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# NASA'S CONTROLS-STRUCTURES INTERACTION PROGRAM

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## ABSTRACT

Spacecraft design is conducted conventionally by estimating sizes and masses of mission-related components, designing a structure to maintain desired component relationships during operations, and then designing a control system to orient, guide and/or move the spacecraft to obtain required performance. This approach works well in cases where a relatively high stiffness structural bus is attainable and where nonstructural components are massive relative to the structure.

Occasionally, very flexible, distributed-mass, structural components, such as solar arrays and antennas are attached to the structural bus. In these, the primary purpose is to maintain geometric relationships rather than support masses which are large relative to the structural mass. Because of their flexibility, potential interactions of such components with the spacecraft control system can reduce performance or restrict operations. This interaction, referred in this document as controls-structures interaction (CSI), also occurs in small components if precision pointing and/or surface shapes/orientations are critical performance factors and in very large systems where attaining a high structural stiffness is detrimental to launch and operations requirements. The degree of success in handling these situations in past designs is uncertain. Reduced performance and unexpected dynamic motions have been observed in operational spacecraft; but, in most cases, the spacecraft were not sufficiently instrumented to determine the cause.

Designing to avoid CSI generally requires either stiffening the structure (costly in mass, inertia and fuel consumption) or slowing down the control system response (costly in performance capability). Using the power available in the control system to reduce the interactive motions is theoretically possible; a great number of approaches to do so have been advanced in the literature. However, reduction of these approaches to practice on hardware has not been accomplished on any meaningful scale. The techniques generally require analytical representations of the system within the control loop. The fidelity, size, accuracy and computational speed of these analyses are integrally related to, and affect the performance of, the combined structure-control system. The structural hardware, the control hardware, and the analytical models cannot be separated in the process of verifying that the system performs as required. Furthermore, if improperly designed, the closed-loop system is subject not only to inadequate performance, but also to destructive dynamic instability.

Future NASA missions are likely to increase the likelihood of CSI because of increased size of distributed-mass components, greater requirements for surface and pointing precision, increased use of articulated moving components, and increased use of multi-mission science platforms (with multiple control systems on board). An SSTAC



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develop the technology to solve the CSI problem. More recently, a NASA CSI Requirements Committee reviewed potential future NASA missions and found the need for CSI technology to be widespread.

A NASA program is about to start which has the objective to advance [redacted] technology to a point where it can be used in spacecraft design for future missions. Because of the close interrelationships between the structure, the control hardware, and the analysis/design, a highly interdisciplinary activity is defined in which structures, dynamics, controls, computer and electronics engineers work together on a daily basis and are co-located to a large extent. Methods will be developed which allow the controls and structures analysis and design functions to use the same mathematical models. Hardware tests and applications are emphasized and will require development of concepts and test methods to carry out.

Because of a variety of mission application problem classes, several time-phased, focus ground test articles are planned. They will be located at the Langley Research Center (LaRC), the Marshall Space Flight Center (MSFC) and at the Jet Propulsion Laboratory (JPL). It is anticipated that the ground tests will be subject to gravity and other environmental effects to the extent that orbital flights tests will be needed for verification of some technology items. The need for orbital flight experiments will be quantified based on ground test results and mission needs. Candidate on-orbit experiments will be defined and preliminary design/definition and cost studies will be carried out for one or more high-priority experiments.

