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LaRC CONTROLS ACTIVITY FOR LSST

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LSST CONTROLS OVERVIEW
LaRC -- FY 79

- MODELING AND CONTROL OF LSS IN ORBIT
- REDUCED ORDER DECOUPLING
- SHAPE CONTROL
- ATTITUDE CONTROL OF LARGE PLATFORMS USING DUAL AMCD's
- ADAPTIVE CONTROL OF SPINNING RING
- LEARNING CONTROL FOR SEP SHUTTLE

Slide 1

As indicated in slide 2 math models have been developed for various types of large flexible structures. These models are being used to study the uncontrolled dynamic characteristics of the structures in orbit and to devise control concepts in order to control their orientation and geometrical shape.

Studies have been made for reduced order decoupled control of the 100-meter long free free beam depicted in slide 3. The objective is to control the in-plane orientation and shape of the beam in a decoupled manner with as few actuators as possible.

Slide 4 illustrates the type of results that are generally obtained when the number of actuators is less than the number of modes considered in the model. Using two controllers, near each end of the beam, to produce a 0.01-radian pitch change, perfect decoupled control is achieved for the rigid body pitch (θ) mode and the first flexible mode (A_1). However, the other two flexible modes cannot generally be included in the decoupling process and hence cannot be controlled.

For a special case where the ratios between the rows of the control-influence coefficient matrix are the same (for example, when the controls are exactly at both ends of the beam) the uncontrolled modes can be included in the decoupling process. Based on information obtained from this special case, a method (referred to as the ratio method) has been developed for adjusting the feedback gains required for control of the complete model. Slide 5 shows the results for the example in slide 4 where these gain adjustments have been made. Almost perfect decoupling is maintained for θ and A_1 and, except for some initial effects, the other two modes are controlled.

Slide 6 illustrates a typical result of the minor effect of modeling errors on the decoupling process. In this case incorrect knowledge of the control characteristics was represented by incorporating random errors of either ± 5 or ± 10 percent in the control influence coefficients. The solid curves correspond to the condition where no errors are present.

