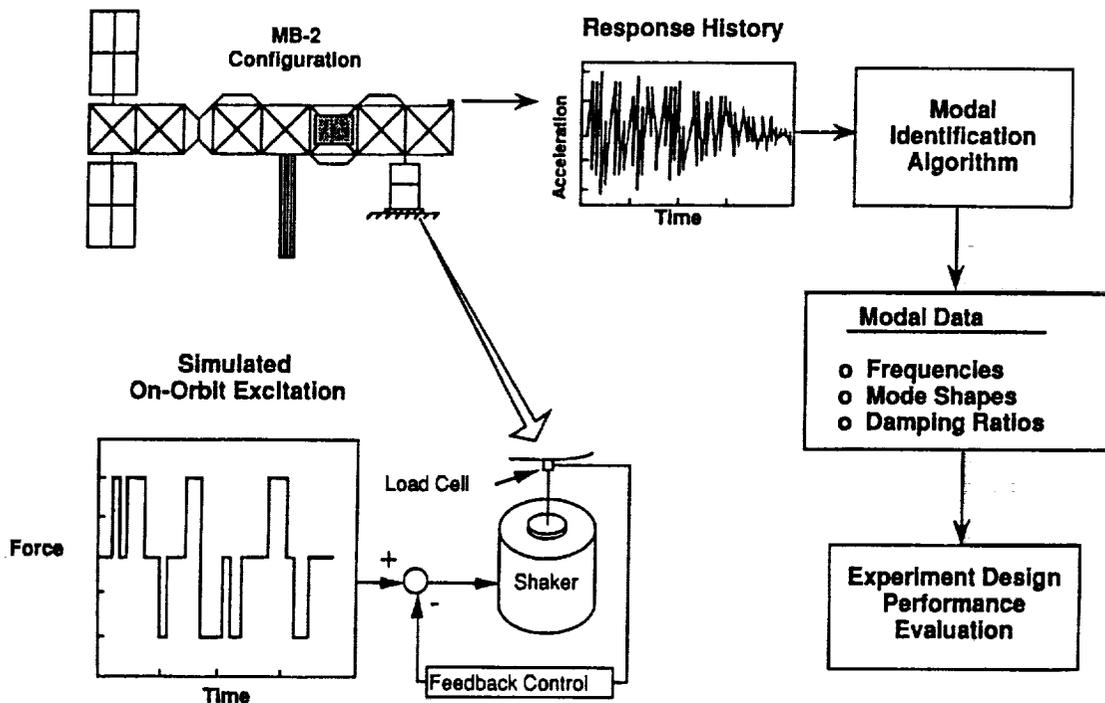
1/10-SIZE GENERIC SPACE STATION MODEL (GMB-2)
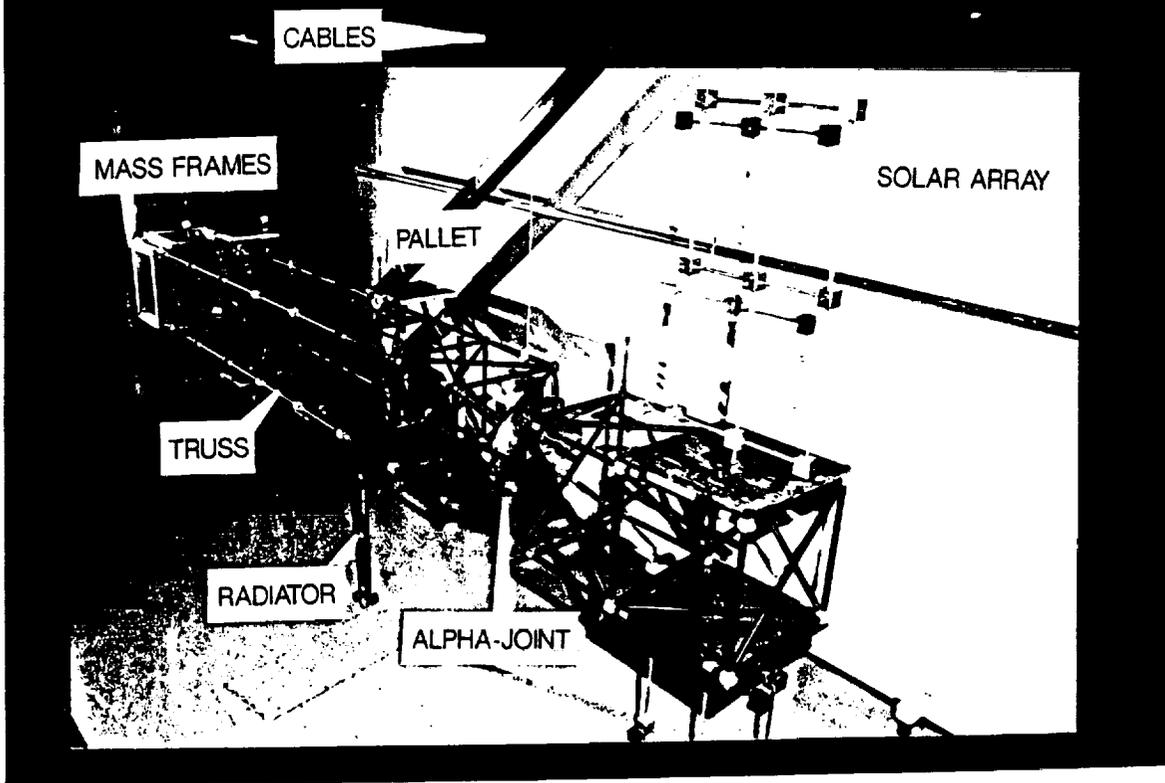
