CONTROL OF LARGE SPACE ANTENNAS:
WRAP-RIB - HOOP/COLUMN

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OUTLINE

This part of the presentation addresses the control work at JPL for large space antenna systems. Included in the discussions are the wrap-rib and hoop/column antenna concepts.

This presentation can be outlined (fig. 1) as follows: First, a brief description will be given for the LSST focus missions calling for the deployment of either wrap-rib or hoop/column antennas. Then, for either antenna concept, control problems will be described, control options discussed, quantitative results presented. System drivers for either antenna concept will be identified. Finally, this presentation will be concluded along with a brief description of the planned work for the upcoming year.

- FOCUS MISSIONS
- CONTROL PROBLEMS
- CONTROL OPTIONS
- RESULTS AND SYSTEM DRIVERS
- PLANNED WORK

Figure 1

LSST ANTENNA FOCUS MISSIONS

The LSST antenna focus missions (fig. 2) such as communications and radiometry call for antennas ranging in size from 10 to 100 meters, operating frequency of the order of GHz, antenna line-of-sight (LOS) pointing accuracy in the neighborhood of 0.04°, and antenna surface accuracy of about 1/40 to 1/20 of a wavelength.

	SIZE (m)	FREQUENCY (GHz)	POINTING ACCURACY (DEG)	SURFACE ACCURACY (mm)	FEED	ORBIT (km)	LIFE (YRS)
COMMUNICATIONS	30-100	0.4-2.5	0.035	6-36	OFFSET	GEO	10
RADIOMETRY	10-100	1-11	0.05-0.025	0.5-6	OFFSET OR ON-AXIS	300-600	10

Figure 2

LMSS ACCURACY REQUIREMENTS

10 Years Operational Phase

A specific mission example is the Land Mobile Satellite System or LMSS which is a communications concept intended to provide telephone service to mobile users in the Continental United States. This concept calls for a single shuttle launch in the midnineties and the deployment of a large antenna in geostationary orbit. Technology readiness is to be flight demonstrated by the late eighties.

In order for the LMSS to provide adequate communication service, system accuracy requirements must be satisfied as shown in figure 3. It is noted that most accuracy requirements for the control subsystem are fractions of system requirements. For example, LOS pointing must be controlled to less than 0.03°, LOS stability must be controlled to less than 0.02°, and dish surface accuracy must be less than 6 mm.

Two antenna configurations being considered for the LMSS mission are shown in figures 4 and 5: the hoop/column and the wrap-rib configurations.

	SYSTEM	CONTROL
POINTING* (AFTER CALIBRATION/ COMPENSATION FOR THERMAL OFFSETS, ETC.)	$\pm 0.10^0$	$\pm 0.03^0$
STABILITY*	$\pm 0.03^0$	$\pm 0.02^0$
DISH SURFACE ACCURACY, RMS	12 mm	6 mm
SOLAR ARRAY POINTING	$\pm 1^0$	$\pm 1^0$

*ILLUSTRATION OF POINTING AND STABILITY ERRORS:

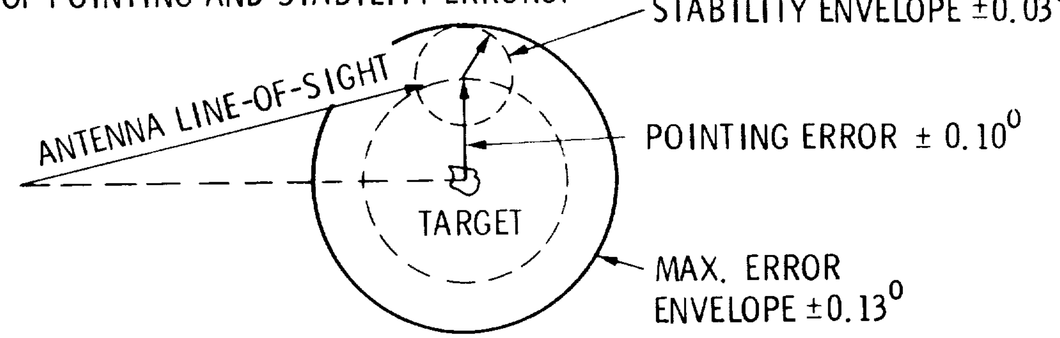


Figure 3

HOOP/COLUMN LMSS

CONFIGURATION AND MASS PROPERTIES

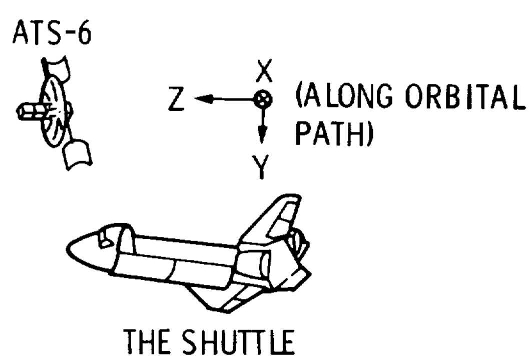
The hoop/column concept (fig. 4) has the following fundamental elements: a 122-meter diameter hoop (the plane of which is perpendicular to the viewgraph), and an 88-meter telescoping mast (or column). The antenna feed system is located at one end and a bus structure is located at the other end of the mast. The antenna reflector is about 118 meters in diameter, and there are a large number of stringers supporting the hoop or maintaining the shape of the reflector mesh.

Total weight of the system is about 10,000 lb, half of which is concentrated at the antenna feed area. The other half of the system weight is almost equally distributed among the hoop, the mast, and the bus.

TOTAL MASS 10,340 LB

MOMENTS OF INERTIA
$$\begin{cases} I_x = 5.89 \times 10^6 \text{ SLUG-FT}^2 \\ I_y = 5.89 \times 10^6 \\ I_z = 1.52 \times 10^6 \end{cases}$$