THE DYNAMICS AND CONTROL OF LARGE FLEXIBLE SPACE STRUCTURES

THRUST - DEVELOP MATH MODELS

INVESTIGATE UNCONTROLLED DYNAMIC CHARACTERISTICS

DEVISE CONTROL LAWS FOR: ORIENTATION, GEOMETRICAL SHAPE

STATUS - LONG THIN FREE-FREE BEAM

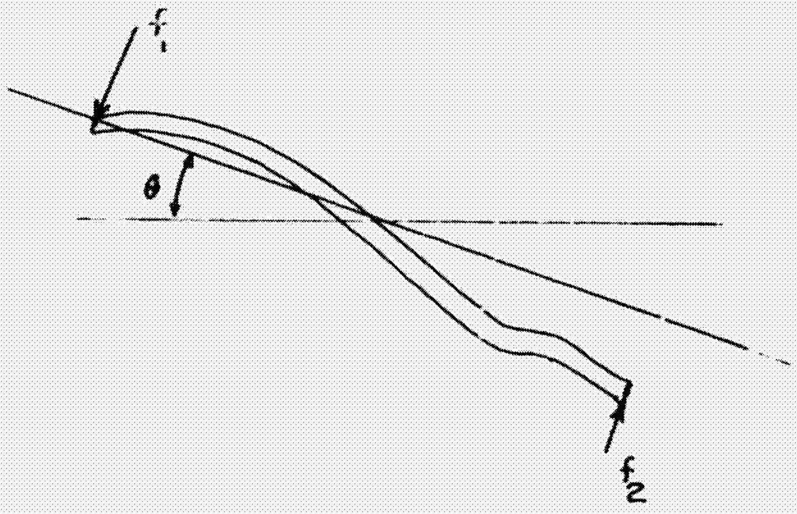
CIRCULAR AND RECTANGULAR MEMBRANE

CIRCULAR AND RECTANGULAR PLATE

FUTURE - SPHERICAL AND PARABOLIC SHELL

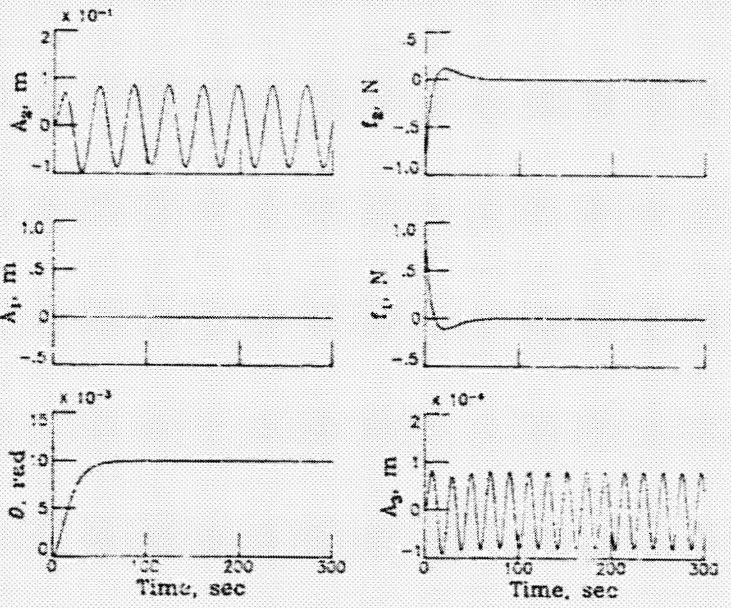
Slide 2

DECOUPLING STUDIES



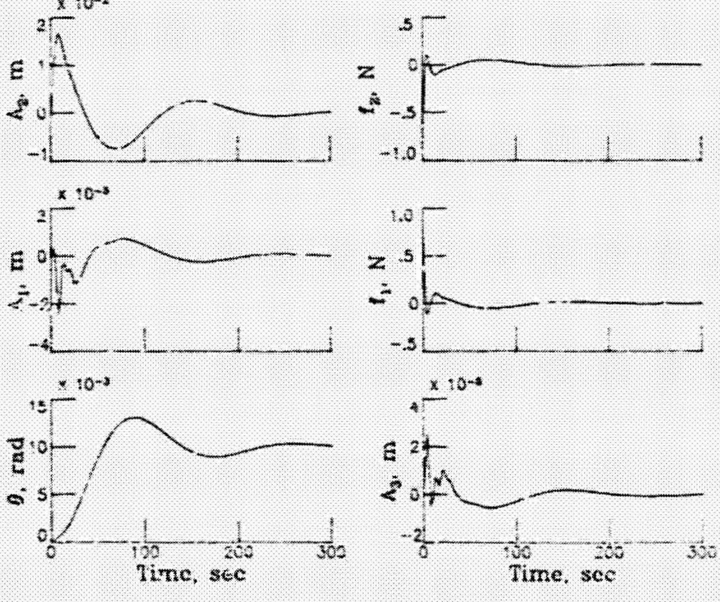
Slide 3

PERFECT DECOUPLING



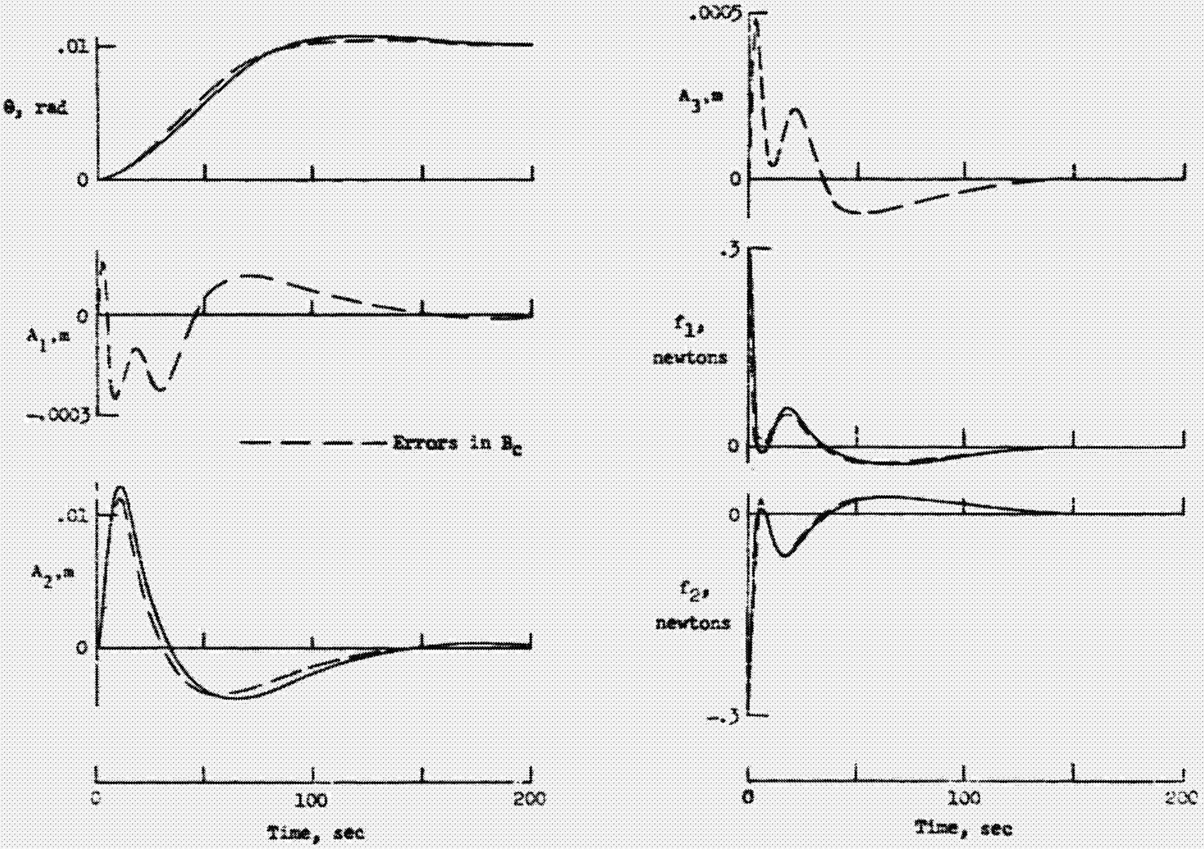
Slide 4

GAIN ADJUSTMENT USING RATIO METHOD



Slide 5

EFFECT OF MODELING ERRORS

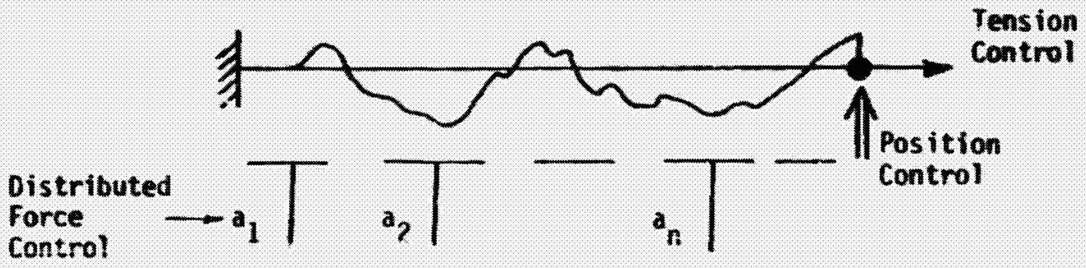


Slide 6

As indicated in slide 7 for shape control three classes of control devices are being considered, boundary control, distributed actuator control, and wave speed control.

Slide 8 is an outline of the time optimal control theory for a string using boundary control and slide 9 is a simulation result. In slide 9, the waves which appear to build up are a result of truncation of the infinite number of system modes to 80 for simulation. The result indicates that some approach other than modal analysis is needed for real time structural control.

SHAPE CONTROL RESEARCH



- SIMILAR TO ELECTROSTATIC MEMBRANE CONTROL BUT SIMPLER VERSION

- THREE DISTINCT CONTROL PROBLEMS:

  (1) BOUNDARY CONTROL

  (2) DISTRIBUTED ACTUATOR CONTROL

  (3) WAVE SPEED CONTROL

Slide 7

BOUNDARY CONTROL

PLANAR VIBRATIONS OF A STRING

$$\frac{\partial^2 y}{\partial x^2}(x,t) = \frac{1}{c^2}\frac{\partial^2 y}{\partial t^2}(x,t)$$

$$c = \tau/\rho$$

BOUNDARY CONDITIONS

$$y(0,t) = 0 \qquad y(\ell,t) = u(t) \qquad \left|\frac{du}{dt}\right| \leq 1$$

INITIAL CONDITIONS

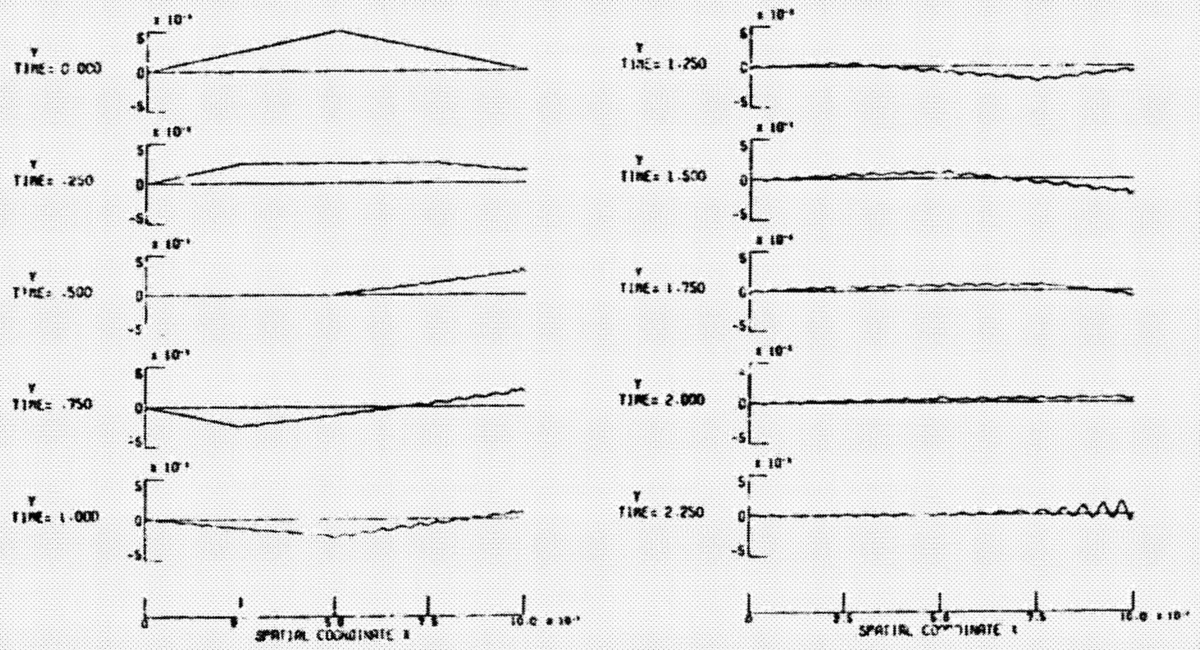
$$y(x,0) = g(x) \qquad \frac{\partial y}{\partial t}(x,0) = v(x)$$

TIME OPTIMAL BOUNDARY CONTROL

$$\frac{du^*}{dt}(t) = -c\,\frac{\partial y}{\partial x}(\ell,t)$$

Slide 8

MINIMUM TIME CONTROL IMPLEMENTATION WITH 80 MODES



Slide 9

Slide 10 concerns the distributed control of a membrane using electrostatic actuators. An optimal control theory has been derived that minimizes the error, Z, between the desired and actual deflection yet considers the amount of control, U, required to accomplish an error reduction. Slide 11 indicates the form of the graphical output used in simulation to indicate the membrane distortion and the position of the actuators behind the membrane. It also shows the initial membrane distortion used in a simulation to test the control law. Slides 12 through 15 represent the membrane distortion at ever increasing times and show the damping effect of the control laws.

