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ELEMENT-SPECIFIC MODAL FORMULATIONS FOR LARGE-DISPLACEMENT MULTIBODY DYNAMICS

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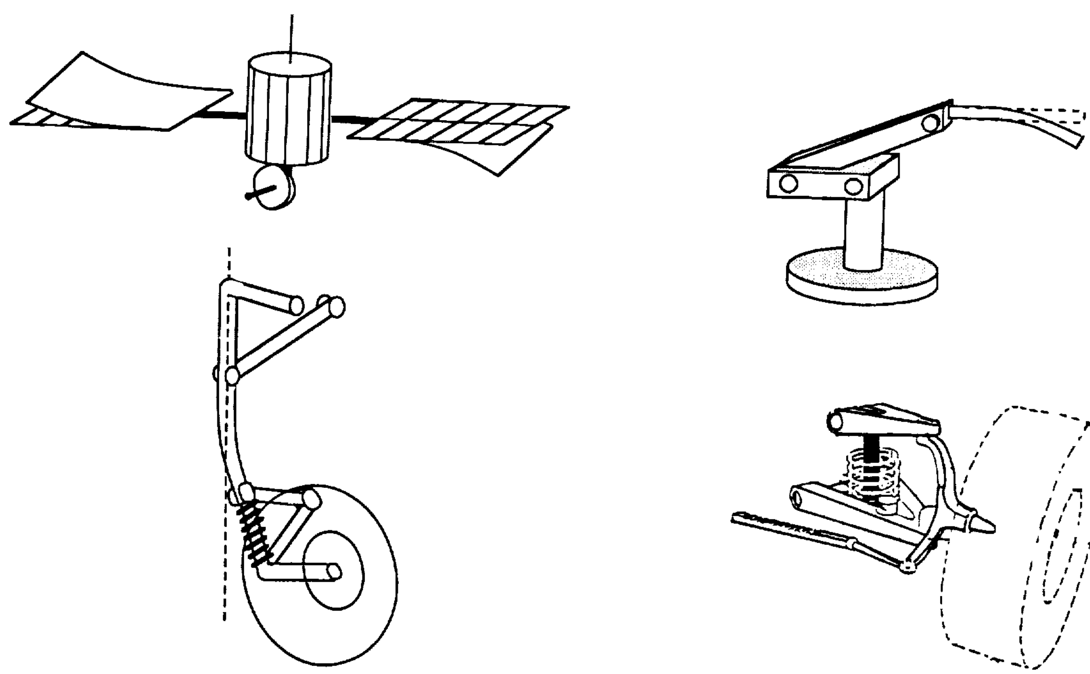
OBJECTIVE

This paper examines large displacement assumed-mode modeling techniques in the context of multibody elastodynamics. The range of both general and element-specific approaches are studied with the aid of examples involving beams, plates, and shells. For systems undergoing primarily structural bending and twisting, with little or no membrane distortion, it is found that fully-linear, element-specific, modal formulations provide the most accurate time history solutions at the least expense. When membrane effects become dominant in structural problems due to loading and boundary conditions, one must naturally resort to a formulation involving a nonlinear stress-strain relationship in addition to nonlinear terms associated with large overall system motion. Such nonlinear models have been investigated here using assumed modes and found to lead to modal convergence difficulties when standard free-free structural modes are employed. A constrained mode formulation aimed at addressing the convergence problem is proposed here.

