LARGE SPACE SYSTEM CONTROL TECHNOLOGY OVERVIEW

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LSST CONTROLS

The controls discussion will be presented by 3 speakers. First, the nature of the problem will be described in an attempt to establish a frame of reference for the more detailed reports to follow. Descriptions of the work that has been done at JPL and at Purdue under contract to JPL will be provided by G. Rodriguez and R. E. Skelton respectively.

LSST CONTROLS

- NATURE OF CONTROLS PROBLEMS
- ADVANCED CONTROL CONCEPT DEVELOPMENT AT JPL
- MODEL ORDER REDUCTION WORK AT PURDUE

THE LSST CONTROLS PROBLEM

The basic LSST Controls problem is simply one of meeting the performance requirements in the face of very complicated vehicle characteristics. Some of the specific requirements might be pointing accuracy and stability, slew rate or perhaps surface contour accuracy. The complications include vehicle flexibility, imperfect knowledge of the structural characteristics, disturbances and the fact that more surface accuracy is required than can be achieved passively. The next series of figures will address these factors individually.

THE LSST CONTROLS PROBLEM

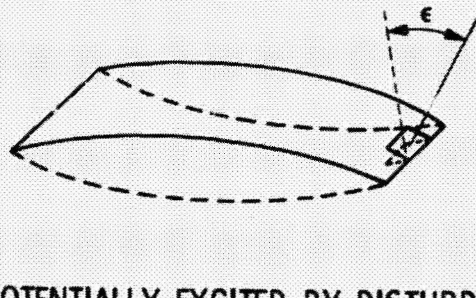
- PROBLEM IS MEETING PERFORMANCE REQUIREMENTS -
  - STABILITY
  - POINTING ACCURACY
  - INSTRUMENT POINTING SLEW RATES
  - SURFACE OR FIGURE ACCURACY
- IN THE FACE OF COMPLICATING VEHICLE CHARACTERISTICS
  - VEHICLE FLEXIBILITY AND SUBSYSTEM INTERACTIONS
  - LESS THAN PERFECT KNOWLEDGE OF STRUCTURAL DYNAMICS
  - DISTURBANCES RELATED TO LARGE VEHICLES
  - PASSIVE SURFACE OR FIGURE CONTROL MAY BE INADEQUATE

VEHICLE FLEXIBILITY

The basic performance requirements such as slew rates and settling times determine the minimum control system bandwidth. If there are structural modes that are not within this bandwidth, they may pose a threat to meeting the performance requirements. Specifically, any uncontrolled motion at the base of an instrument mount that is of a higher frequency than the bandwidth of the instrument mount control system will show up directly in the pointing of the instrument. The motion may be the result of structural modes excited by disturbances. The instrument mount control system bandwidth must be increased to control or compensate for this motion.

VEHICLE FLEXIBILITY

- PERFORMANCE REQUIREMENTS DETERMINE THE MINIMUM CONTROL SYSTEM BANDWIDTH
- STRUCTURAL MODES <u>OUTSIDE</u> THE CONTROL SYSTEM BANDWIDTH PRESENT A THREAT TO MEETING EXPERIMENT OR ANTENNA POINTING ACCURACY REQUIREMENTS
  - FOR EXAMPLE



FIRST FREE BENDING MODE

  - POTENTIALLY EXCITED BY DISTURBANCES
- THEREFORE, TO INSURE SATISFYING PERFORMANCE REQUIREMENTS THE BANDWIDTH MAY HAVE TO BE OPENED TO INCLUDE MORE MODES

VEHICLE FLEXIBILITY (Cont'd)

Increasing the bandwidth to include structural modes can only be done if stability can be guaranteed. Stability requires precise knowledge of the motion in each of the modes to be controlled. It also requires knowledge of the effect of applying control on all of the modes. The measurements that are made on the spacecraft structures are of the combined effect of the motion in all of the modes. An estimator is used to derive the required modal motion from the measurements. The estimator consists of an analytical model of the vehicle in which the modal motions are adjusted so that its overall response best correlates with the vehicle measurements. The modal motions that achieve this best correlation are used as the estimates for the control process. It follows that these estimates will be in error and stability will be threatened by inadequacies of the analytical model.

VEHICLE FLEXIBILITY (contd)

- STRUCTURAL MODES WITHIN THE BANDWIDTH PRESENT A THREAT TO STABILITY
  - PRECISE KNOWLEDGE OF THE MOTION IN EACH MODE IS REQUIRED TO PROVIDE DAMPING
  - MEASUREMENTS REFLECT THE COMBINED MOTION RESULTING FROM THE SUM OF ALL ı. MODES
  - INDIVIDUAL MODAL MOTION INFORMATION IS DERIVED FROM AN ESTIMATOR BASED ON AN ANALYTICAL MODEL OF THE STRUCTURE
  - THE ANALYTICAL MODEL IS ADJUSTED TO MAKE THE MODEL OVERALL BEHAVIOR BEST CORRELATE WITH THE MEASUREMENTS OF THE SPACECRAFT - MODAL MOTIONS REQUIRED IN THE MODEL FOR THE "BEST CORRELATION" ARE THE "ESTIMATES" USED FOR ACTUAL CONTROL
  - ESTIMATES WILL BE IN ERROR AND STABILITY WILL BE THREATENED BY INADEQUACIES OF THE MODEL

STRUCTURAL MODEL ERRORS

The models used in the estimation process are in error by two factors: 1) errors of form or parameter values due to lack of knowledge and 2) modifications made to the model to make it practically implementable. The complexity and untestability of very large structures create basic uncertainty of mode frequencies and shapes. The truncating process consists of selecting the modes to be retained in the estimator model. The development of rational truncation criteria is the subject of the work that will be reported on by R. E. Skelton.