# A BRIEF OVERVIEW OF THE CONTROLS-STRUCTURES INTERACTION (CSI) PROGRAM

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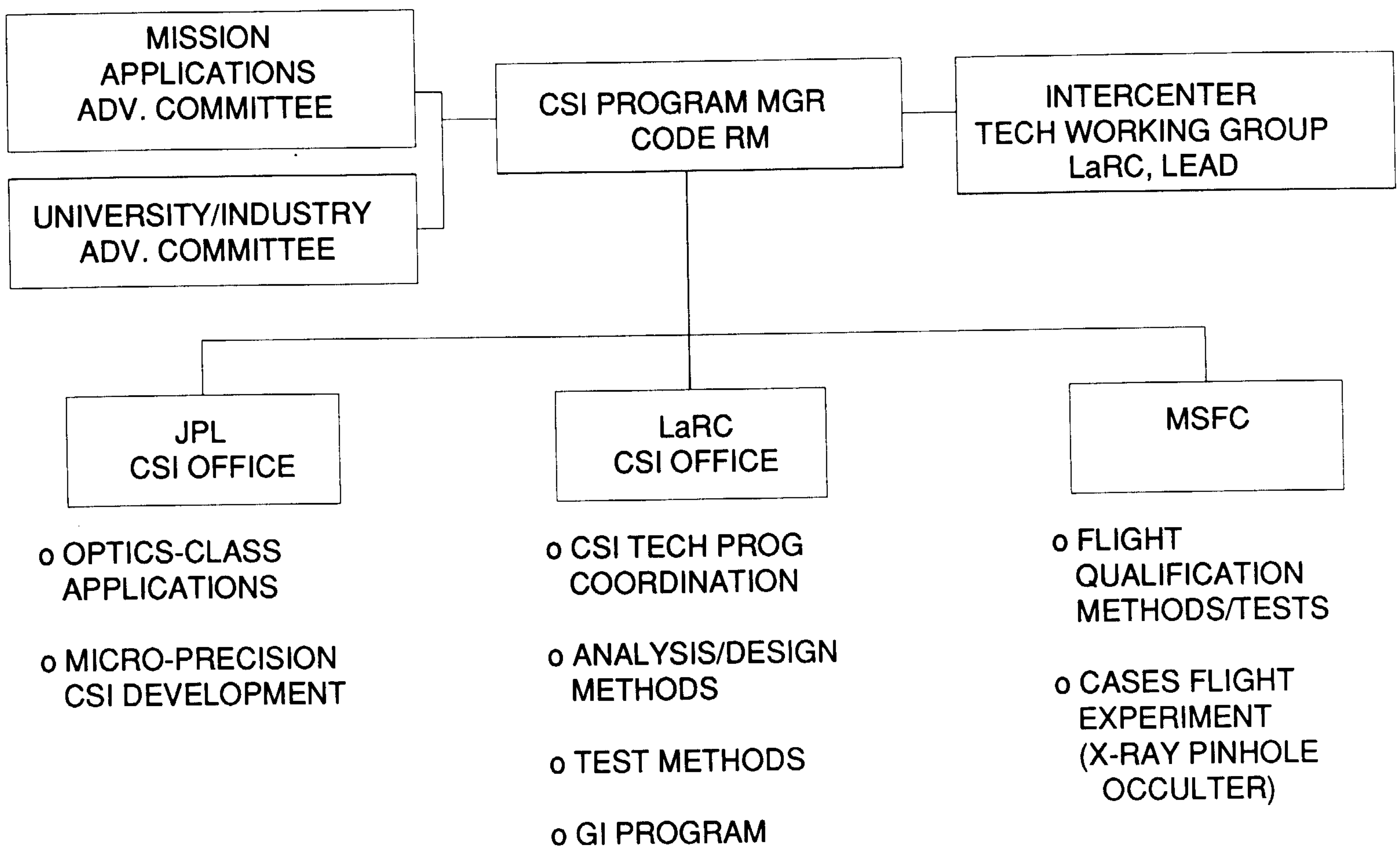
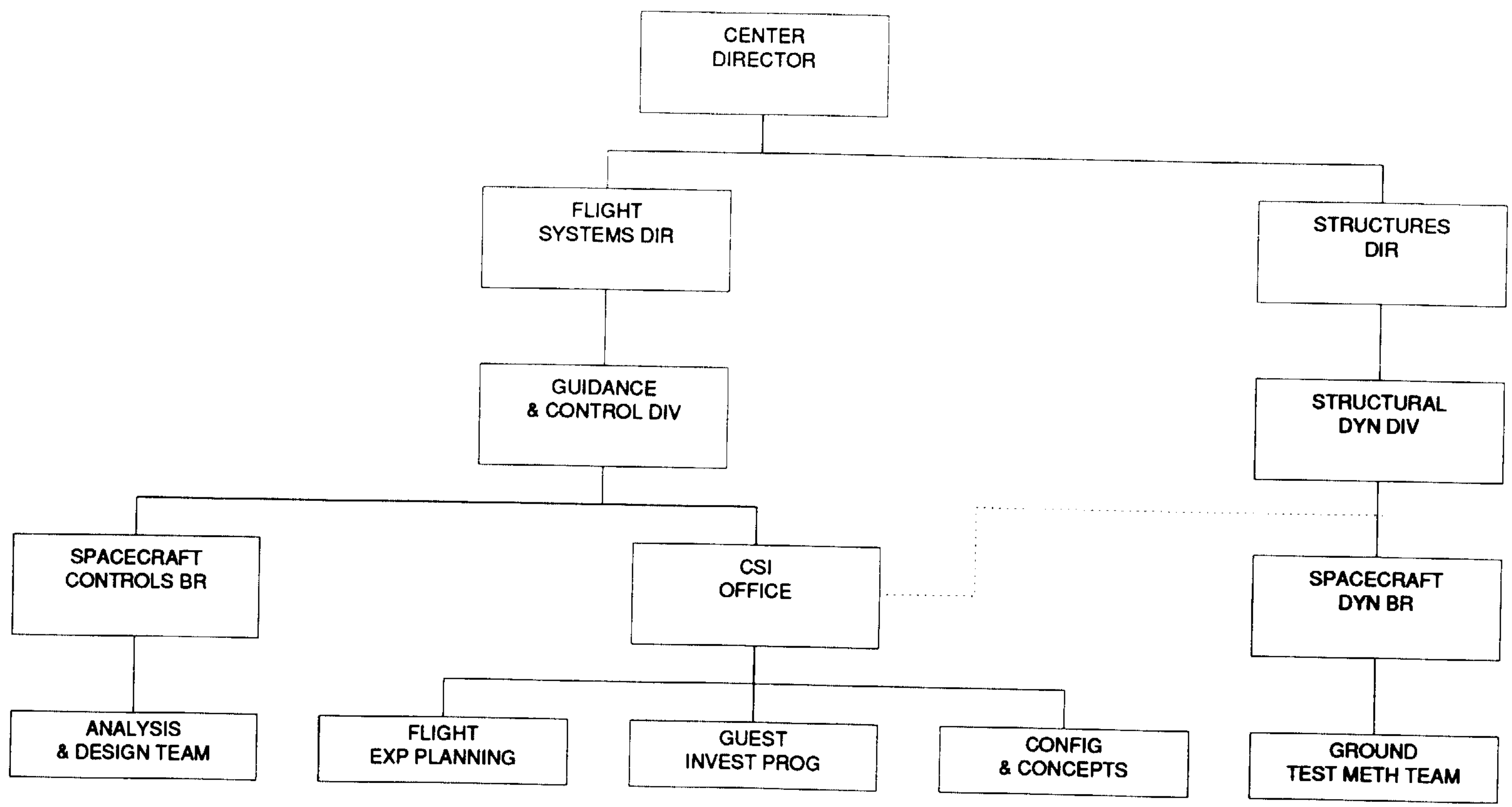
# THE NASA CONTROLS-STRUCTURES INTERACTION (CSI) PROGRAM