PRODUCTS OF INERTIA $I_{xy} = I_{yz} = I_{yz} = 0$



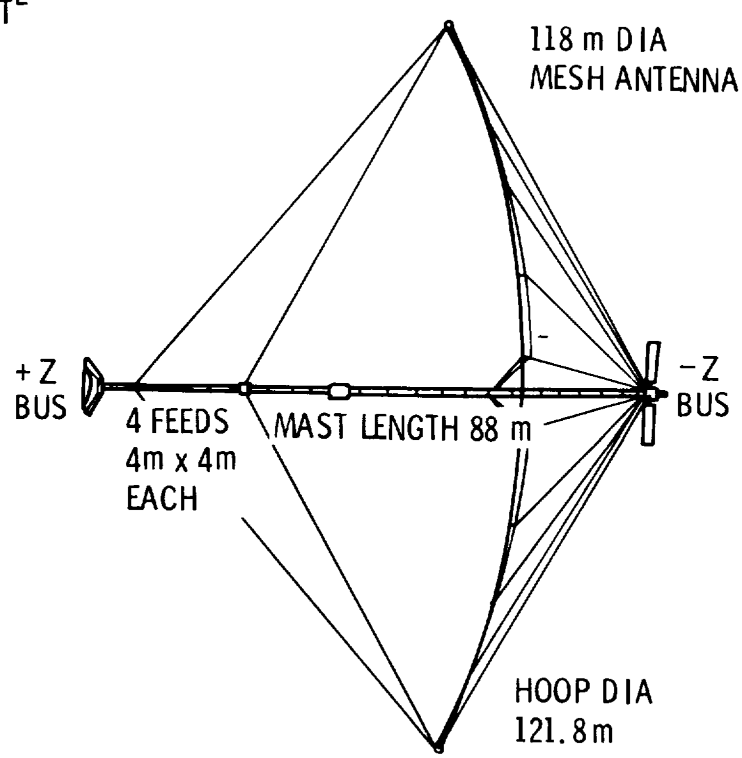


Figure 4

WRAP-RIB LMSS

CONFIGURATION AND MASS PROPERTIES

The wrap-rib concept (fig. 5) has a 55-meter diameter dish to the right and a feed array mounted on the spacecraft bus which is about 80 meters to the left of the dish. The dish and the bus are connected by the boom structure. The short boom is about 33 meters long and the long boom measures about 80 meters. Total weight of the system is about 9700 lb, 80% of which is concentrated at the bus area, and the other 20% at the dish.

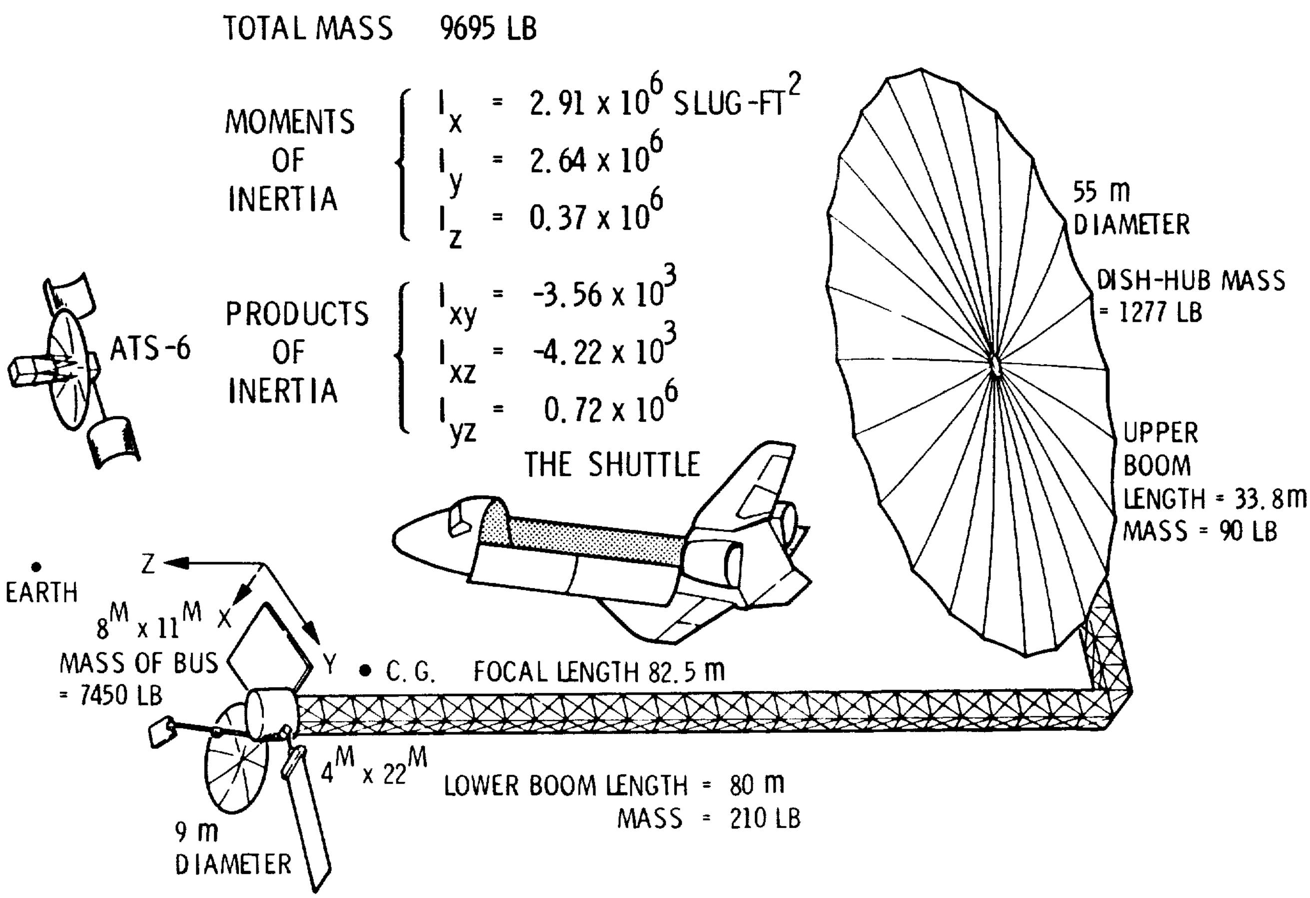


Figure 5

OBJECTIVES

The long range objective is to develop control technology for missions such as LMSS requiring large space antenna systems.

Specific objectives (fig. 6) are to identify control problems and system drivers, to develop control solutions, to establish control performance regime achievable, and to recommend system trade options.

First consider the control of the hoop/column antenna systems.

- IDENTIFY SYSTEM DRIVERS
- DEVELOP CONTROL TECHNOLOGY
- ESTABLISH SYSTEM PERFORMANCE REGIME
- PERFORM SYSTEM TRADES

Figure 6

CONTROL DESIGN DRIVERS

(HOOP/COLUMN)

In addition to attitude control, there are other important control requirements (fig. 7) as discussed in the following:

The feed and the dish are physically separated but are connected by the flexible mast. Their relative stability must be maintained, or dish pointing error and antenna defocus error can result.

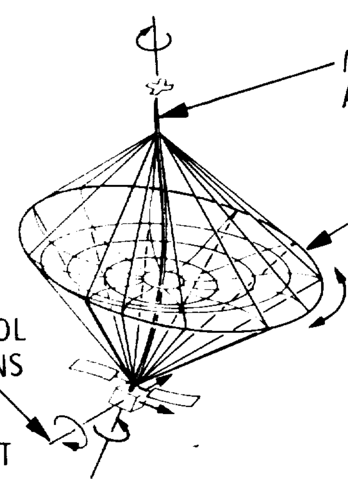
The dish itself is also flexible. Its vibration or deformation can cause dish surface error, resulting in RF gain loss.