STRUCTURAL MODEL ERRORS

- BASIC UNCERTAINTY OF MODE FREQUENCIES AND SHAPES
  - COMPLICATED DYNAMIC DESCRIPTION
  - UNTESTABILITY OF VEHICLE DYNAMICS
  - VARIABLE CONFIGURATION
- MODEL TRUNCATION TO PERMIT PRACTICAL CONTROL SYSTEM IMPLEMENTATION
  - USE OF A LIMITED SET OF ALL OF THE MODES FOR THE ESTIMATOR MODEL
  - DEVELOPMENT OF RATIONAL TRUNCATION CRITERIA PEQUIRED

DISTURBANCES

Certain disturbance processes pose a greater problem to large space structures than to current generation S/C just on the basis of the large dimensions. Solar pressure, gravity gradient torques, and aerodynamic drag all have effects related to size. Disturbance from thermal transients, onboard mechanisms and control interaction must also be accommodated.

DISTURBANCES

- LSS ARE SUBJECT TO DISTURBANCES THAT CAUSE MODAL DEFLECTIONS (INTERNAL AND EXTERNAL - MODELED AND UNMODELED)
  - THERMAL TRANSIENTS
  - THRUSTER FIRINGS AND MOMENTUM INTERCHANGE DEVICES
  - ON BOARD MECHANISMS
  - SOLAR PRESSURE
  - GRAVITY GRADIENTS
  - GRAVITY FIELD VARIATIONS
  - AERODYNAMIC DRAG

SURFACE OR FIGURE CONTROL

Distributed sensing may be required to determine the static shape with sufficient fidelity. In addition, if modal vibrations are to be controlled, distributed sensors may provide information not present at any single point and thus minimize estimation errors. Distributed actuation may be required to effect the geometric control required, while minimizing actuator size and complexity. It is also unlikely that all of the modes to be controlled can be influenced at a single point. In cases where continuous high accuracy figure control is required, onboard, closed loop, distributed systems will be required to control the static shape as well as modal vibrations.

SURFACE OR FIGURE CONTROL

- DISTRIBUTED SENSING MAY BE REQUIRED TO MAKE NECESSARY MEASUREMENTS
  - STATIC SHAPE DETERMINATION
  - INFORMATION ON ALL PERTINENT MODES MAY NOT BE AVAILABLE AT ANY ONE LOCATION
  - ESTIMATION ERROR REDUCED BY USING MORE SENSORS
- DISTRIBUTED ACTUATION MAY BE REQUIRED TO ACHIEVE SHAPE ADJUSTMENT
  - REDUCE ACTUATOR SIZE AND STRUCTURAL STRESS CONCENTRATION
  - NOT ALL MODES MAY BE CONTROLLABLE AT ANY GIVEN LOCATION
- ON-BOARD CLOSED-LOOP SYSTEMS REQUIRED FOR MANY APPLICATIONS

SUMMARY OF LSST CONTROL PROBLEMS

Modal vibrations of large space structures can preclude satisfaction of mission requirements. No means exists to directly measure the modal motion that must be controlled. The motion must be estimated and the estimation process is imperfect. We need to improve it. If perfect knowledge of the motion was available, no means exists to influence the modes desired without affecting others in a possible deleterious way. The estimation and control inadequacies are interactive and must be addressed jointly by advanced concepts.

SUMMARY OF LSST CONTROL PROBLEMS

- NO DIRECT MEASUREMENTS AVAILABLE OF MOTION TO BE CONTROLLED
  - MOTION MUST BE ESTIMATED
  - ERRORS ARE INHERENT IN ESTIMATION PROCESS
  - ADVANCED CONCEPTS NEED DEVELOPMENT TO MINIMIZE ERRORS
- EVEN AFTER KNOWLEDGE OF MOTION IS ESTABLISHED, CONTROL ACTUATORS CANNOT DIRECTLY INFLUENCE THE MOTION TO BE CONTROLLED
  - MOTION EXTENDS OVER LARGE DIMENSIONS
  - CONTROL EFFORT MAY CAUSE UNDESIRABLE EXCITATIONS
  - ADVANCED CONCEPTS WILL MINIMIZE INTERACTIONS
- ESTIMATION AND CONTROL PROBLEMS ARE INTERACTIVE AND COMPLICATE EACH OTHER