DISTRIBUTED ACTUATION

ACTIVE CONTROL OF A MEMBRANE

EQUATION OF MOTION:

$$z_{tt} + Az = u$$

WHERE

$$Az = -c^2(z_{xx} + z_{yy}) \quad \text{and} \quad c = \sqrt{T/d}$$

COST FUNCTION:

$$C = \frac{1}{2}\int_0^{\infty}\int_0^{b}\int_0^{a} w(x,y)\left[Q z^2 + R u^2\right] dx\, dy\, dt$$

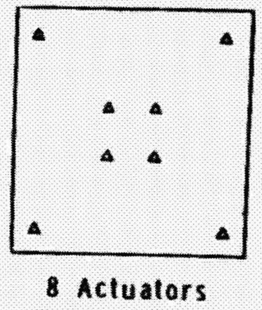
UNCONS. OPT. PROB : FIND $u^*(x,y,t)$ min. C

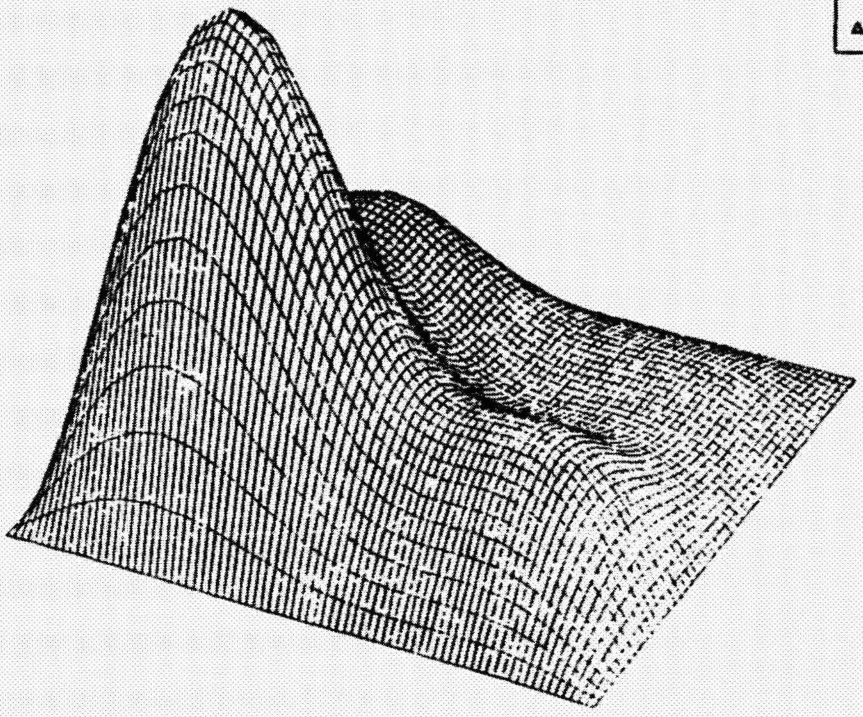
OPTIMIZATION WITH CONTROL CONSTRAINT: $u_a(x,y,t) = \sum_{i=1}^{m} v_i(t)\, f_i(x,y)$

$$v^* = \min \left\| \sum_{i=1}^{m} v_i(t)\, f_i(x,y) - u^*(x,y,t) \right\|$$

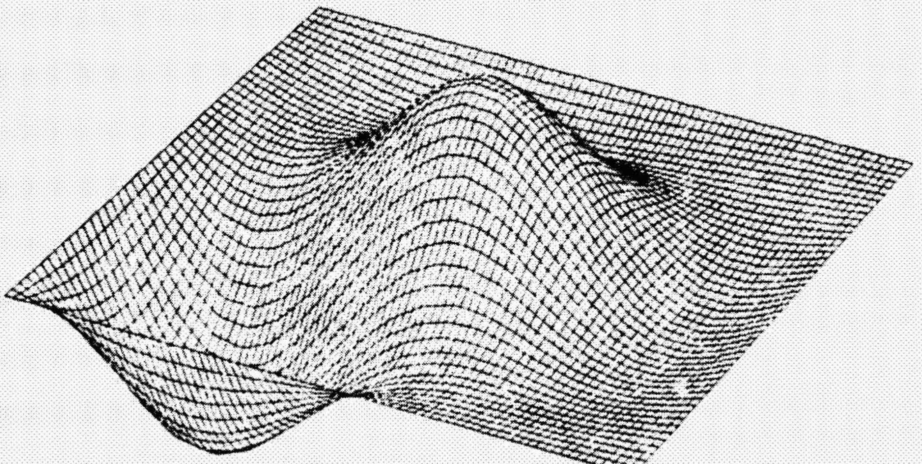
Slide 10

MEMBRANE DEFLECTION AT TIME = 0. sec.

