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DYNAMIC ANALYSIS OF SPACE STRUCTURES INCLUDING ELASTIC, MULTIBODY, AND CONTROL BEHAVIOR

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The Problem

To develop analysis methods, modeling strategies, and simulation tools to predict with assurance the on-orbit performance and integrity of large complex space structures that cannot be verified on the ground.

Problem Incorporates:

- Large Reliable Structural Models (including non-linear)
- Multi-Body Flexible Dynamics
- Multi-Tier Controller Interaction
- Environmental Models Including 1g and Atmosphere
- Various On-Board Disturbances
- Linkage to Mission-Level Performance Codes

All areas are in serious need of work, but weakest link is multi-body flexible dynamics.

Some Definitions

Structural Dynamics:	Motions of an elastic continuous structure under time-varying forces.
Dynamics:	Motions of a rigid particle or continuum.
Multi-Body Dynamics:	Motions of an assembly of rigid and/or flexible elements mutually interacting via non-elastic connections (trees or rings)

Multi-Body Dynamics are Encounted in Spacecraft with:

1. Very Flexible Fixed Appendages
2. Rotating Appendages
3. Dual-Spinners
4. Isolators or Gimbals between Significant Parts of S/C
5. During Deployments

MULTI-BODY TOOLS WILL PROBABLY BE NEEDED FOR:

NASA SSTM	NAME
A-18	PINHOLE OCCULTER FACILITY (50 M)
A-20	LARGE DEPLOYABLE REFLECTOR (20 M)
C-6	GEOSTATIONARY PLATFORM
U-4	TETHERED SATELLITE
U-5	SPACE STATION
A-24	INFRARED RADIOMETER (100 M)
A-25	GRAVITY WAVE INTERFEROMETER (1,000 M)
A-26	COSMIC (34 M)
A-27	100 M THINNED APERTURE
A-28	VERY LARGE SPACE TELESCOPE
L-1	SEARCH FOR EXTRA-TERRESTRIAL INTELLIGENCE (300 M)
U-6	GEOSYNCHRONOUS SPACE STATION

Multi-Body Dynamics Code Needs can be Gathered into Following Classes:

1. Large Area Antenna
2. Space Station
3. Generalized Deployment
4. Optical Systems
5. Miscellaneous General-Purpose Codes

GENERAL-PURPOSE CODE

- FIRST-ORDER ASSESSMENT OF NEW CONCEPTS
  - SAILS, TETHERS, MULTI-RINGS, DEPLOYMENTS
- SMALL TO MEDIUM-SIZE PROBLEMS
- CONTROL-STRUCTURE INTERACTION
- LARGE MINI-COMPUTER ENVIRONMENT, MACHINE INDEPENDENT
- USER-FRIENDLY, FLEXIBLE
- EVOLUTIONARY VERSION OF CURRENT DISCOS