- A RESTRUCTURING OF THE COFS PROGRAM
- EMPHASIZES INCREASED GROUND TESTING AND ANALYSIS WITH A CONSERVATIVE FLIGHT EXPERIMENT SCHEDULE
- MISSION APPLICATIONS WEIGHTED TOWARD EARTH OBSERVATION SPACECRAFT FOR 2000+
- JOINT EFFORT OF NASA HEADQUARTERS AND THREE FIELD ORGANIZATIONS, LANGLEY, MARSHALL AND JPL
- MANAGED BY HEADQUARTERS CODE RM, SPECIFIC ROLES FOR EACH FIELD ORGANIZATION, OVERALL TECHNICAL COORDINATION BY LANGLEY

# NASA CSI PROGRAM ORGANIZATION



# LaRC CSI ORGANIZATION



# CSI PROGRAM GENERAL OBJECTIVES

- o REDUCE DYNAMIC RESPONSE FOR GIVEN MANEUVERS/LOADS WITHOUT INCREASING MASS OR CONTROL ENERGY
- o DEVELOP ACCURATE METHODS FOR PREDICTION OF ON-ORBIT RESPONSE BASED ON ANALYSIS TUNED BY GROUND TESTS
- o DEVELOP UNIFIED MODELING, ANALYSIS AND DESIGN METHODS WHICH PROVIDE BETTER AND FASTER RESULTS THAN CURRENT METHODS
- o VERIFY THE CAPABILITY TO VALIDATE ON-ORBIT CSI PERFORMANCE BY GROUND-BASED METHODS

# CSI PROGRAM ELEMENTS

CONFIGURATIONS & CONCEPTS
- QUANTIFY MISSION REQUIREMENTS & BENEFIT TRADE-OFFS
- EXPAND CONFIGURATION AND TECHNOLOGY OPTIONS

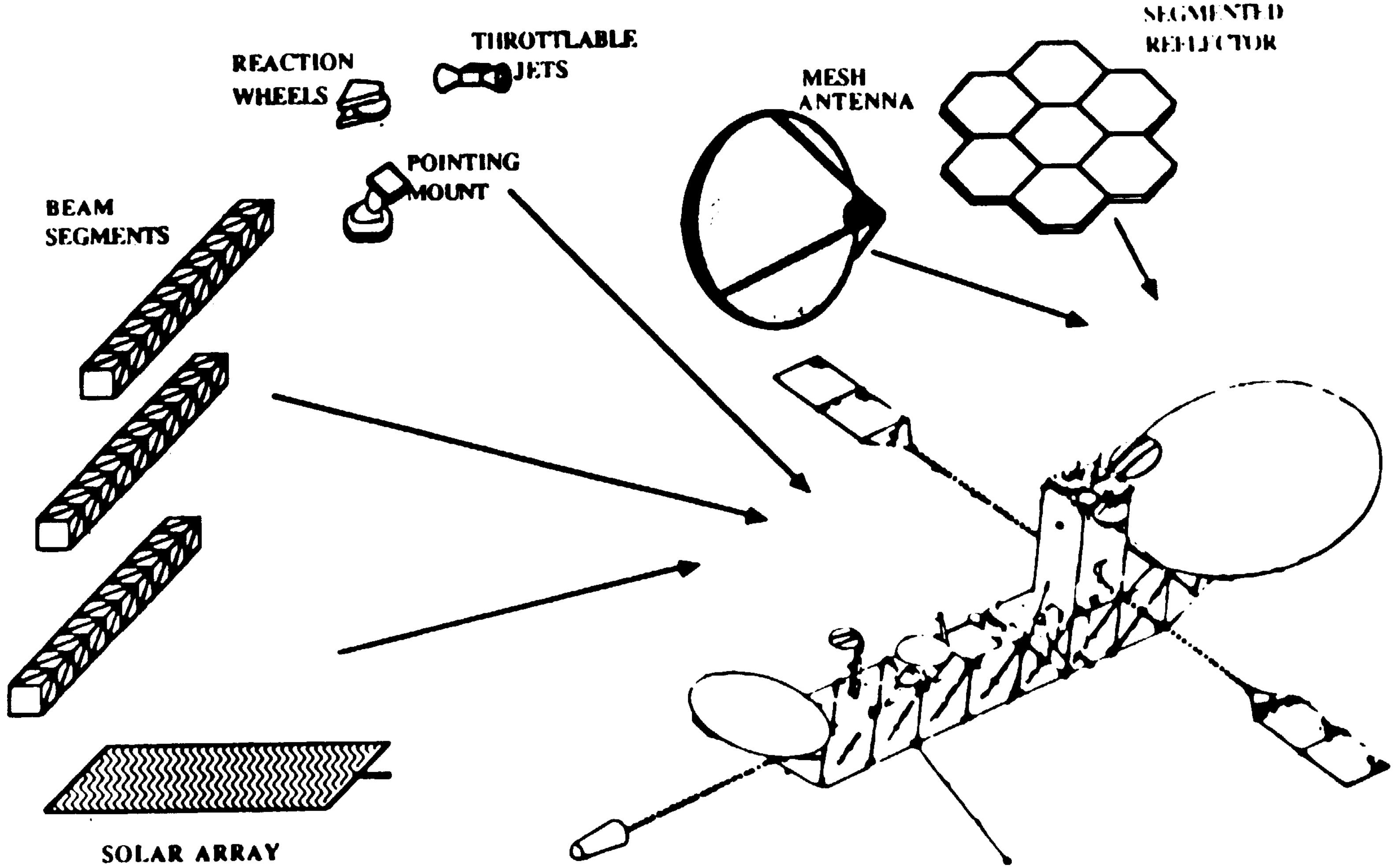
INTEGRATED ANALYSIS & DESIGN
- DEVELOP UNIFIED MODELING & ANALYSIS TECHNIQUES
- DEVELOP IMPROVED CSI SYSTEM DESIGN APPROACHES