OVERVIEW

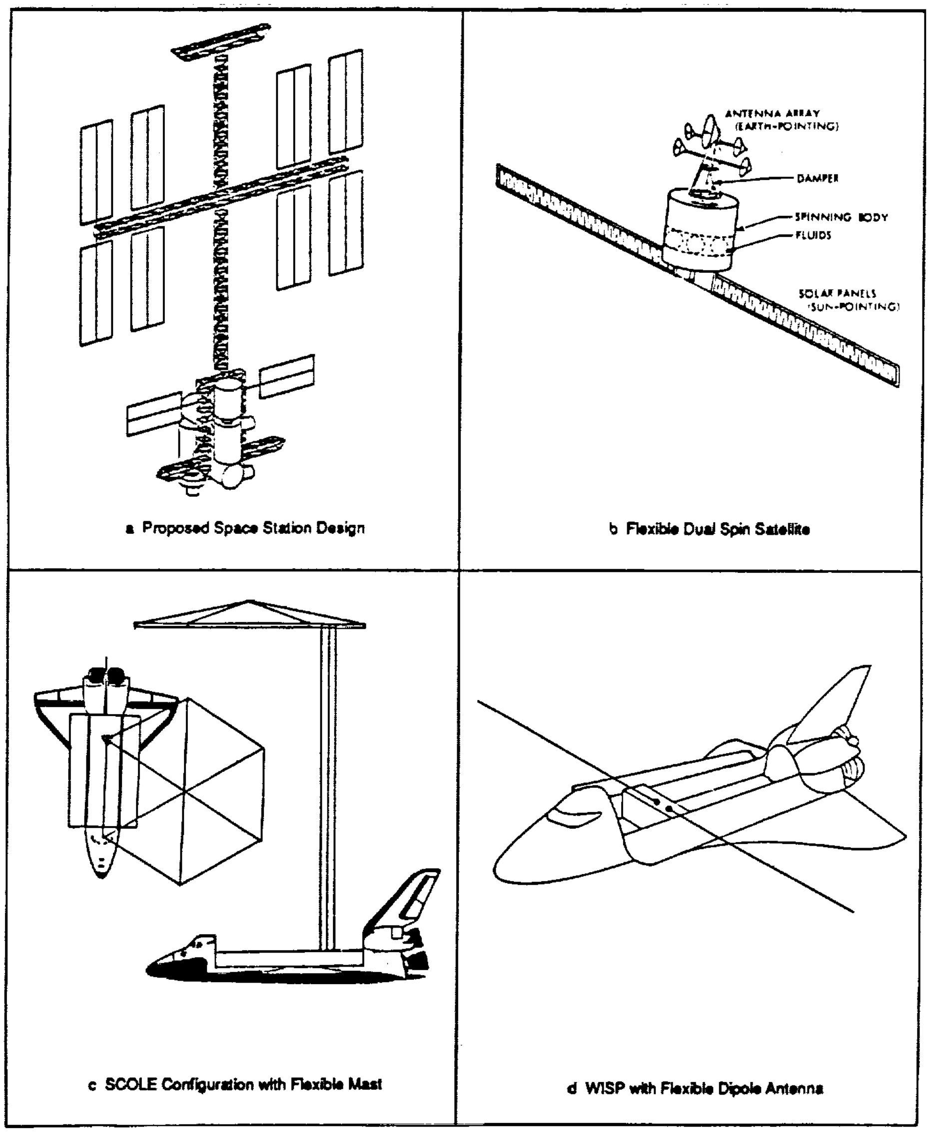
The general design trend for mechanical systems including machines and mechanisms, spacecraft and satellites, robotic manipulators, and large space structures is toward ever lighter, more flexible systems with increasingly faster dynamic response and minimal power requirements. A consequence of the extreme flexibility of structural elements comprising these systems is that elastic deformation of components often occurs during standard operational motions. The deformations interacting with the control law performance can lead to drastic effects on overall motion. These new designs have motivated increased research, such as that summarized here, aimed at producing accurate models of such systems for purposes of simulation, structural verification, dynamic stability determination, and control law design. The role of simulation, in particular, has increased dramatically in importance in recent years due mainly to two factors: (1)for many new aerospace multibody system designs, Earth-based experimental testing in a non-zero gravitational field cannot provide accurate answers concerning the behavior of the system in its actual space environment, and (2)the increased competitiveness of worldwide consumer industries necessitates fewer mechanical prototypes and more reliance on *computational prototyping* procedures. A basic requirement of models intended for general-purpose simulation of these newer designs is that they must be able to account properly for both large overall rotational and translational motions and concurrent small strain elastic deformations of flexible body components as well as accurately include the important coupling effects existing between these two types of dynamic behavior. In particular, full consideration should be given to the variations in flexible body stiffness caused by inertia forces arising from rapid overall motion. In other words, when a component of a multibody system undergoes rotational maneuvers or moderate-to-fast translational accelerations, the resistance of the component to deformation may change considerably; this fact should be incorporated in the system model used for simulation.



SPACECRAFT APPLICATIONS

Although multibody dynamic analysis spans many application areas, including automotive and off-highway vehicles, rail cars, agricultural and construction equipment, consumer products, biomechanical systems, and robotic manipulators, perhaps the most rigorous testing ground for general multibody dynamic analysis techniques occurs in spacecraft applications due to the total freedom of translational and rotational motion, the large amplitude inertia forces, the high flexibility of light-weight aerospace structures, and the complex behavior of the active control systems.

In order to focus our study of multibody elastodynamic techniques on key issues of concern for the majority of space transportation vehicles, space stations, Earth satellites, and complex interplanetary probes, we will limit our investigations to four typical categories of overall system motion, namely: (1)stationkeeping, (2)constant spin rotational motions, (3)*slewing* or repositional maneuvers, and (4)spin-up or spin-down motions.



a Proposed Space Station Design

b Flexible Dual Spin Satellite

c SCOLE Configuration with Flexible Mast

d WISP with Flexible Dipole Antenna

OUTLINE

The following discussion begins with a summary of two necessary, but not sufficient, requirements for multibody elastodynamic programs to accurately simulate uncontrolled and actively-controlled systems containing deformable structural elements undergoing large overall rotation and translation as well as small deformation.