Consider the Z-axis inertia given in figure 4. Except the mass of the hoop, other system mass is largely concentrated along the mast or the Z-axis. Therefore 80% of the Z-axis inertia is contributed by the hoop. But the stiffness associated with hoop rotation is relatively small. As a result, the frequency associated with the rotation of the hoop may be low, which can cause control/structure dynamics interactions.

Furthermore, consider a situation where dynamic coupling can occur. Suppose a control action is applied at the bus as shown, to correct errors associated with the antenna feed positions. As indicated the distortion of the dish, the mast and the hoop can result.

All these problems can be compounded by the model uncertainty problem, which refers to the dynamic discrepancy that always exists between the on-board controller model and the real structure. Later on reasons for this discrepancy will be given and the resulting problem will be quantified.

- MAINTAIN STABILITY AND ACCURATE RF POINTING BY MINIMIZING
  - ATTITUDE ERRORS
  - FEED DISPLACEMENT
  - DISH DEFORMATION
  - HOOP ROTATION
- ACHIEVE PRECISION CONTROL IN THE PRESENCE OF
  - MODEL UNCERTAINTY
  - DYNAMIC COUPLING



LMSS CONTROL REQUIREMENT

	SYSTEM	CONTROL SUBSYSTEM
POINTING ACCURACY	0.10°	0.03°
STABILITY	0.03°	0.02°
SURFACE ACCURACY	12 mm	6 mm

Figure 7

CONTROL HIERARCHY

(HOOP/COLUMN)

There are a number of control options for the hoop/column antenna systems. Applicability of each option depends on factors such as mission objectives, system accuracy requirements, disturbance environment, and cost and risk involved.

As described earlier, fundamental elements of the hoop/column system are the bus, the feed, and the hoop. (See fig. 1.) It is thus reasonable to first consider a lumped controller located at either the bus or the feed. When the controller is located at the bus, it is referred to as the bust controller. Similarly, when the controller is located at the feed, it is referred to as the feed controller.

Both the bus and the feed controllers are referred to as single-site controllers. Either controller is assumed to have attitude sensing and torque actuation capabilities like current spacecraft attitude controllers.

A natural extension of the single-site controller is the two-site controller, which calls for attitude sensing and torque actuation at the bus and at the feed.

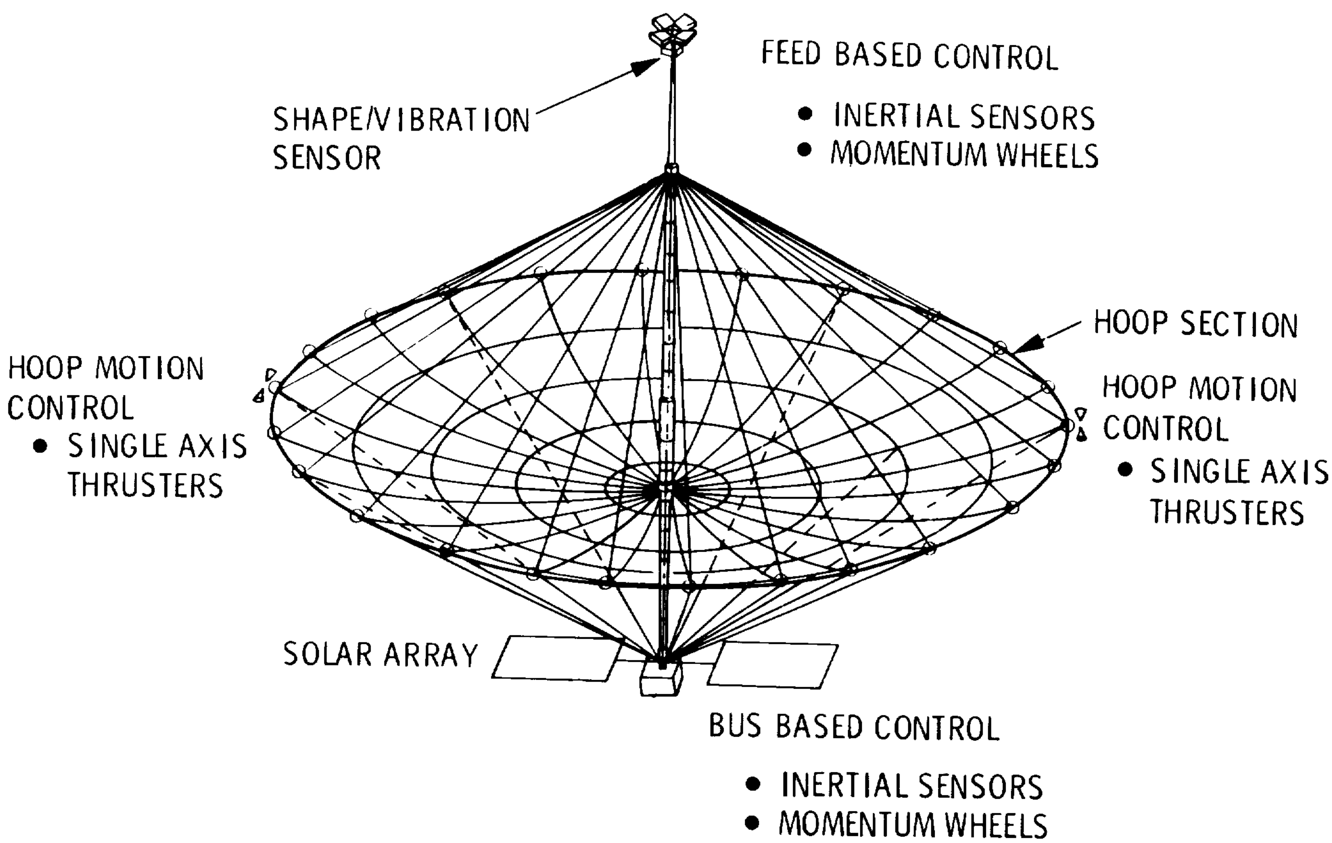


Figure 8

(HOOP/COLUMN)

The third system is the two-site controller plus hoop motion sensing and hoop rotation control. Hoop motion sensing can be performed with either inertial or optical sensors. Hoop rotation control can be achieved with single axis thrusters.

The fourth system is the third system plus static or dynamic dish shape control with existing control stringers. This system may be required for missions of very high performance.

Single-site and two-site controllers represent current technology and they were considered for the hoop/column systems. Their results will be presented shortly. The third and fourth systems represent reasonable extrapolations of current technology and are under study. (See fig. 9.)