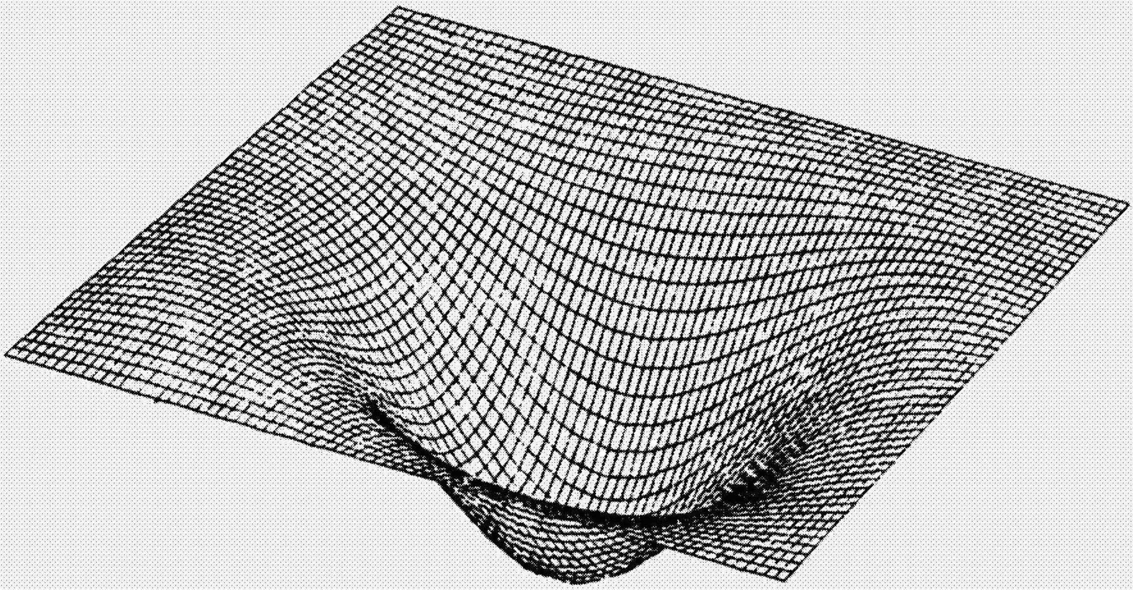




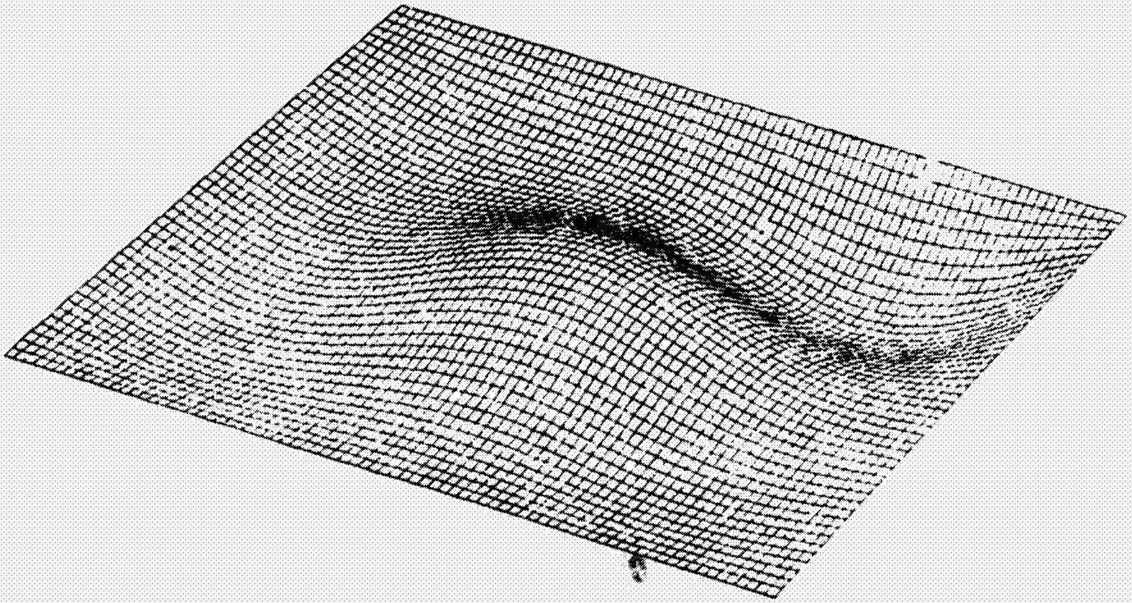
Slide 11



Slide 12



Slide 13



Slide 14

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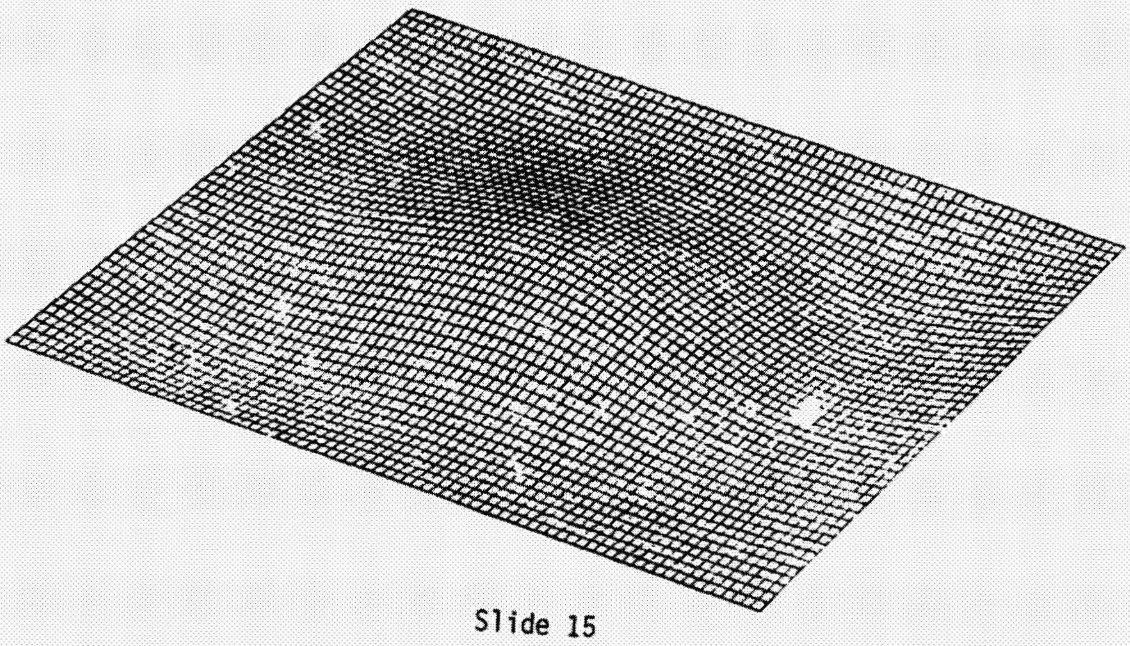
OF POOR QUALITY



Slide 15

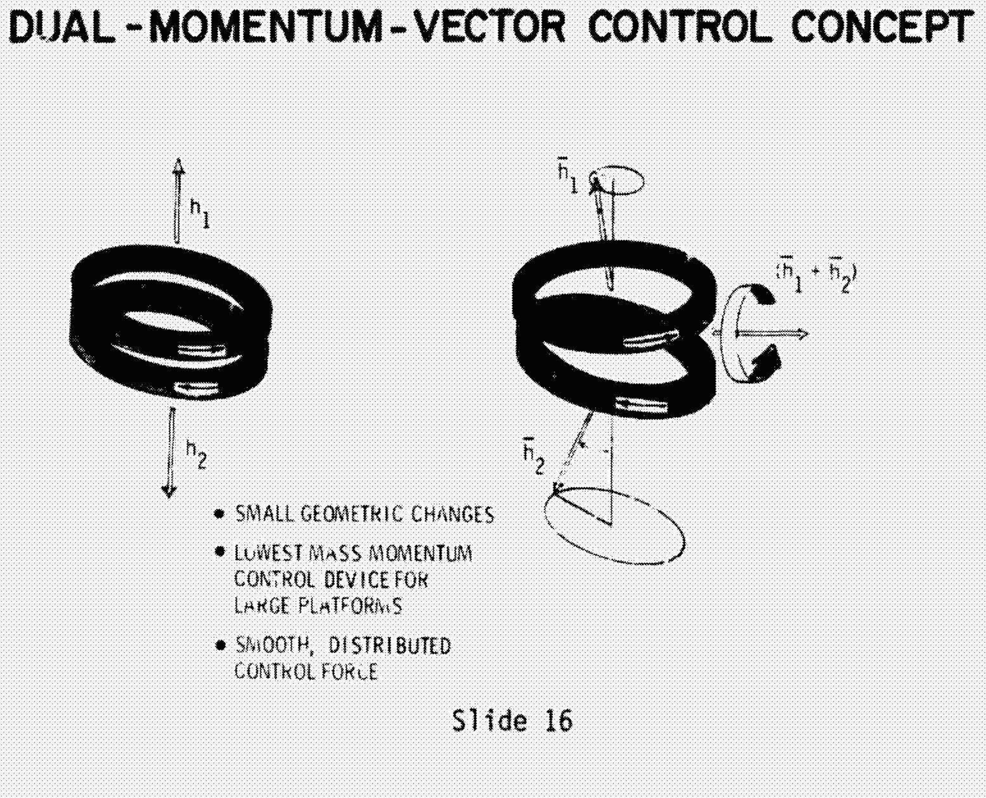
Slide 16 indicated an attitude control concept appropriate for large area platforms. Two large rings spin in the plane of the platform and are scissored to produce a change in momentum that rotates the platform. The rings are attached to the platform by noncontacting magnetic or electrostatic bearings. Because of flexibility a novel adaptive/learning control system concept was developed to suppress elastic marks of the spinning rings while still allowing adequate precisional torques for control.

Slide 17 illustrates the free vibration of the ring as seen by an observer that is spinning with he ring. Points indicated by an * represent where position is sensed by sensors located at fixed points on the platform. The symbol ↑ indicates the application of a force at a bearing fixed to the platform. Slide 18 shows the response of the ring caused by a constant force of 20 N at a bearing station.

Slide 19 shows a desirable ring damping characteristic which requires feedback and knowledge of the modes of motion to achieve.

Slide 20 shows what can happen if the control system is designed with the wrong assumption regarding the modes of motion. In this case the motion does not decay but rather amplifies.