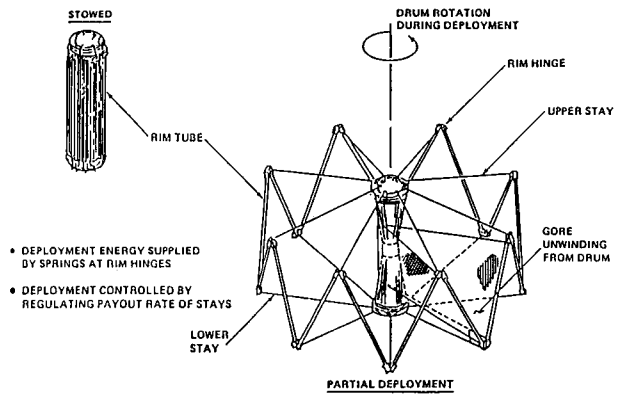
DEPLOYMENT CODE

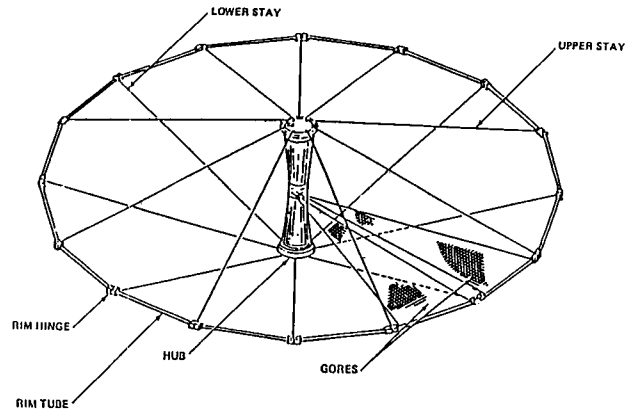
- DRIVEN MAINLY BY LARGE LIGHTWEIGHT ANTENNAS
- TREES OR RINGS WITH MANY BODIES
- MASS FLOW DURING DEPLOYMENT
- GEOMETRIC STRUCTURAL NON-LINEARITIES
- TIME-VARYING LARGE STRUCTURAL MODEL
- OPEN OR CLOSED-LOOP CONTROL OF DEPLOYMENT

ASSESSMENT ISSUES

- DEPLOYMENT INTO UNACCEPTABLE CONFIGURATION
- DEPLOYMENT INTO NON-RECOVERABLE SPIN MODES
- ENTANGLEMENTS, BREAKAGE, STRUCTURAL INSTABILITY