1. SINGLE-SITE CONTROL WITH INERTIAL SENSORS AND ACTUATORS AT SPACECRAFT BUS OR FEED

2. TWO-SITE CONTROL WITH SENSORS AND ACTUATORS AT BOTH BUS AND FEED

3. FEED-DISH-HOOP MOTION CONTROL WITH HOOP ACTUATORS AND SENSOR

4. "3" + SURFACE SHAPE CONTROL

Figure 9

CONTROL/DYNAMICS SIMULATION SYSTEM

(HOOP/COLUMN)

In order to evaluate control performance, a simulation software program was developed, and its block diagram is shown in figure 10.

It consists of 3 major blocks, one of which is the control system representing either single-site or two-site controllers as discussed earlier. The second block represents the structural model for the hoop/column antenna system. The parameters of the antenna model can be changed and the resulting performance is computed and recorded in the performance evaluation block. Various performance parameters can be obtained.

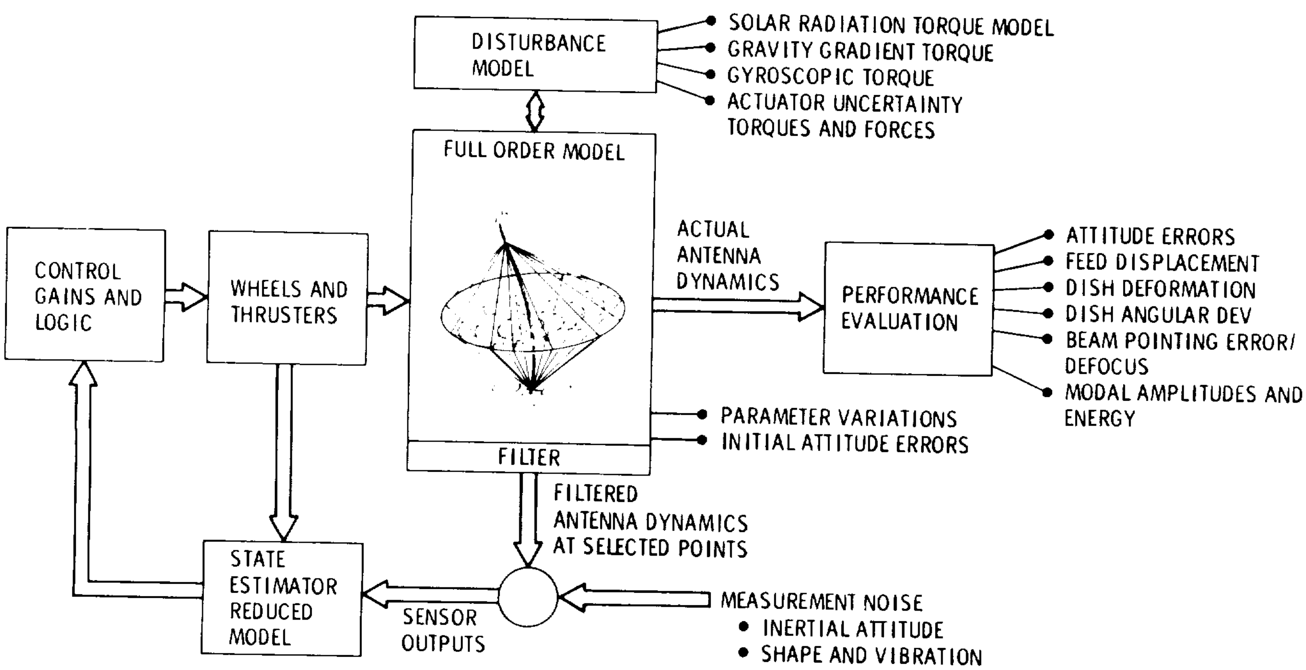


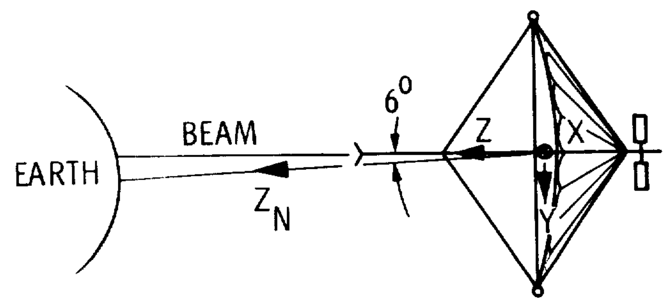
Figure 10

64-m DIAMETER HOOP/COLUMN ANTENNA CHARACTERISTICS

The best available model for the hoop/column antenna system is the 64-m diameter model developed by the Harris Corporation and is shown in figure 11. It was therefore integrated in the control simulation program.

- MODAL FREQUENCIES

NO.	FREQ, HZ	DESCRIPTIONS
7	0.10	1ST MAST TORSION
8	0.43	1ST MAST ROLL BENDING
9	0.43	1ST MAST PITCH BENDING
10	0.58	2ND MAST TORSION
11	1.07	3RD MAST TORSION
12	1.83	2ND MAST/DISH ROLL BDG
13	1.90	2ND MAST/DISH PITCH BDG
14	3.20	DISH WARPING
15	3.28	DISH WARPING
16	3.36	DISH WARP MAST BENDING
17	3.37	DISH WARP MAST BENDING
18	4.43	DISH WARP MAST BENDING



- 64-mD ANTENNA
- QUAD-APERTURE

- MASS PROPERTY
  - MASS: 2790 kg
  - MOMENT OF INERTIA
    1.42×10^6 kg-m^2
    1.42×10^6
    2.73×10^5
  - BALANCED CONFIGURATION

- MAX DISTURBANCE TORQUES
  - GRAVITY GRADIENT 1.89×10^{-3} N-m
  - GYROSCOPIC 6.30×10^{-4}
  - SOLAR PRESSURE 6.23×10^{-3}

Figure 11

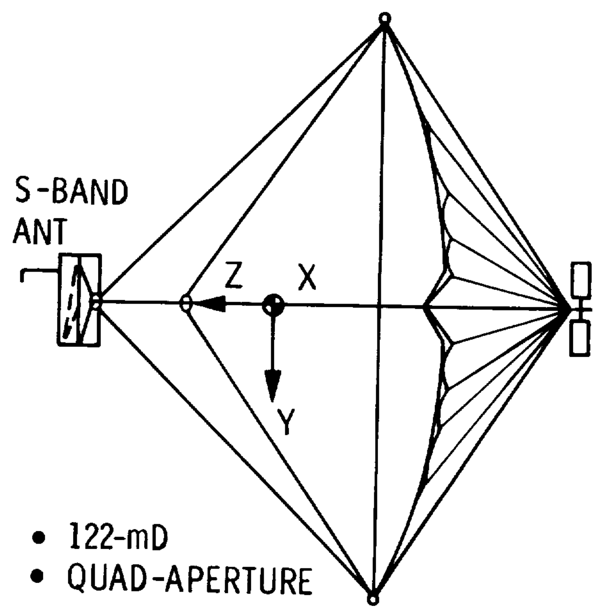
122-m DIAMETER HOOP/COLUMN CONFIGURATION

LMSS POINT DESIGN

An ongoing effort at Harris aims to develop a 122-m diameter model to represent the LMSS design. Modal frequencies for the 122-m model as currently estimated by the Harris Corporation are shown in figure 12. The 122-m model development is expected to be completed in January and the resulting model will be integrated into the control simulation program.