Slide 21 indicates the effectiveness of an adaptive controller. The control system was initially that used in figure 20 which was unstable. Because of the adaptive feature, however, the system identified the required modal information and adjusted the feedback gains to obtain a stable response.

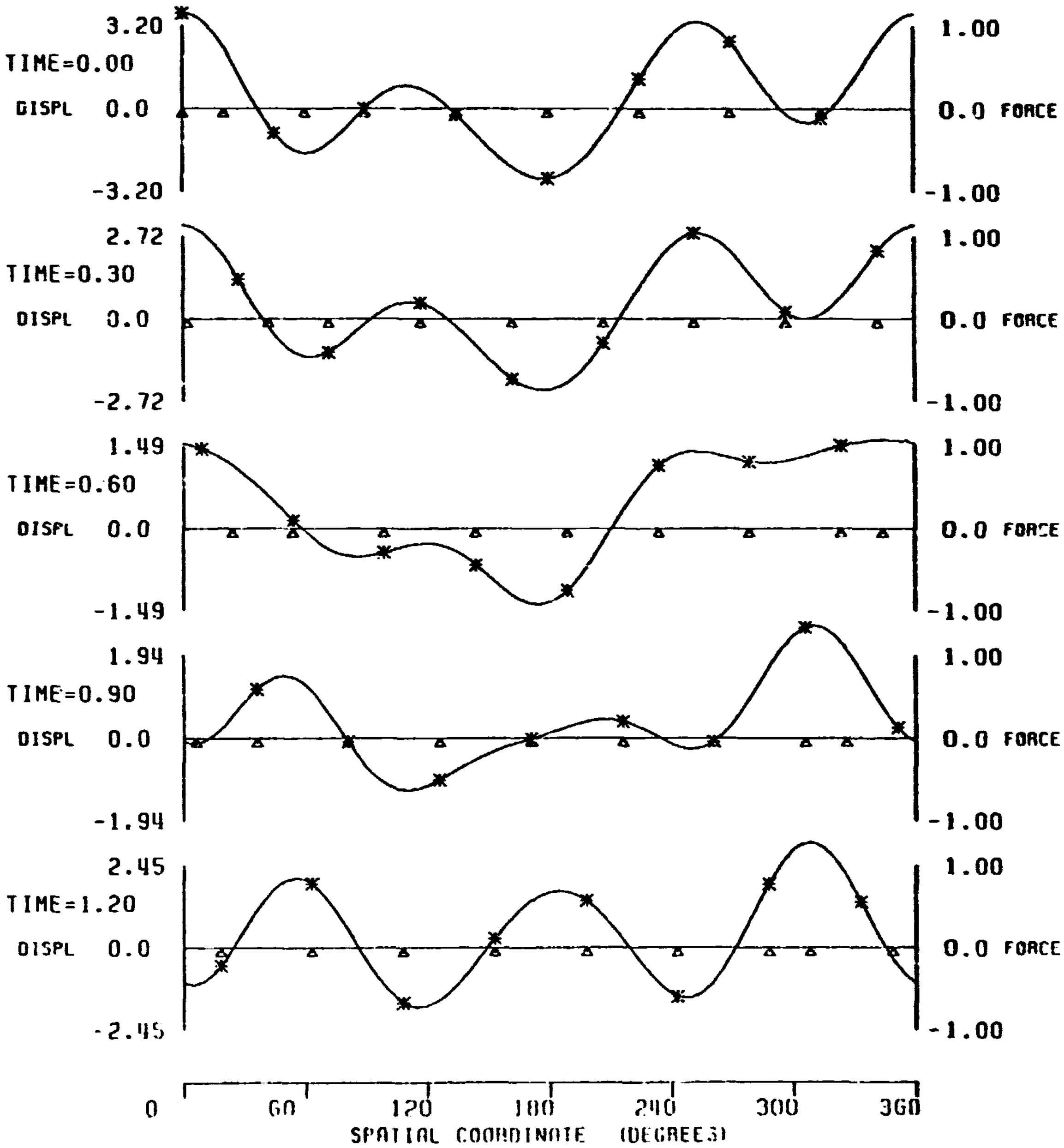


DUAL-MOMENTUM-VECTOR CONTROL CONCEPT

- SMALL GEOMETRIC CHANGES
- LOWEST MASS MOMENTUM CONTROL DEVICE FOR LARGE PLATFORMS
- SMOOTH, DISTRIBUTED CONTROL FORCE

Slide 16

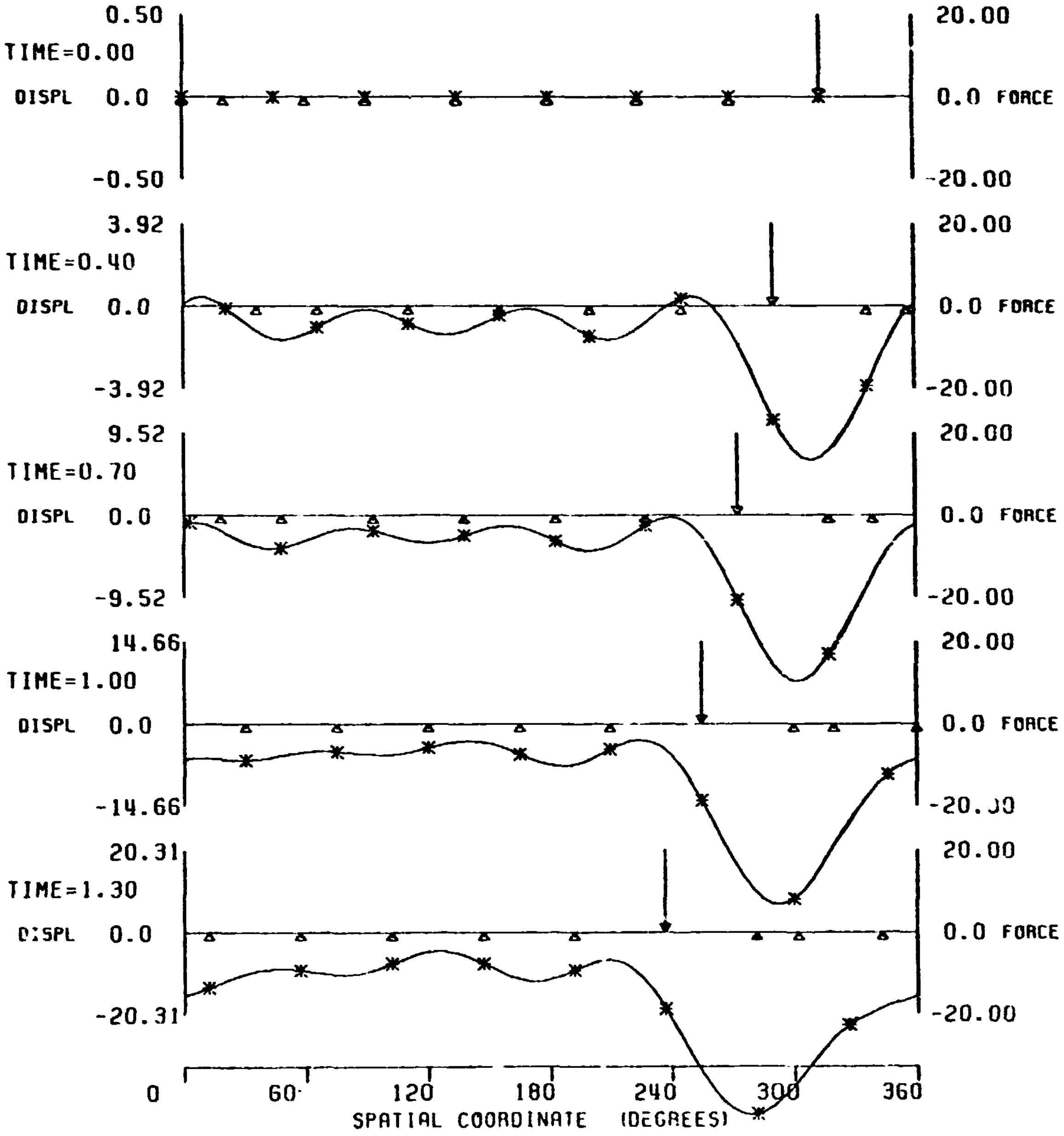
FREE INITIAL CONDITION RESPONSE



Slide 17

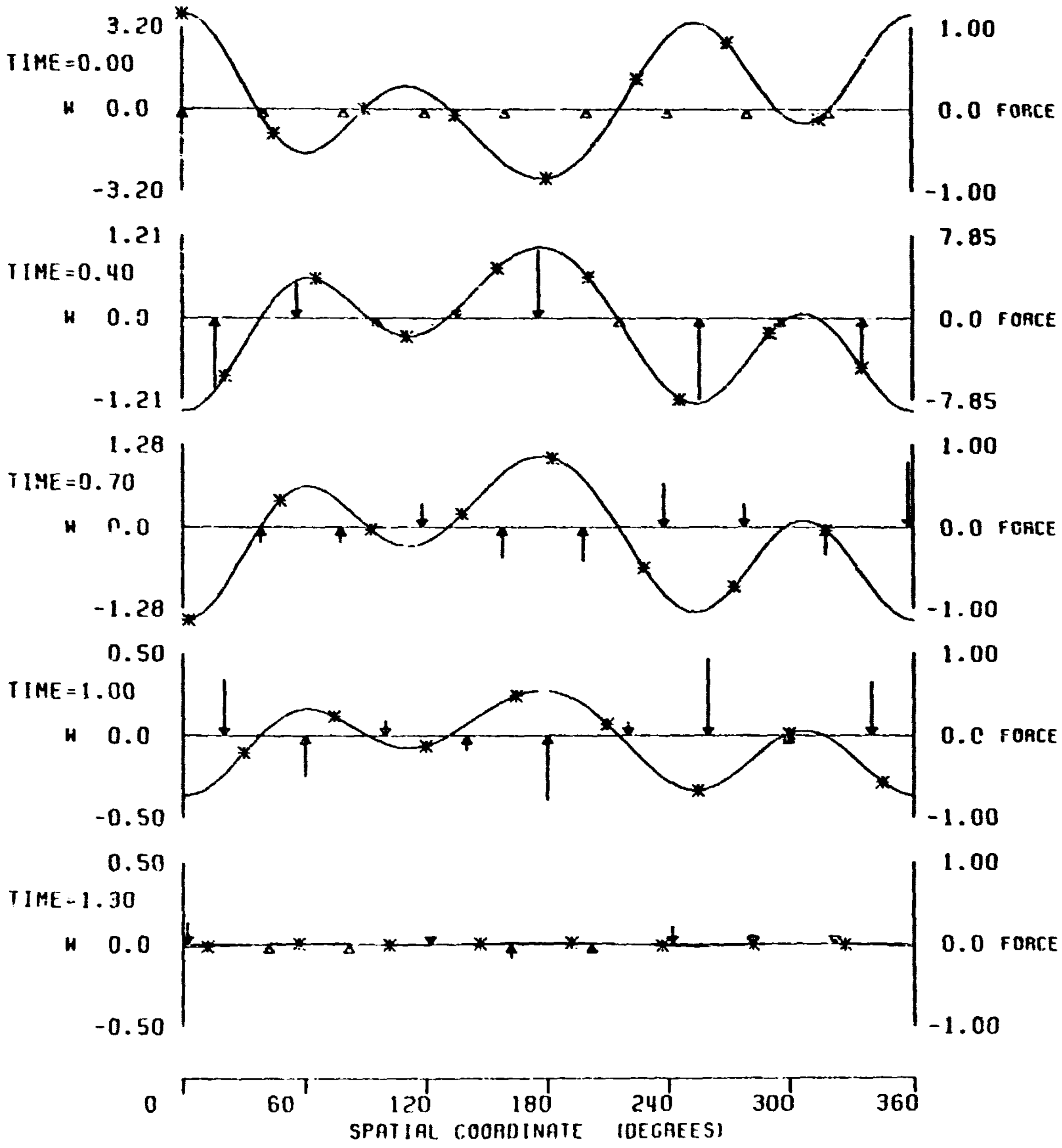
C-5

UNCOMPENSATED STEP RESPONSE



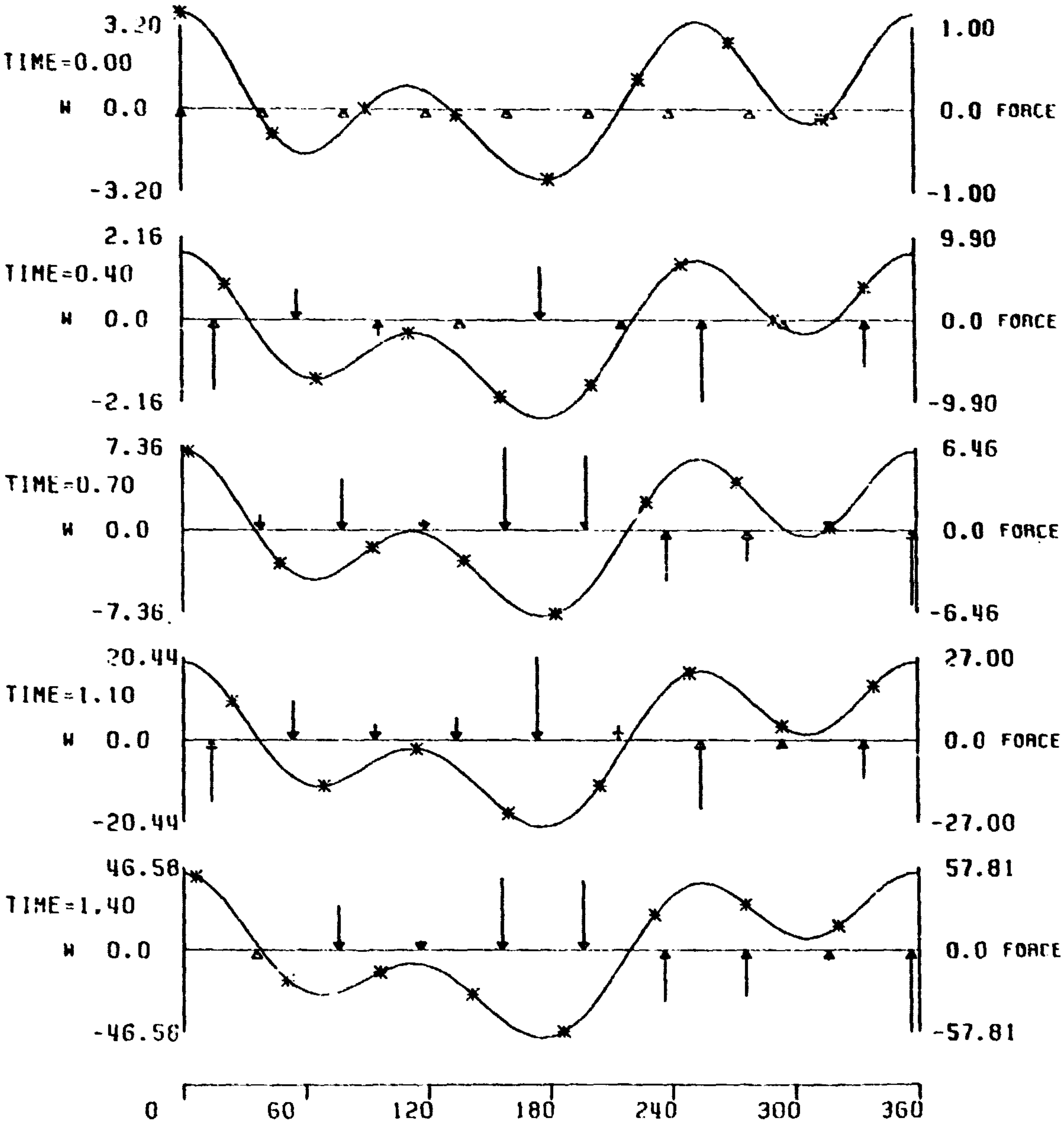
Slide 18

DESIRED DEFORMATION DAMPING



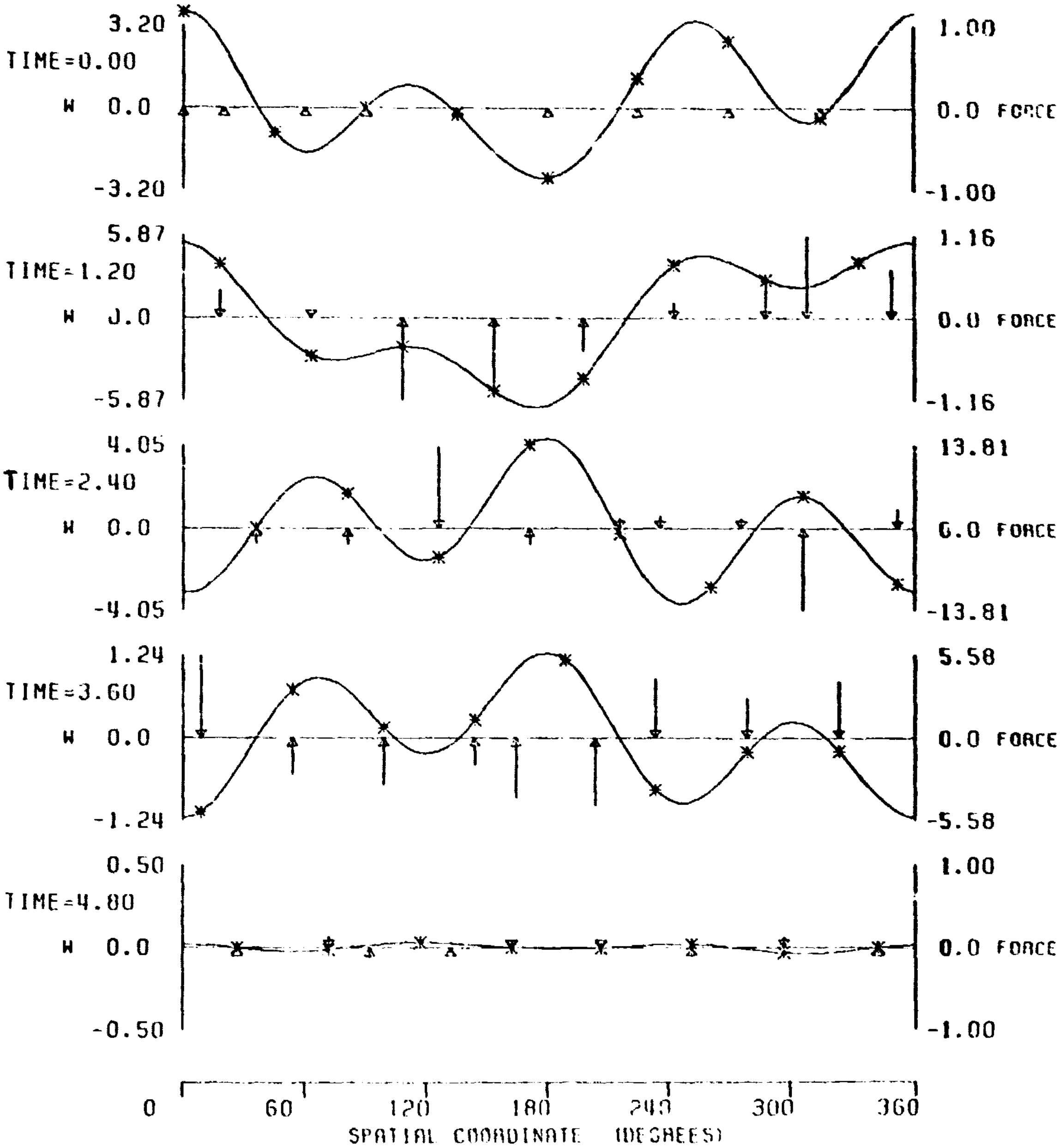
Slide 19

INCORRECT ESTIMATE FIXED CONTROLLER



Slide 20

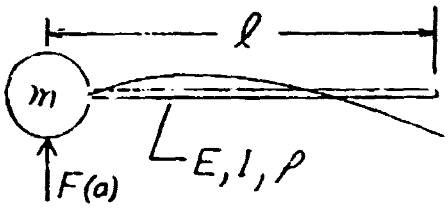
ADAPTION OF UNSTABLE REGULATOR

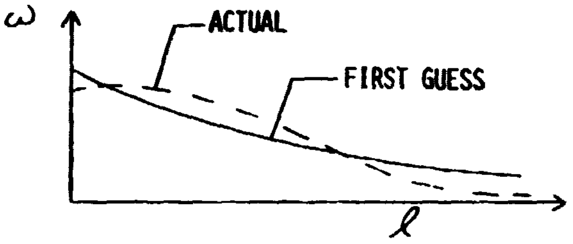