# MIE SIMULATIONS USING GENERIC MODEL
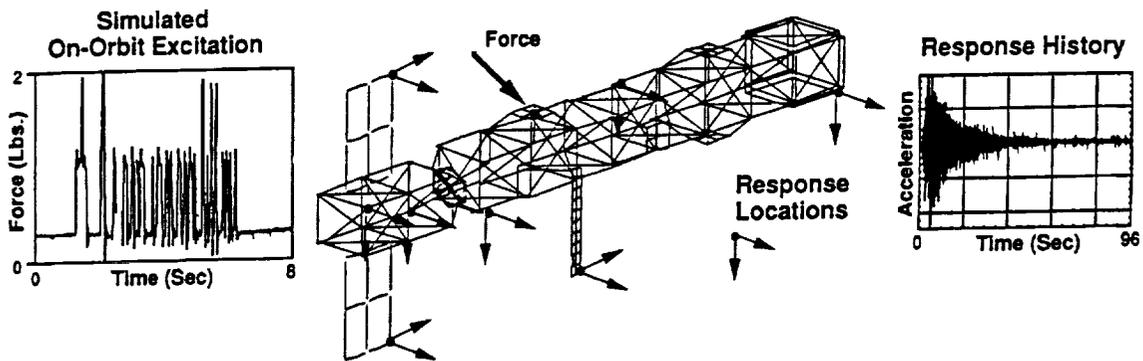
MIE simulations correlated well with modal test results