- ESTIMATED MODAL FREQUENCIES

NO.	FREQ. HZ	DESCRIPTIONS
7	0.35	MAST TORSION
8	0.18	ROLL BENDING
9	0.18	PITCH BENDING
10	0.31	MAST TORSION
11	0.56	MAST TORSION
12	0.95	MAST/DISH ROLL BENDING
13	0.99	MAST/DISH PITCH BENDING
14	1.68	DISH WARPING
15	1.71	DISH WARPING
16	1.76	DISH WARPING MAST BENDING
17	1.77	DISH WARPING MAST BENDING
18	2.42	DISH WARPING MAST BENDING



- 122-mD
- QUAD-APERTURE

- MASS PROPERTY
  - MASS: 4218 kg (9279 LB)
  - MOMENT OF INERTIA
    7.53×10^6 kg-m^2
    7.56×10^6
    1.49×10^6
  - BALANCED CONFIGURATION

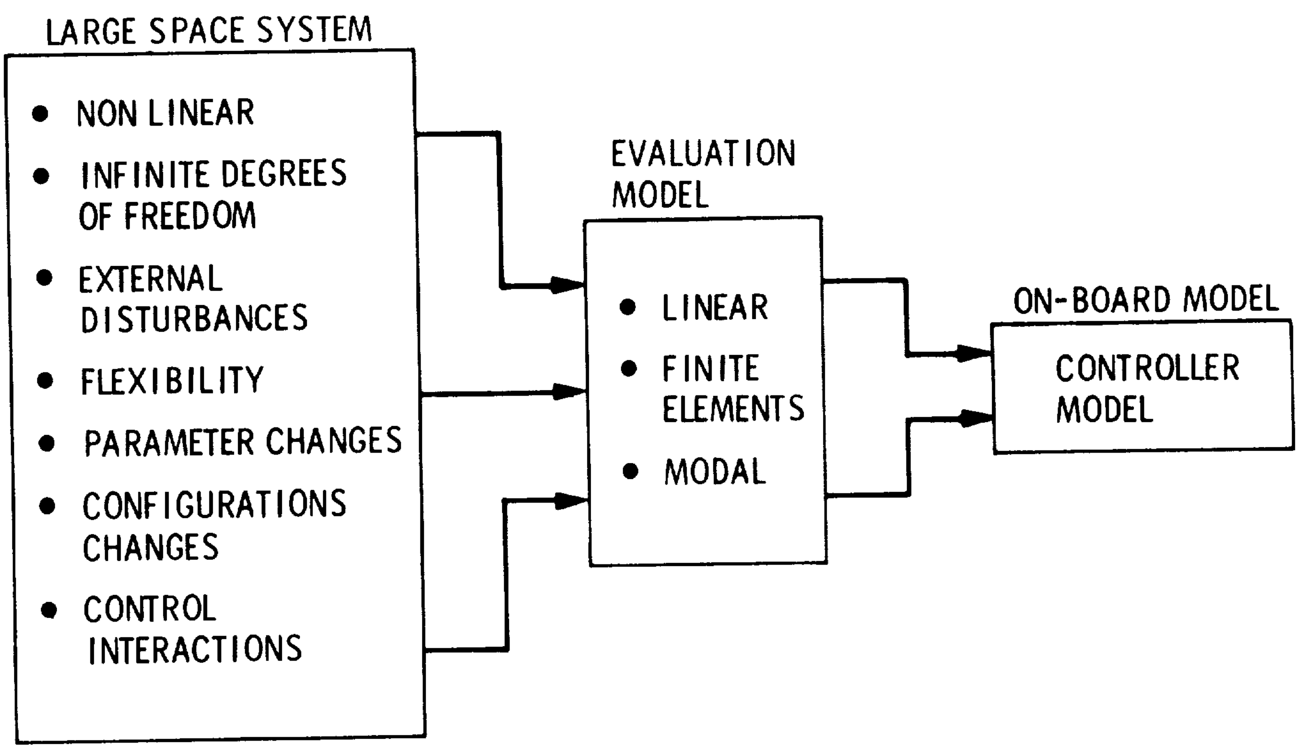
- MAX DISTURBANCE TORQUES
  - GRAVITY GRADIENT 1.0×10^{-2} N-m
  - GYROSCOPIC 3.3×10^{-3}
  - SOLAR PRESSURE 2.48×10^{-2}

Figure 12

MODELING PROBLEMS

(HOOP/COLUMN)

With antenna models selected and control systems designed, control performance of the hoop/column antenna system can be evaluated. However, control performance evaluation will not be complete, if model uncertainty is not considered. Again, model uncertainty here refers to the dynamics discrepancy that always exists between on-board controller model and the real large space system. Figure 13 illustrates that large space systems are characterized by nonlinearities, infinite degrees of freedom, flexibility, parameter changes, etc. Due to practical limitations, the best model available is often represented by a linear finite-element model of very high dimension. Even if the on-board controller can implement this very best model of very high dimension, there still exists a dynamic discrepancy between the on-board controller model and the real large space system. Therefore in control performance evaluation, model uncertainty is considered a significant control system design driver.



• LARGE STRUCTURES ARE INFINITE-DIMENSIONAL SYSTEMS THAT CANNOT BE COMPLETELY MODELED

Figure 13

CONTROL SENSITIVITY SUBJECT TO PARAMETER ERRORS

(HOOP/COLUMN)

For the hoop/column antenna, figure 14 illustrates that significant changes in control performance can occur when the modal frequencies of the actual hoop/column antenna system are different from those of the on-board controller model. First consider the feed controller. Suppose in this case the dish surface error is 1 mm, when the actual system frequency is the same as the design frequency. As the actual system frequency differs from the design frequency, the dish surface error may increase or decrease. But, as the actual system frequency is reduced by more than 20% or increased beyond 30%, the feed controller becomes unstable.