Slide 21

In the area of attitude control, we have considered developing adaptive/learning control system theory for use in handling large space structures. One problem where adaptive/learning theory is needed is in handling of large space objects using the space shuttle. During barging, towing, assembly, and construction operations involving large space structures adequate control requires precise knowledge of the structural dynamics of the objects involved. As indicated in slide 22, this requirement cannot be satisfied using techniques based on analysis or ground testing because of fundamental limitations of these techniques. The adaptive/learning system is conceived on the premise that structural testing must be conducted on the objects involved in the operational space environment. Using in-flight testing, the system identifies parameters of the structures within a class of mission structural models (slide 23). The parameters are used to adjust the control system design to affect acceptable attitude control. Additional tests are required to maintain acceptable attitude control because the dynamics change during operations. The number of such tests is substantially reduced by using model extrapolation based on analysis, thereby conducting tests only when the divergence between the observed dynamics and the model results in unacceptable stability and control margins.

SPACE APPLICATION CONTROL

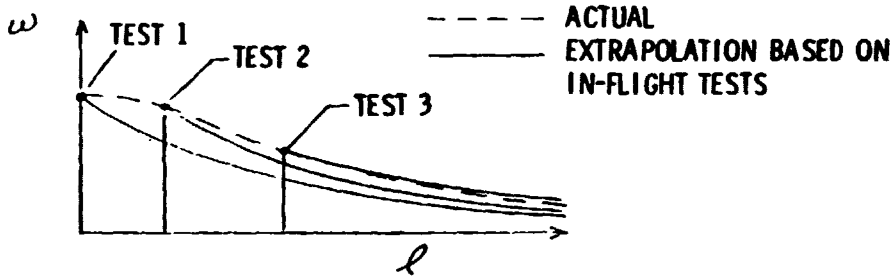




- o PROPER PHASING OF $\underline{F}$ REQUIRES PRECISE KNOWLEDGE OF THE STRUCTURAL DYNAMICS
- o ADEQUATE ANALYTICAL DEFINITION NOT POSSIBLE FOR COMPLEX STRUCTURES - PROVIDES FIRST GUESS ONLY
- o GROUND TESTING NOT POSSIBLE - GRAVITY, MASS, STIFFNESS CONSIDERATIONS

HENCE: TESTING DURING FLIGHT OF THE ARTICLE TO BE CONTROLLED IS THE ONLY METHOD TO OBTAIN THE REQUIRED STRUCTURAL DYNAMICS KNOWLEDGE

LEARNING SYSTEM DESCRIPTION
(SPACE APPLICATION)