	MODAL TESTS	MIE SIMULATIONS
# of sensors	96	16
# of shakers	2	1
# of modes identified	20	16
# of primary modes	13	11

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DSMT HYBRID SCALE HMB-2F MODEL

Labels in figure: SUSPENSION CABLES, EPS RADIATOR, BETA-JOINT, PALLETS, ALPHA-JOINT, SOLAR ARRAY, GANTRY SUPPORT STRUCTURE, TCS RADIATOR, TRUSS STRUCTURE
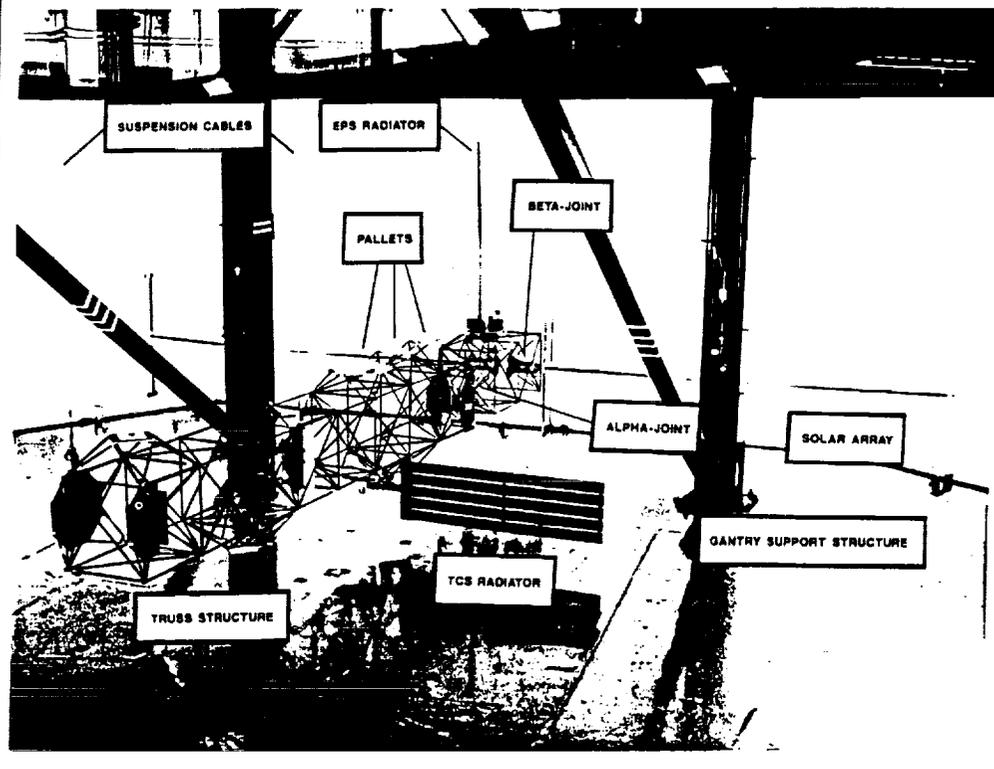
MIE SIMULATIONS USING HYBRID MODEL

Input Signal — Pounds (lb.), Time (sec.)

Response — Acceleration (m/s²), Time (sec.)
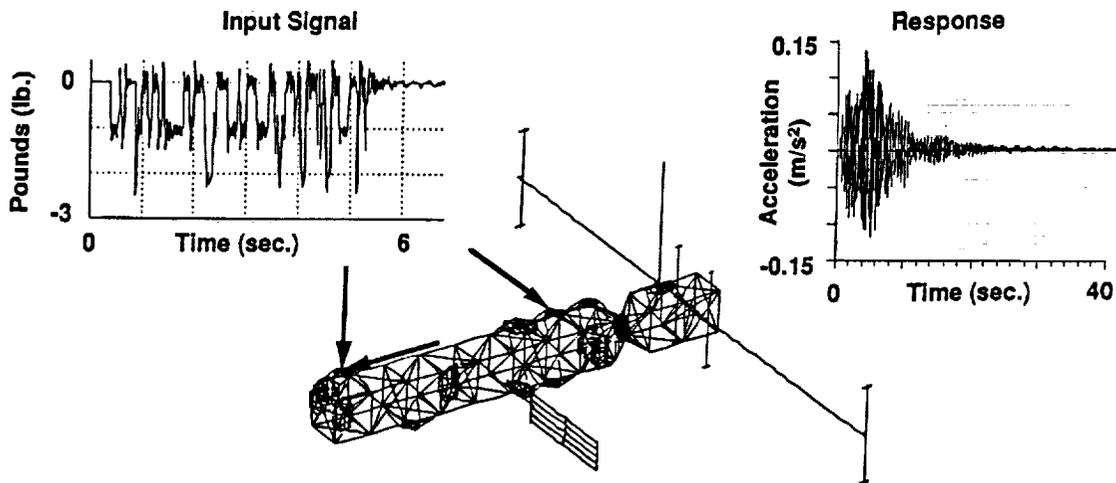
	GVT	MIE
No. of Sensors	107	13
No. of Shakers	3	3
No. of Modes Recovered	54	22