GROUND TEST METHODOLOGY
- DEVELOP TEST METHODS FOR VERIFYING CSI DESIGNS
- VALIDATE THEORETICAL CSI TECHNICAL APPROACHES

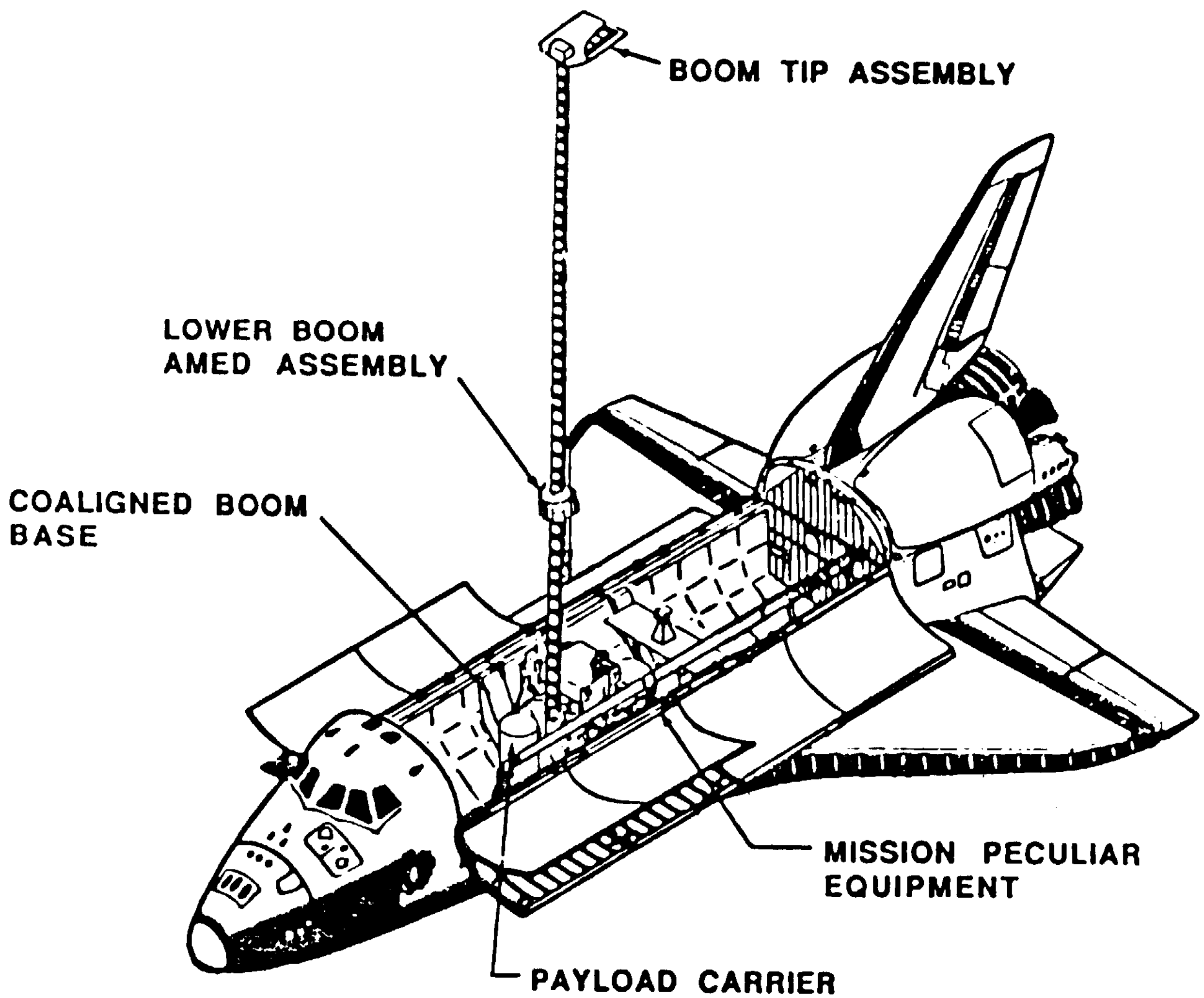
IN-SPACE FLIGHT EXPERIMENTS
- INVESTIGATE PHENOMENA MASKED IN GROUND TESTS
- CALIBRATE PROPOSED VERIFICATION TEST & ANALYSIS METHODS

GUEST INVESTIGATOR PROGRAM
- PROVIDE MECHANISM/FUNDS FOR INCORPORATING IDEAS & CAPABILITIES OF NON-NASA RESEARCHERS

# EVOLUTIONARY GROUND TEST SYSTEM



# FLIGHT STRUCTURES CONTROL EXPERIMENT



# USEFUL WORKSHOP OUTPUT

CASES WHERE PROBLEMS WERE CAUSED BY THE FOLLOWING:
- INACCURATE MATH MODELS
- INACCURATE COMPUTATIONAL ALGORITHMS
- INABILITY TO TEST SYSTEM
- SLOW DESIGN ITERATION TURNAROUND
- FLEXIBLE STRUCTURE INTERACTION WITH CONTROLS

EXAMPLES OF SIGNIFICANT DESIGN IMPACT TO AVOID CSI PROBLEMS:
- BY LIMITING CAPABILITY
- BY REDUCING REQUIREMENTS
- BY "BEEFING-UP" DESIGN

QUANTIFIED EXAMPLES OF THE COMPUTATIONAL BURDEN
- ITERATION TIMES
- COMPUTER "HORSEPOWER" REQUIREMENTS

PRIORITIZED AREAS OF EXPECTED BENEFIT FROM RESEARCH

# UPCOMING CSI PROGRAM EVENTS

- FIRST GI CONTRACTS TO BE ANNOUNCED - AUGUST
- GI/UNIVERSITY ENGR RESEARCH CENTERS/OUTREACH COORD MEETING - OCTOBER
- THIRD NASA/DOD CSI CONFERENCE, JANUARY 89
- NEXT GI PROPOSAL SOLICITATION - 1st QUARTER 89