This is followed by a brief review of possible modeling techniques and pitfalls to be avoided. Element-specific approaches involving physical discretization, Galerkin finite element discretization, and modal discretization techniques are examined. Advantages and disadvantages of each approach are discussed.

Then, new element-specific linear and nonlinear modal formulations for beams, plates, and shells are introduced and compared to other techniques. Finally, simulation results indicating the effectiveness and accuracy of various methods are presented.

I. Requirements For General Flexible Multibody Formalisms
- Element-Specificity
- Proper Coupling of Deformation/Overall Motion

II. Possible Modeling Approaches
- General Modal Continuum Modeling
- Element-Specific Discrete and Continuous Modeling

III. Linear and Nonlinear Element-Specific Formulations
- Consistently Linearized Beam, Plate, and Shell
- Second-Order Beam and Plate Models

IV. Simulation Results
- Membrane/Bending Problems
- Convergence

REQUIREMENTS

In order to accurately predict motion of joint-connected systems of rigid and deformable bodies undergoing both large overall motion and small deformation, a dynamic formalism must satisfy a number of important criteria. Two of these criteria which will be explicitly discussed here are: (1)the ability of the formalism to model specific element types differently and completely, and (2)to include motion-induced stiffness variations.

I. Treat Structural Element Types Distinctly

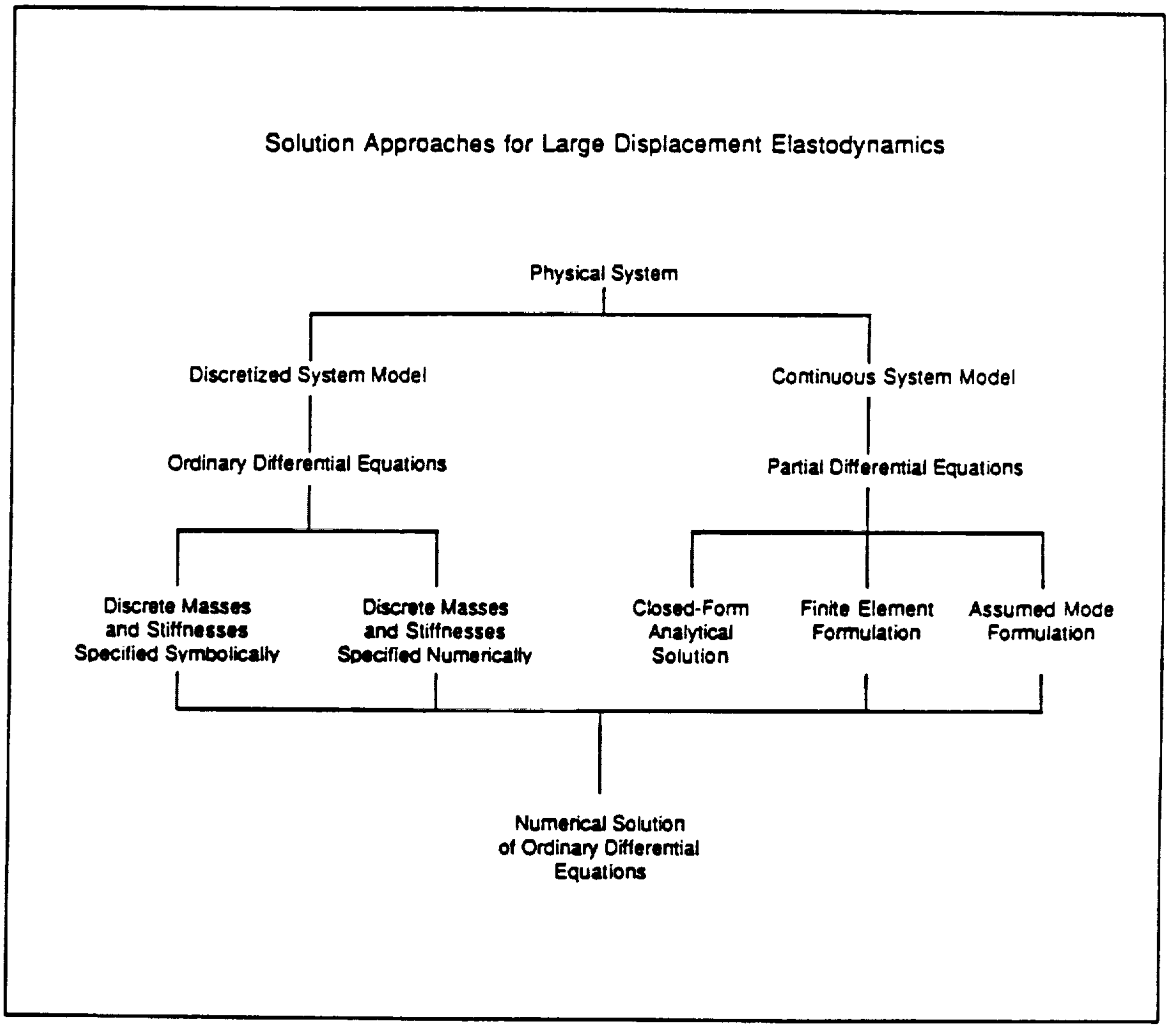
- Different Models for:
  - Beams,
  - Plates,
  - Shells,
  - Solids, etc