- o AUTOMATICALLY CONDUCTS IN-FLIGHT TESTS WHEN CONFIDENCE IN STRUCTURAL DYNAMICS DEFINITION PRODUCES UNACCEPTABLE STABILITY AND CONTROL MARGINS
- o ADAPTS TO CHANGES IN ORBITAL, MASS, INERTIA, AND FLEXIBILITY CHARACTERISTICS USING GAIN SCHEDULING BASED ON EXTRAPOLATION

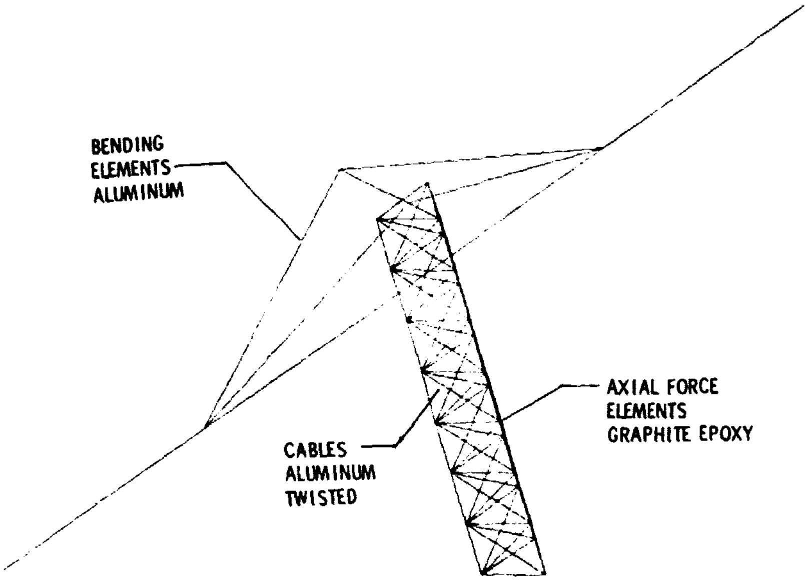
The adaptive/learning system important features are listed on slide 24. The system is being developed using an analytical model of the SEP array. The model was created using a finite element model and the SPAR computer program (slide 25).

LEARNING SYSTEM FEATURES

- In-flight definition of structural dynamics
- Optimal decision theory used to initialize testing and adjust feedback law
- Optimal tolerance to control system sensor/actuator failures using analytical redundancy
- "Dither" signal inputs needed for adaptive control are suppressed during operations for which they are not compatible
- Gain scheduling provides adaptation in absence of "dither" inputs based on extrapolation

Slide 24

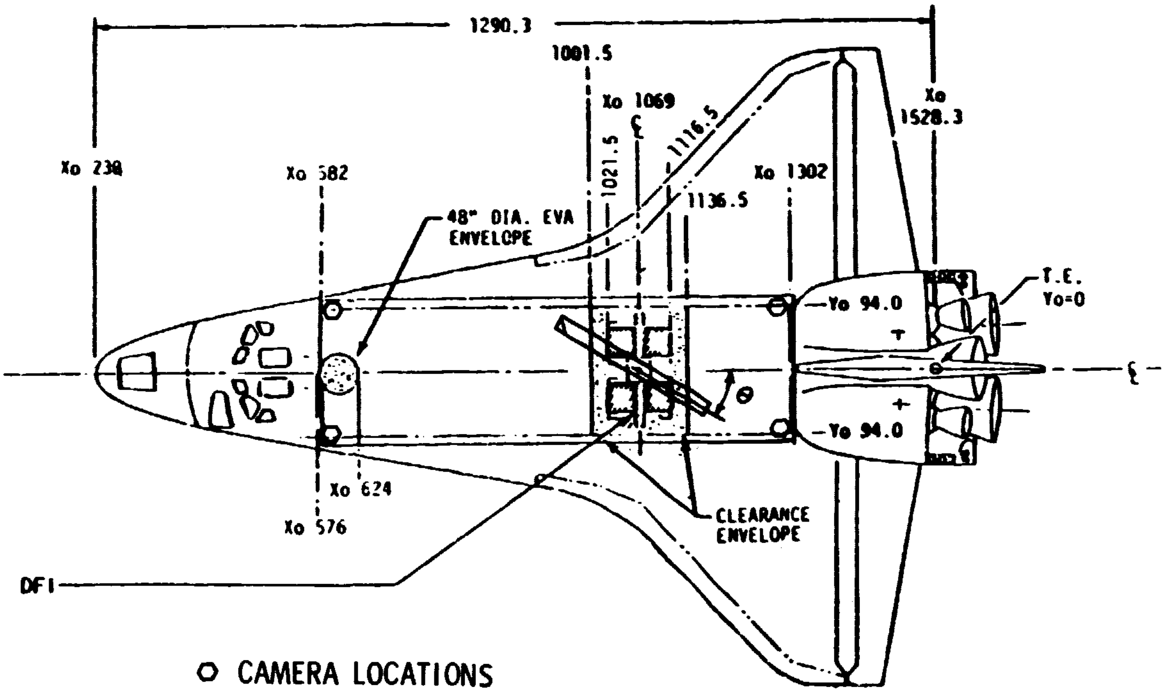
SEP SPAR MODEL TOP OF SEP



Slide 25

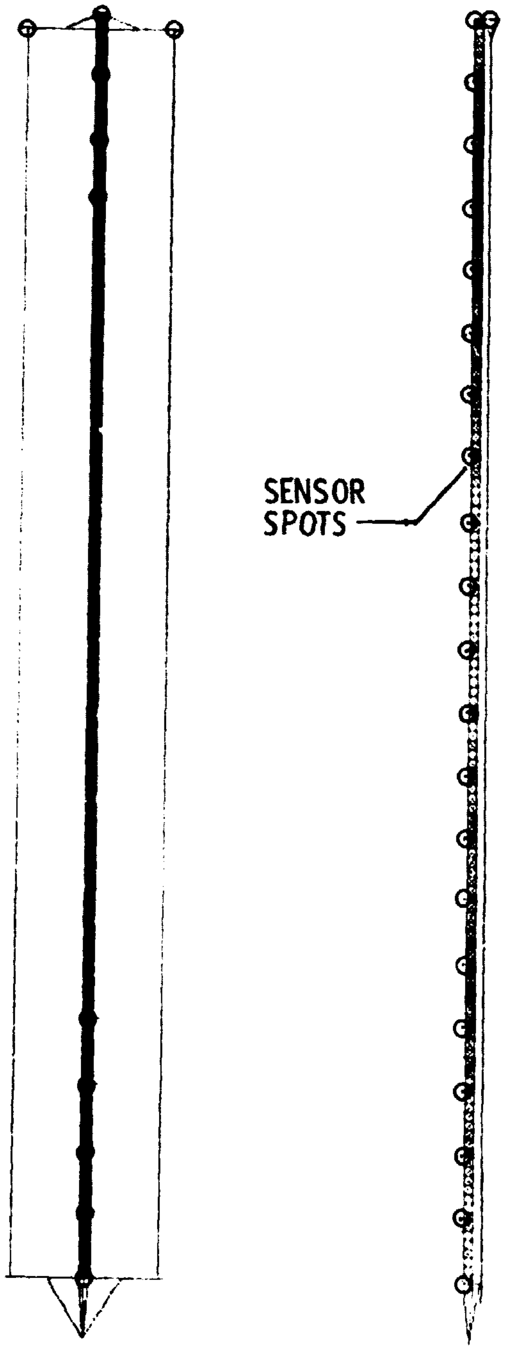
The sensing concept assumed in the adaptive/learning system is a remote sensing concept being studied at LaRC where TV cameras are used in conjunction with a spot pattern on the array. Slide 26 shows the location of the cameras in the shuttle payload bay and the SEP array inclined on angle θ with the shuttle center line. Slide 27 shows the array spot pattern that is used in a simulation program to develop adaptive/learning control schemes.

SEP/SHUTTLE - SENSOR CAMERAS



Slide 26

SEP/SHUTTLE - SENSOR - SPOTS



Slide 27