For the bus controller, the result indicates that the performance is relatively better than that of the feed controller. But the system becomes unstable when the actual system frequency is reduced by 20% or increased by 17%.

Figure 14 further illustrates that the two-site controller with attitude sensing and torque actuation at both the bus and the feed can perform better and can be more robust than the other two controllers. This means that the model undertainty problem can be reduced by different control designs.

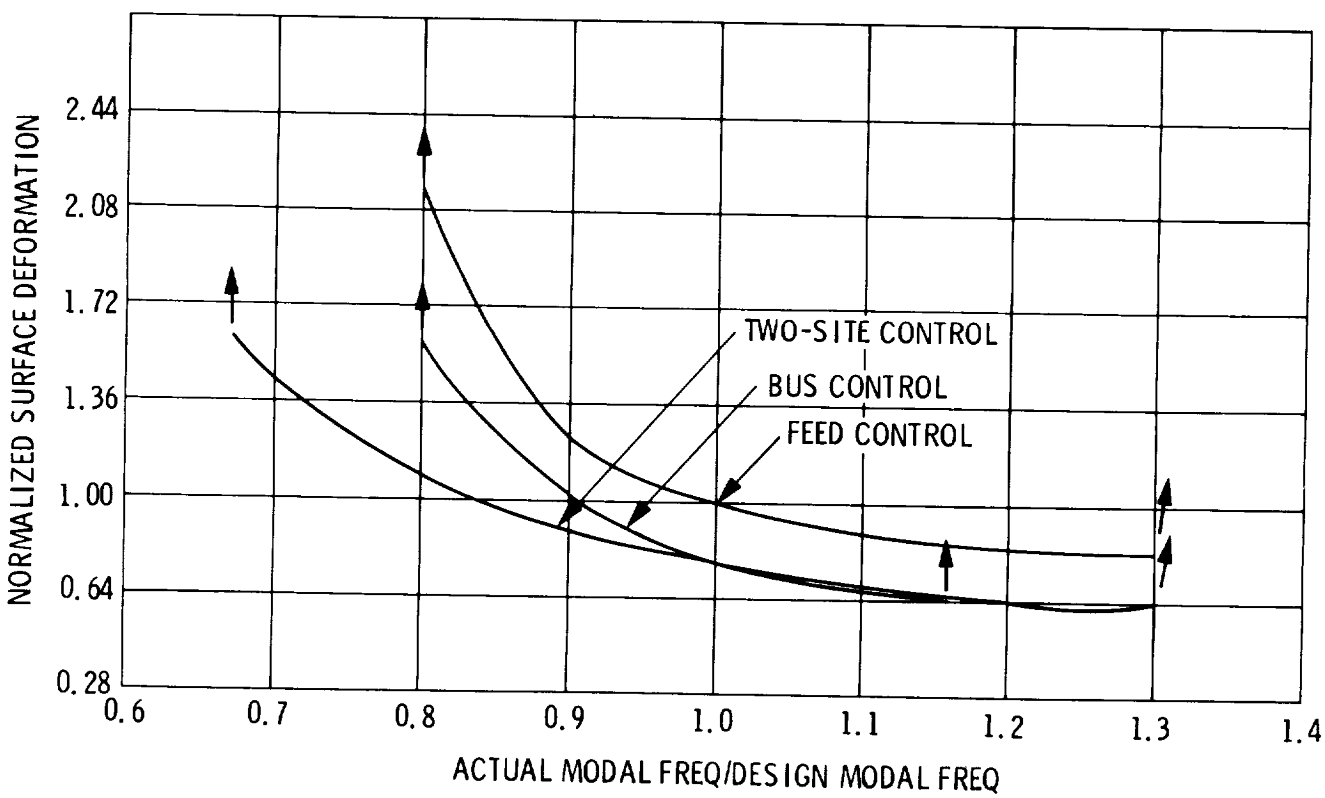


Figure 14

TWO-SITE CONTROL PERFORMANCE SENSITIVITY

TO PARAMETER ERRORS

(HOOP/COLUMN)

The other antenna performance parameters exhibit similar results as the actual system frequency differs from the design frequency. For example, in the case of the two-site controller, the bus pointing, in general, is better than the feed pointing until the control system becomes unstable. The feed/dish relative displacement error exhibits similar results as indicated in figure 15.

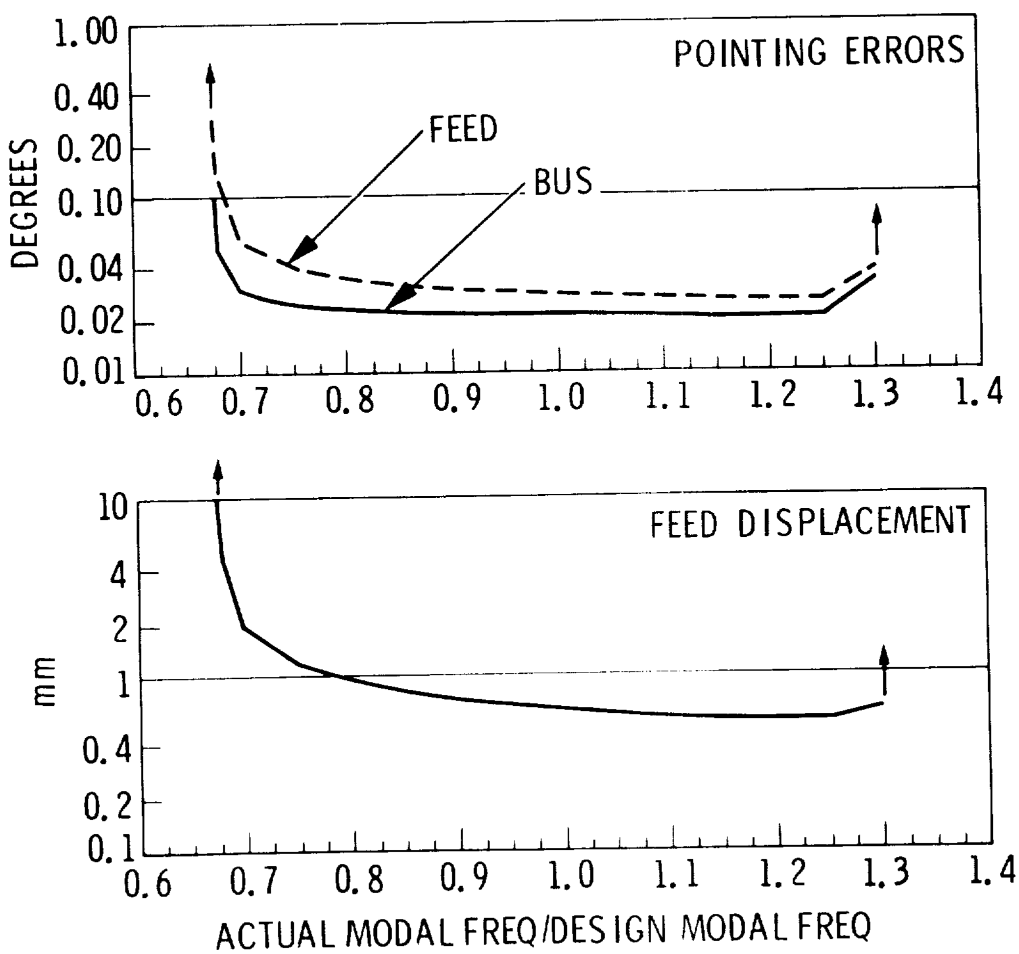


Figure 15

IDENTIFICATION OF CRITICAL MODAL PARAMETERS

(HOOP/COLUMN)