LARGE ANTENNA DEPLOYMENT





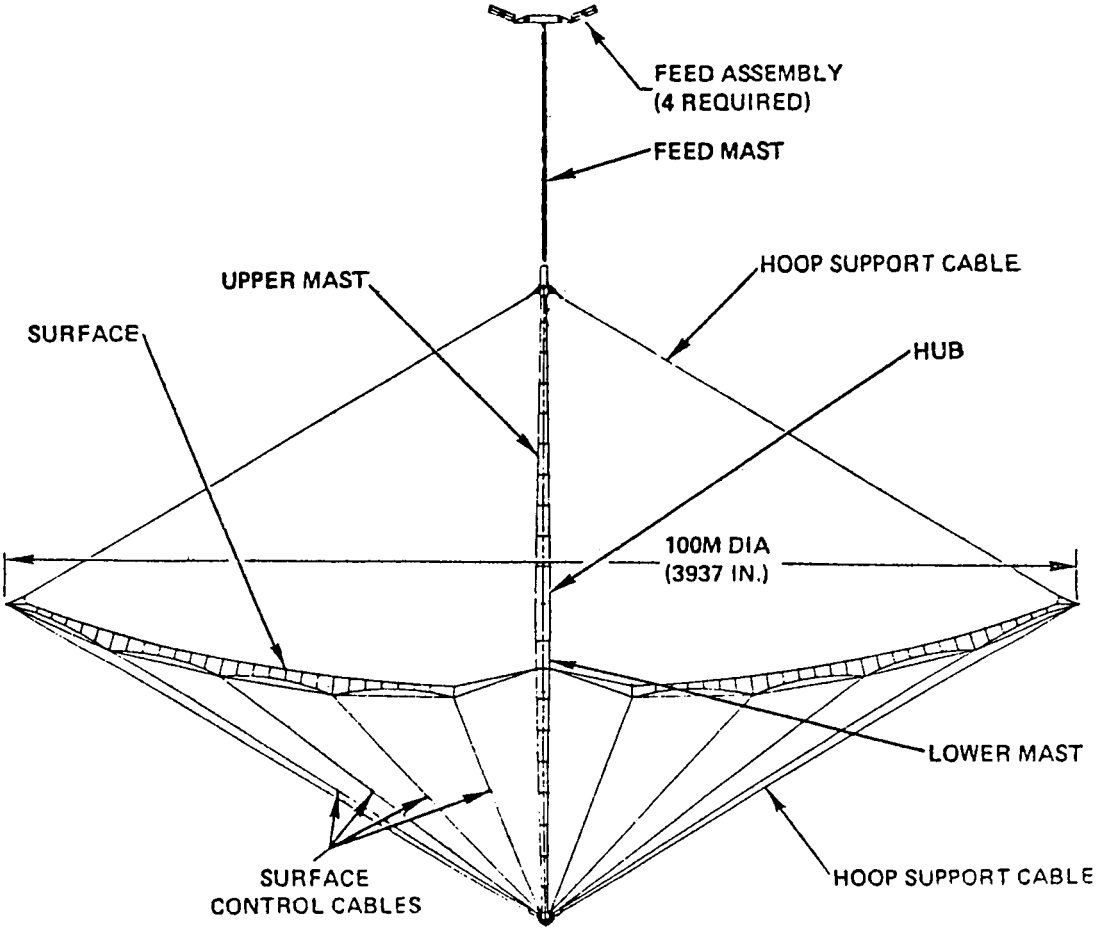
VERY LARGE ANTENNA CODE

- OPERATIONAL CONFIGURATION - LIMITED MULTI-BODY
- VERY LOW-FREQUENCY STRUCTURE
- VERY LARGE STRUCTURAL MODEL (10-50,000 DOF)
- MEMBRANE OR OTHER GEOMETRIC NONLINEARITIES
- CONTROLLED SURFACE, FEED ALIGNMENT, SYSTEM POINTING
- MODAL VS. TRAVELLING-WAVE REPRESENTATION

ASSESSMENT ISSUES

- MAIN LOBE LOSS OF GAIN
- SIDE-LOBE STRUCTURE
- DYNAMIC INTERACTION WITH ENVIRONMENTAL DISTURBANCES
- MAJOR STRUCTURE-CONTROL INTERACTION

TYPICAL
LARGE ANTENNA



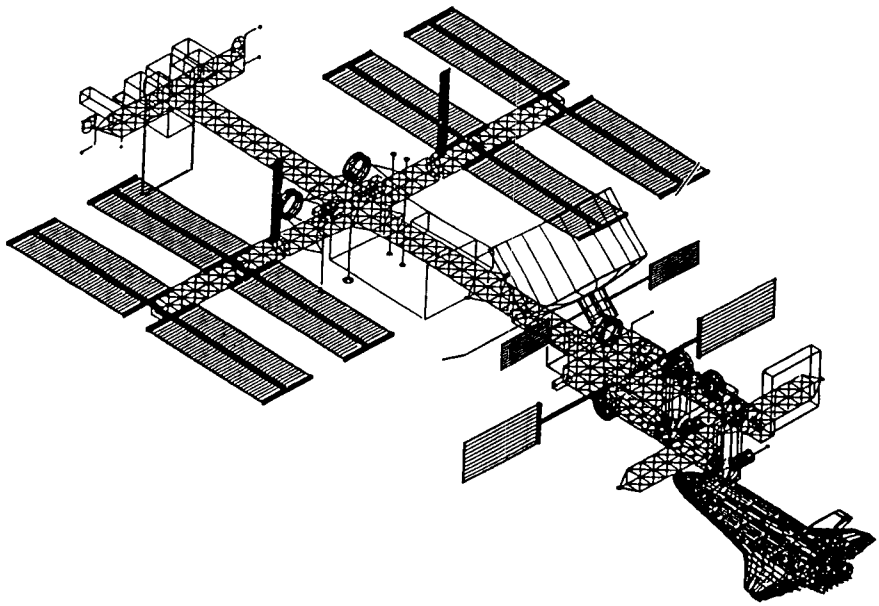
SPACE STATION CODE

- MULTI-BODY TREES (APPENDAGES & PAYLOAD SENSORS)
- LARGE STRUCTURAL MODEL
- SYSTEM AND EXPERIMENT POINTING CONTROL
- SIGNIFICANT INERTIA CHANGES (CONSTRUCTION, DOCKING)
- EXPERIMENT DISTURBANCES