BASELINE EXPERIMENT DESIGN

FINITE ELEMENT MODELS

PMC Configuration
(SC-17)

MTC+ Configuration
(SC-7)
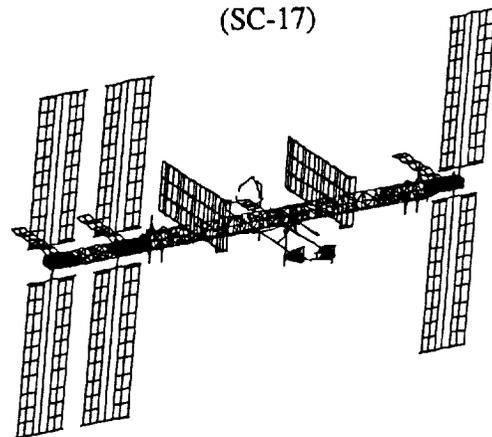
Degrees of Freedom in Preliminary Design Model

Unreduced   20500   52500
Reduced   996   2467

SELECTION OF IMPORTANT MODES

- Emphasis on global structural modes of integrated structure with frequencies below 5 Hz

- Several global mode indicators used in selection

- Resultant mode set includes truss bending and torsion modes, as well as solar array and radiator modes

- Frequencies of all modes below 2 Hz

- For MTC+: 13 Modes (0.53 - 2.09 Hz)
  For PMC: 18 Modes (0.17 - 1.32 Hz)

MIE RANDOM EXCITATION PATTERNS

Typical Excitation Patterns of Thrusters
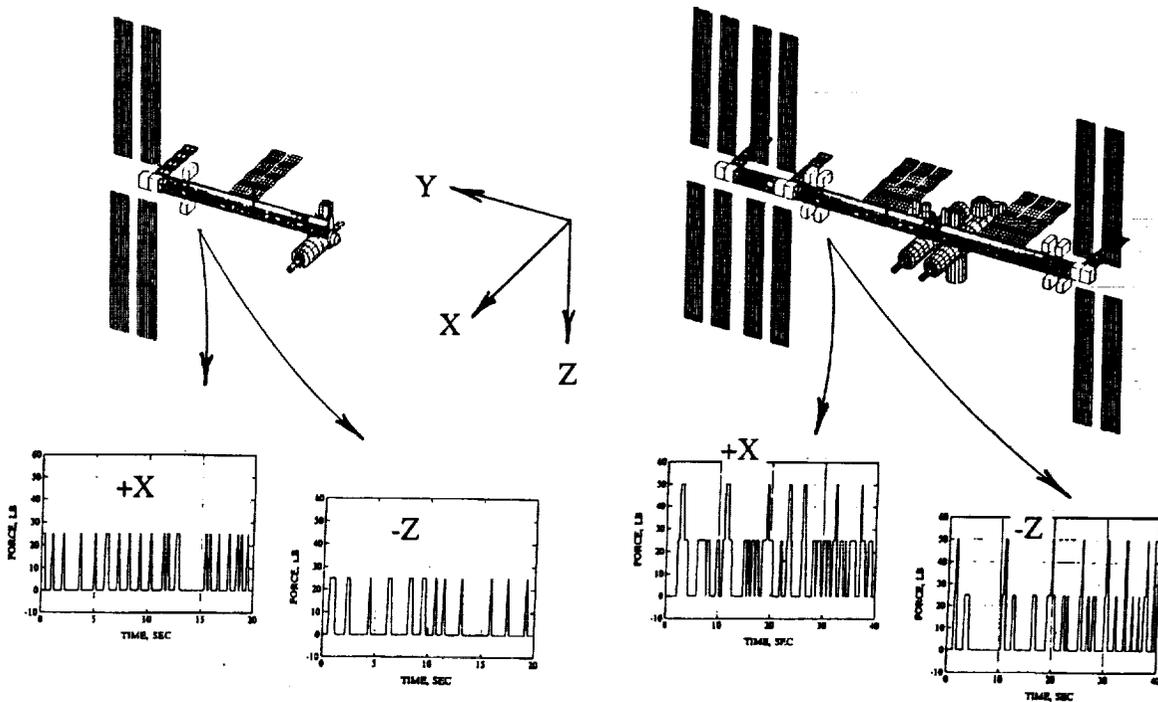
BASELINE MEASUREMENT SET FOR MIE
Instrumentation Locations