Results of figures 14 and 15 are summarized in the bottom of figure 16 as the category of all modes. For example, the feed control and the bust control both become unstable as the actual system frequencies of all modes are reduced by 20%. Similarly, two-site control remains stable in the region of 0.67 to 1.3 as before.

However, if only frequencies of torsional modes or if only frequencies of bending modes change, different results occur. Figure 16 indicates that as far as the stability is concerned, the accuracy of torsional frequencies is more important than that of the bending frequencies.

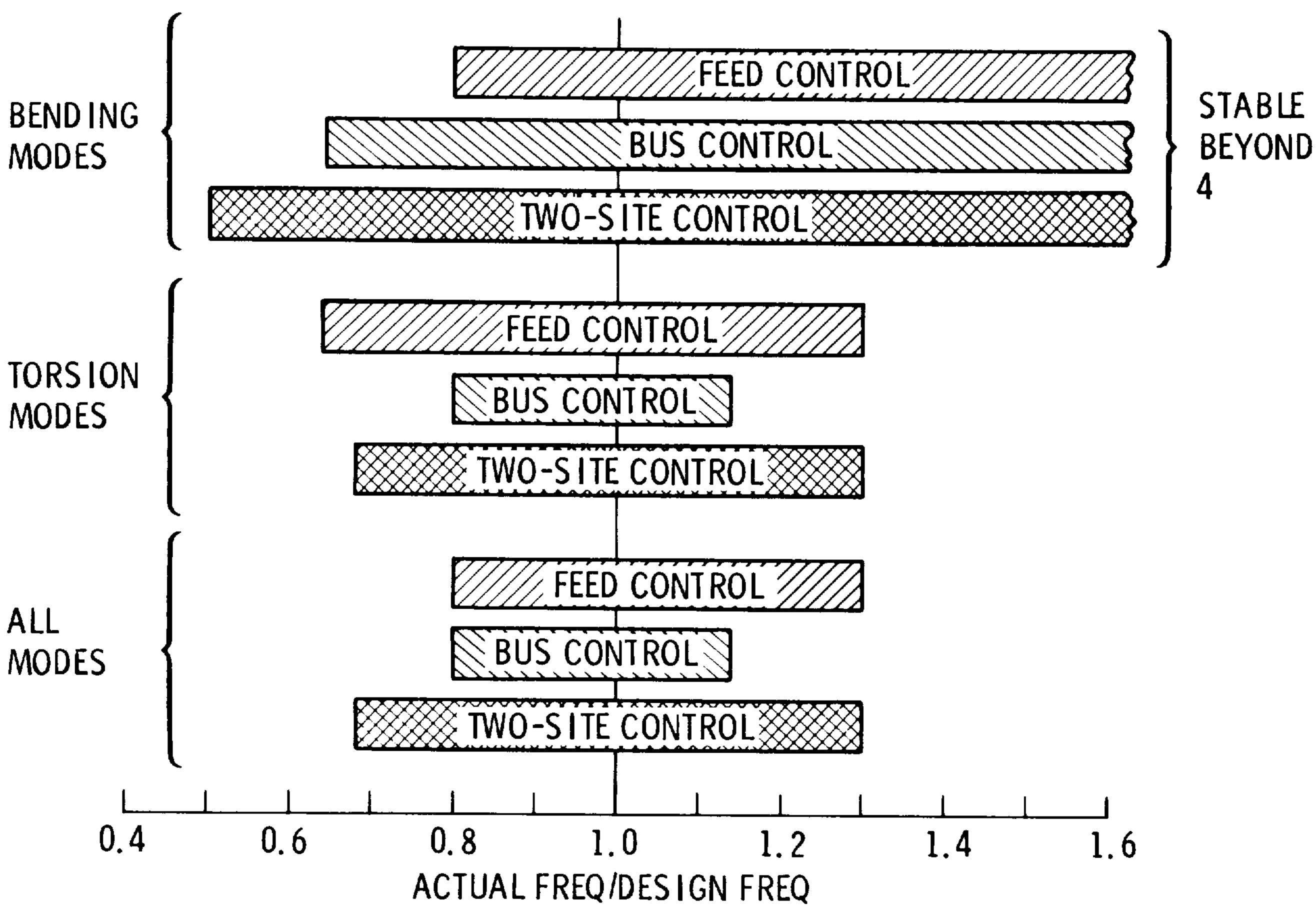


Figure 16

SUMMARY

(HOOP/COLUMN)

- The system drivers are summarized in figure 17 and are the following:

  1. Inevitable uncertainties or dynamics discrepancy that always exists between controller design model and the real structure; this can cause system instability

  2. Low structural frequencies associated with hoop/mast torsions; these modes determine system stability margins

- Two-site control system is more robust than single-site controllers in the presence of system frequency uncertainties

  As the two-site control system concept is applied to the LMSS design, it results in reasonable hardware requirements, the details of which will be reported as part of the LMSS study presentation contained elsewhere within this review.

- Finally, it appears that identification of critical modes can allow a control system to achieve its best performance. However, identification of critical modes must be performed while the large space antenna system is being controlled. The reason is that some modes may be critical to one type of controllers but not critical to others.

- SYSTEM DRIVERS
  - UNCERTAINTIES IN CONTROL/STRUCTURAL INTERACTIONS
  - LOW STRUCTURAL FREQUENCIES
    - HOOP
    - MAST
- TWO-SITE CONTROL SYSTEM
  - MORE ROBUST THAN SINGLE-SITE CONTROLLERS
  - RESULTING IN REASONABLE HARDWARE REQUIREMENTS AS APPLIED TO THE LMSS MISSION
- IDENTIFICATION OF CRITICAL MODES INSURES BEST CONTROL PERFORMANCE

Figure 17

CONTROL PROBLEMS

(WRAP-RIB)

Next, consider the control of wrap-rib antenna systems (fig. 18).