ASSESSMENT ISSUES

- EXPERIMENT ISOLATION FROM ACCELERATION
- EXPERIMENT POINTING & TRACKING
- OCCUPANT COMFORT
- CONSUMABLES

SPACE STATION



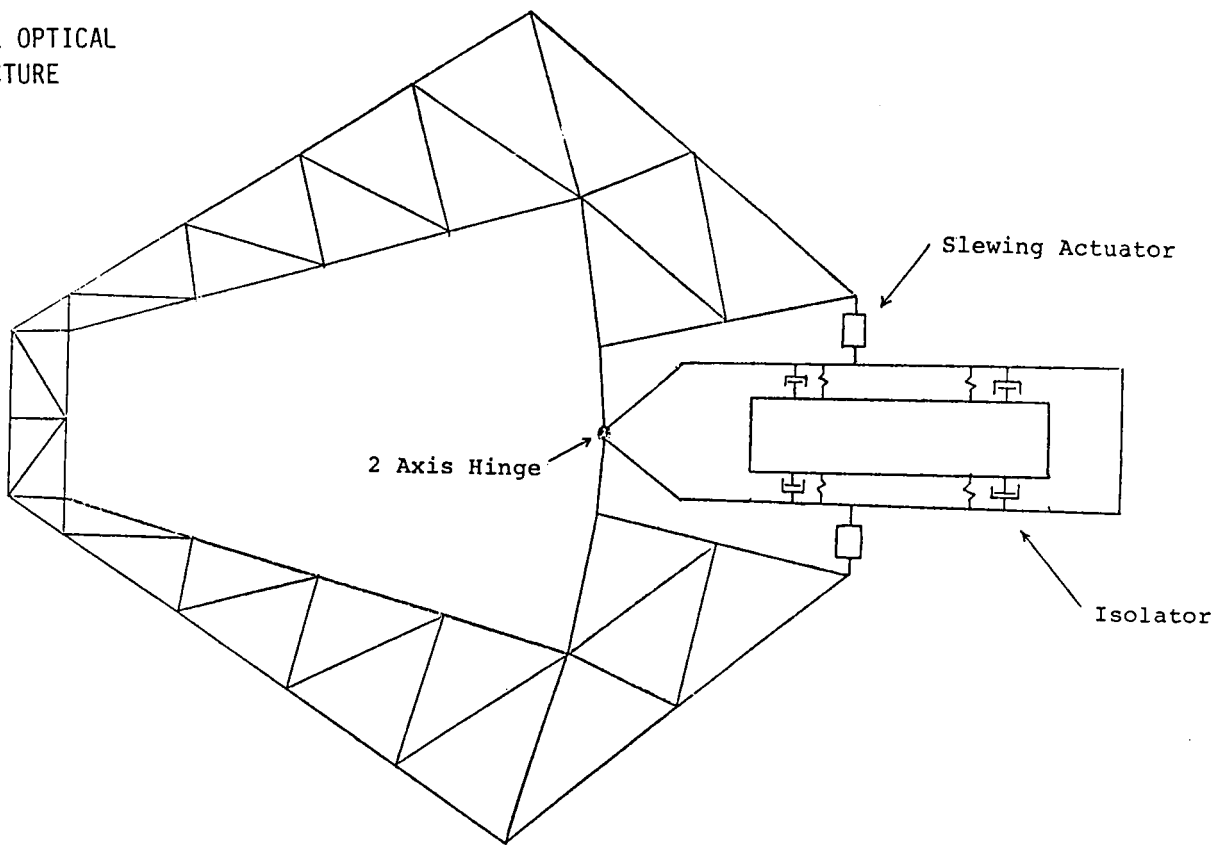
OPTICAL STRUCTURES CODE

- OVERLAPPING CONTROL SYSTEMS
  - SURFACE (WAVEFRONT)
  - VIBRATION
  - RAPID SLEW
  - PRECISION POINTING
- MULTIBODY (TREES)
- ISOLATORS
- MANY SOURCES OF DISTURBANCE
- SLOSH AND POGO
- RAPIDLY VARYING INERTIAS
- RAPID CONFIGURATIONAL CHANGES
- VERY LARGE ELASTIC MODEL