II. Model Motion-Induced Stiffness Variations

- Axial Inertial Force Contributions
- Rotational Inertial Force Contributions

MODELING APPROACHES

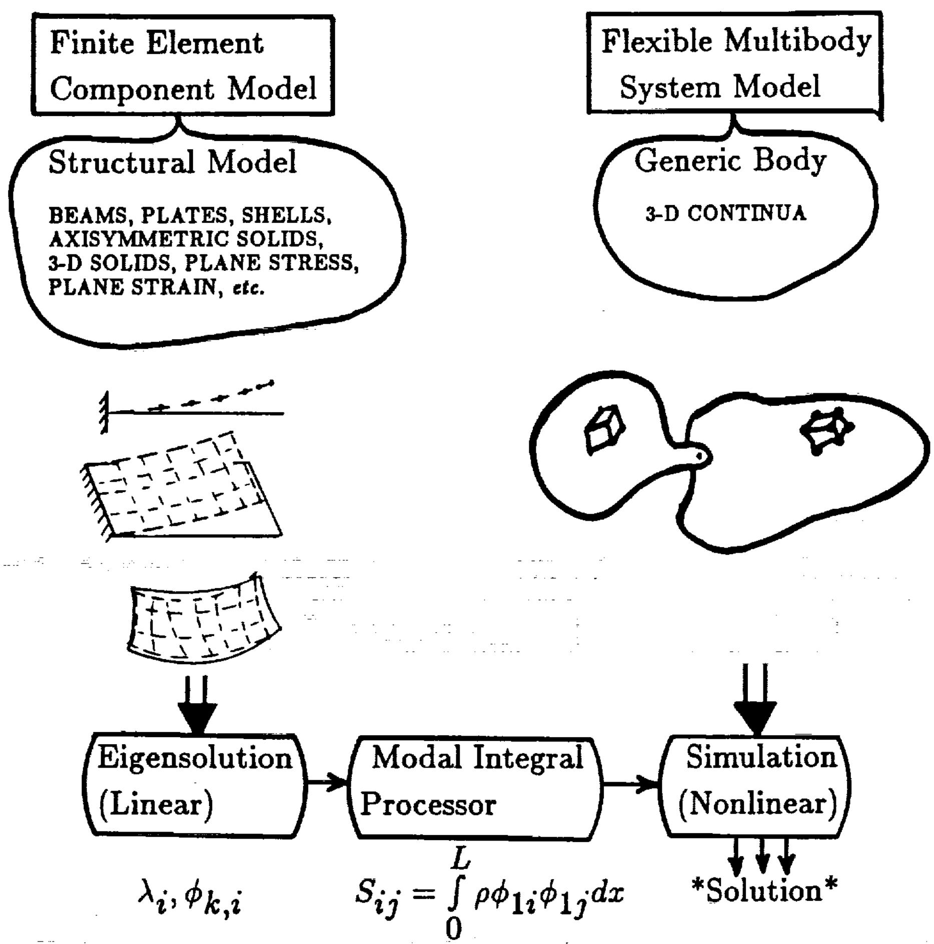
There are numerous ways to characterize the deformability of elastic bodies in a multibody system. The techniques range from pure physical discretization methods to mathematical discretization procedures involving local (Galerkin finite element) or global (Rayleigh-Ritz assumed mode) shape functions.



Solution Techniques for Large Displacement Elastodynamics

These methods can be further sub-divided according to the manner in which component bodies are treated directly within the multibody formalism in question. Some formalisms model each component body, regardless of its actual composition, as a general three-dimensional continuum whose flexibility is characterized entirely by component modes obtained from a separate finite element analysis wherein the component was modeled in detail using structural elements. However, in order to provide proper model fidelity, it will be shown that the components also must be modeled using structural elements directly within the multibody formalism, even if modes are obtained from a separate detailed structural finite element model.

General Modal Linear Continuum Modeling



ELEMENT SPECIFICITY PROBLEMS

SLOW REPOSITIONAL MANEUVER OF CHANNEL BEAM

In order to examine differences between formalisms that are element-specific and those that employ general linear continuum modeling, we will use the two methods to predict response of a sample system. Shown below is a flexible channel section beam which is to be repositioned slowly through an angle Ψ of 180°. The time history of the angle Ψ, shown in the sketch, is given below.