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

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

<table>
<thead>
<tr>
<th>NASA SSTM</th>
<th>NAME</th>
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<tr>
<td>A-18</td>
<td>PINHOLE OCCULTER FACILITY (50 M)</td>
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<td>A-20</td>
<td>LARGE DEPLOYABLE REFLECTOR (20 M)</td>
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<td>C-6</td>
<td>GEOSTATIONARY PLATFORM</td>
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<td>INFRARED RADIOMETER (100 M)</td>
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<td>A-25</td>
<td>GRAVITY WAVE INTERFEROMETER (1,000 M)</td>
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<td>COSMIC (34 M)</td>
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<td>A-27</td>
<td>100 M THINNED APERTURE</td>
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<td>A-28</td>
<td>VERY LARGE SPACE TELESCOPE</td>
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<tr>
<td>L-1</td>
<td>SEARCH FOR EXTRA-TERRESTRIAL INTELLIGENCE (300 M)</td>
</tr>
<tr>
<td>U-6</td>
<td>GEOSYNCHRONOUS SPACE STATION</td>
</tr>
</tbody>
</table>

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

FEED ASSEMBLY (4 REQUIRED)
FEED MAST

UPPER MAST
HUB

100M DIA (3937 IN.)
LOWER MAST

SURFACE CONTROL CABLES
HOOP SUPPORT CABLE
HOOP SUPPORT CABLE
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
STATUS OF SPACE-SYSTEMS ORIENTED MULTI-BODY TECHNOLOGY

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

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

3. 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).
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