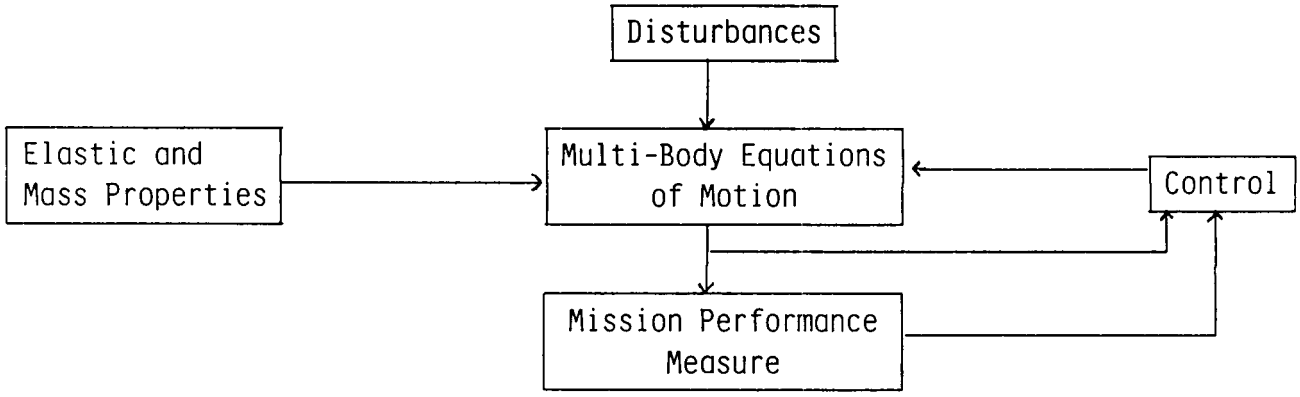
ASSESSMENT ISSUES

- SYSTEMS-LEVEL PERFORMANCE (LINKAGE TO OPTICS CODE)
- ROBUSTNESS OF MULTI-TIER CONTROL

TYPICAL OPTICAL STRUCTURE



Generic Assessment Tool



STATUS OF SPACE-SYSTEMS ORIENTED MULTI-BODY TECHNOLOGY

- DIVERSITY OF FORMULATIONS
  - TWO GENERAL FAMILIES
    - ANALYTICAL MECHANICS - "DISPLACEMENT METHOD"
    - EULER/NEWTON - "FORCE METHOD"
  - SEVERAL SCHOOLS OF THOUGHT WITHIN FAMILIES

- DIVERSITY OF SOFTWARE CODES
  - SOME EXCELLENT, MANY MARGINAL
  - SIGNIFICANT LEARNING CURVES, USER HOSTILE
  - GENERALLY LONG RUNNING TIMES
  - UNCERTAIN ACCURACY/VALIDITY
  - MANY USERS UNSOPHISTICATED, TREAT AS BLACK BOX

- GENERALLY AN IMMATURE AREA (UNLIKE STRUCTURAL DYNAMICS)