● X, Z ACCELEROMETERS
■ X, Y, Z ACCELEROMETERS
► X ACCELEROMETERS
▲ Y ACCELEROMETERS
▼ Z ACCELEROMETERS

Y ← → X
↓ Z

PV   PV   EPS   HRS   HRS   EPS   PV

PM   PM

GN&C   PM   PM

JEM
ESA   NODE-2
NODE-1   PLM   LAB
HAB

PV   PV   PV

187 accelerometers proposed
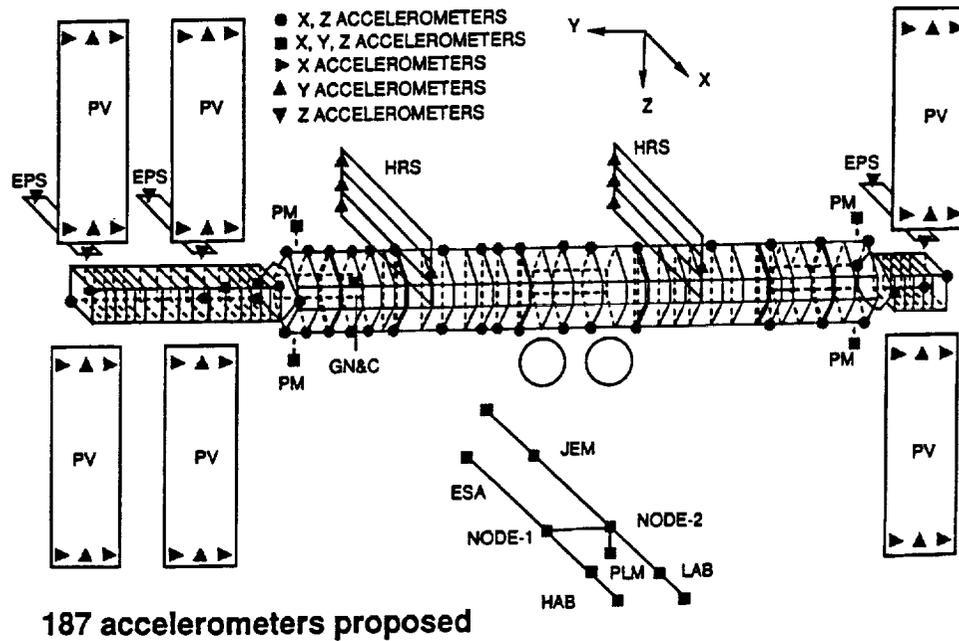
BASELINE SIMULATIONS

- Intended to demonstrate adequacy of baseline experiment design to identify important modes

- Simulated experimental data contained expected types and levels of data acquisition errors

- Eigensystem Realization Algorithm (ERA) used to extract modal parameters from time-domain free-decay responses

- Modal characteristics of all target modes for MTC+ identified

- All target modes except the two with highest frequencies identified for PMC

SUMMARY AND CONCLUDING REMARKS

- Modal Identification Experiment utilizing Space Station Freedom feasible

- Conceptual design of baseline experiment completed

- Simulations of experiment demonstrated adequacy of design to identify selected important modes

- If implemented, experiment would yield data of both engineering and research value

- Accelerometer complement proposed by SSFP as part of on-orbit verification instrumentation suite does not meet all MIE requirements

- Doubtful if additional sensors will be authorized

- Need to make best use of whatever number of accelerometers will be on Space Station