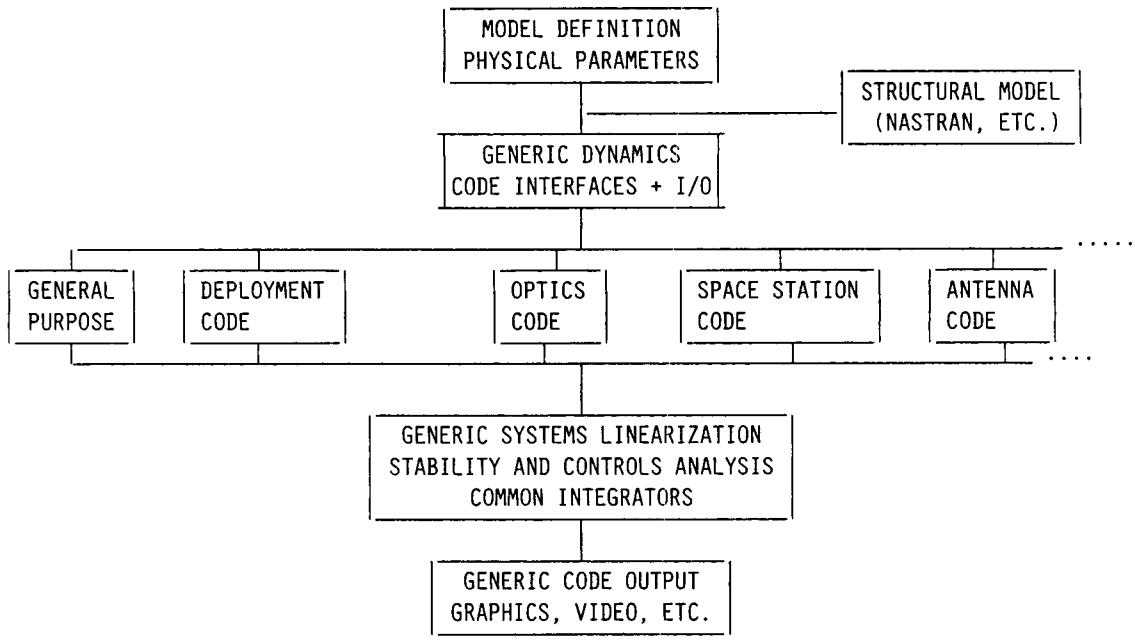
CONCERN:

- We are proposing more complicated satellites than our current analytical tools can reliably predict.
- In the multi-body area there is a vast diversity of opinion on the proper approach to the formulations.
- The time to develop a unified formulation, and convert it into code, will exceed the time available for immediate needs.

Two Approaches to Resolution

- Integration of available and other near-term codes (2-4 years).
- Basic research and development activity leading to NASTRAN-like multi-body code (5-8 years).

PATCHED DYNAMICS CODES (INTERIM SOLUTION)



OBJECTIVES OF NEW MULTI-USER CODE

- ENDURING BUT EFFICIENT COMMON FORMULATION
  - TREES, RINGS, MASSFLOW
  - LARGE STRUCTURAL MODELS
  - MULTI-LEVEL CONTROL
- SOFTWARE FEATURES
  - USER-FRIENDLY PROBLEM-LANGUAGE I-O
  - OBJECT-ORIENTED PROBLEM ASSEMBLY
  - INCORPORATED SYMBOLIC MANIPULATION
  - STRIPPED, EFFICIENT CODE FOR EXECUTION
- MACHINE-INDEPENDENCE AND ACCESSIBILITY
  - SUPER-MINIS
  - MAINFRAMES
  - SUPERS
  - FEDERATED PARALLEL PROCESSORS

Basic Approach to Development

- Consolidate Multi-Agency Government Support
- Theory Phase $T = T_0$
  - Technical Participation by Government, Industry, Academia
  - Study and Consolidation of Alternate Formulations
  - Preliminary Software Architecture Studies
- Prototype Phase $T = T_0 + 2$
  - Reduce to 2 or 3 Major Formulation and Software Approaches
  - Continue Support to Universities to Train Users
- Coding Phase $T = T_0 + 3$
  - Choose Best Overall Approach to Code
- Preliminary Testing Phase $T = T_0 + 5$
  - First Release to Selected Users
- Public Release $T = T_0 + 6$

Summary

- The problems are there, funding should be pursued
- On-going capabilities fall short
- Near-term needs require the integration of existing codes
- Far-term needs must follow a return to basics