The task is to control the wrap-rib system (fig. 5) to meeting accuracy requirements shown in figure 3. First control problem is associated with the imbalanced configuration of the wrap-rib antenna system. The imbalanced configuration is evidenced by the fact that 80% of system mass is concentrated at the bus area and 20% at the dish area. Therefore, the axis of minimal inertia is 17° off from the local vertical which is the Z-axis in figure 5. This results in a large constant gravity gradient torque on the system with magnitude of 1.14×10^{-2} ft-lb.

Another difficulty caused by the imbalanced configuration is that it results in a large cross product of inertia. This inertia causes significant dynamic coupling between two attitude axes.

For wrap-rib antenna systems, feed and dish are also physically separated but connected with the flexible boom structure. Their relative motions can cause dish pointing and antenna defocus errors.

- IMBALANCED CONFIGURATION
  - LARGE CROSS PRODUCT OF INERTIA
  - COUPLING BETWEEN CONTROL AXES
- FEED/DISH RELATIVE MOTIONS
  - DISH POINTING ERRORS
  - DEFOCUS ERRORS
- DISH VIBRATIONS
  - RF GAIN LOSS
  - COUPLING WITH FEED MOTIONS
- LOW FREQUENCIES OF BOOM
  - CONTROL/STRUCTURE INTERACTIONS
- STRUCTURAL UNCERTAINTIES/MODEL ERRORS
  - ERROR IN BOOM FREQUENCIES

Figure 18

FEED MOTION AND BOOM DISTORTION

(WRAP-RIB)

The 55-m diameter dish is also a flexible structure. Its vibrations will have two distinct impacts on system performance. First, its vibrations can cause dish surface errors, resulting in RF gain loss. Second, its vibrations can couple with dynamics of other parts of the system as illustrated by figure 19. Consider a torsional motion of the dish. It can cause the short boom to bend and twist. The elbow of the boom is translated. As a result, the long boom is bending and the feed/bus is therefore experiencing attitude errors.

Next, all models to date indicate that lowest vibration frequencies of the system are associated with the boom structure. The low frequencies of the boom can cause control/structure interactions, resulting in performance degradation. This problem is further compounded by the model uncertainty problem discussed earlier. Consequently, low frequencies of the boom with uncertain values can cause serious problems such as system instability.

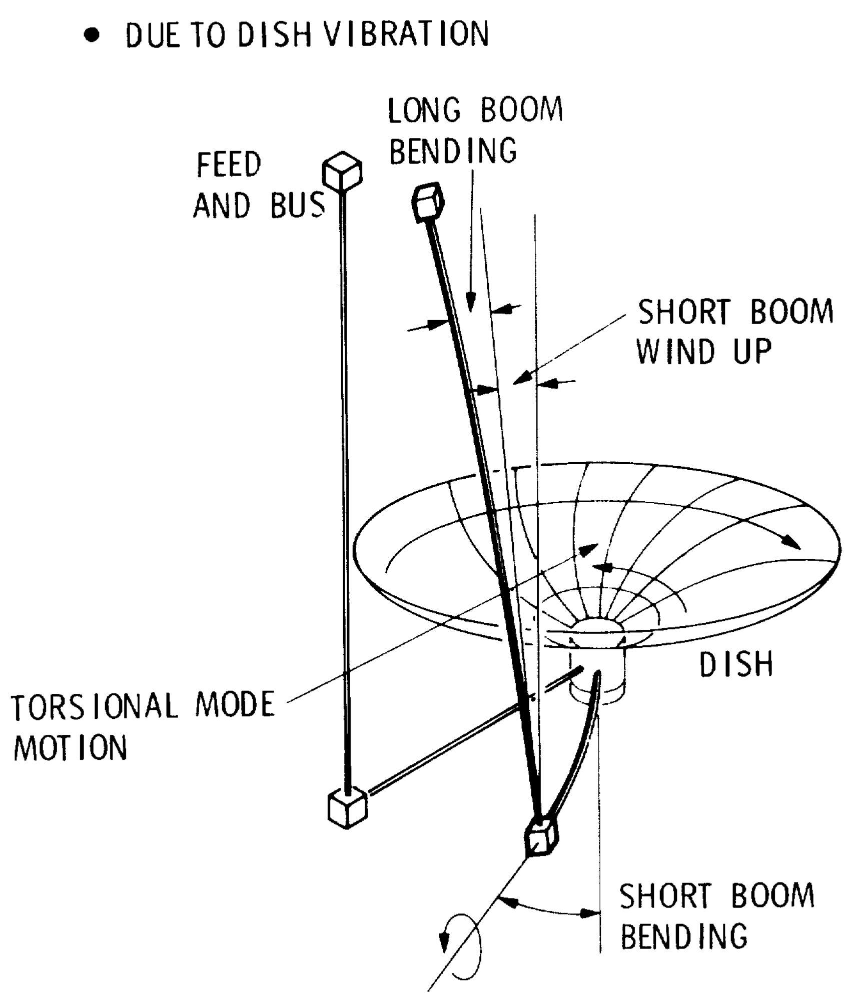


Figure 19

CONTROL SYSTEM HIERARCHY

(WRAP-RIB)

The control system hierarchy is summarized in figure 20.

Control System 1 is typical of the current attitude controllers for 3-axis spacecraft stabilization. Attitude sensors and actuators are lumped together and mounted on the bus of the antenna system. Flexible dynamics associated with the boom and the dish may only be inferred from attitude sensor outputs.

Control System 2 represents a departure from system 1 in that it calls for an optical sensor at the bus to perform multipoint distributed sensing of the dish. The reason for having this sensor is to obtain information about flexible dynamics of the boom and the dish directly. Since the information about feed/dish relative motion is measured and available, it is possible to control this motion with reduced performance sensitivity to uncertainties associated with boom dynamics. However, the control is still performed at the bus.

Control System 3 represents system 2 plus extra control authority at the hub of the dish to stabilize boom motions. The reason is that it is difficult to control boom motions such as the short boom twist with a controller at the bus that is 80 meters away. This is exactly what happens as will be illustrated in detail.

Control System 4 may be reasonable for missions with even more stringent requirements. For LMSS, however, Systems 1, 2, and 3 were considered and their results will be presented.

1: LUMPED CONTROLLER AT SPACECRAFT BUS

2: "1" + MULTIPOINT SENSING OF DISH

3: "2" + CONTROLLER AT HUB OF DISH

4: "3" + DISTRIBUTED CONTROL OF DISH AND BOOM

Figure 20

ILLUSTRATION OF CONTROL HIERARCHY

(WRAP-RIB)

The control hierarchy is illustrated by figure 21.

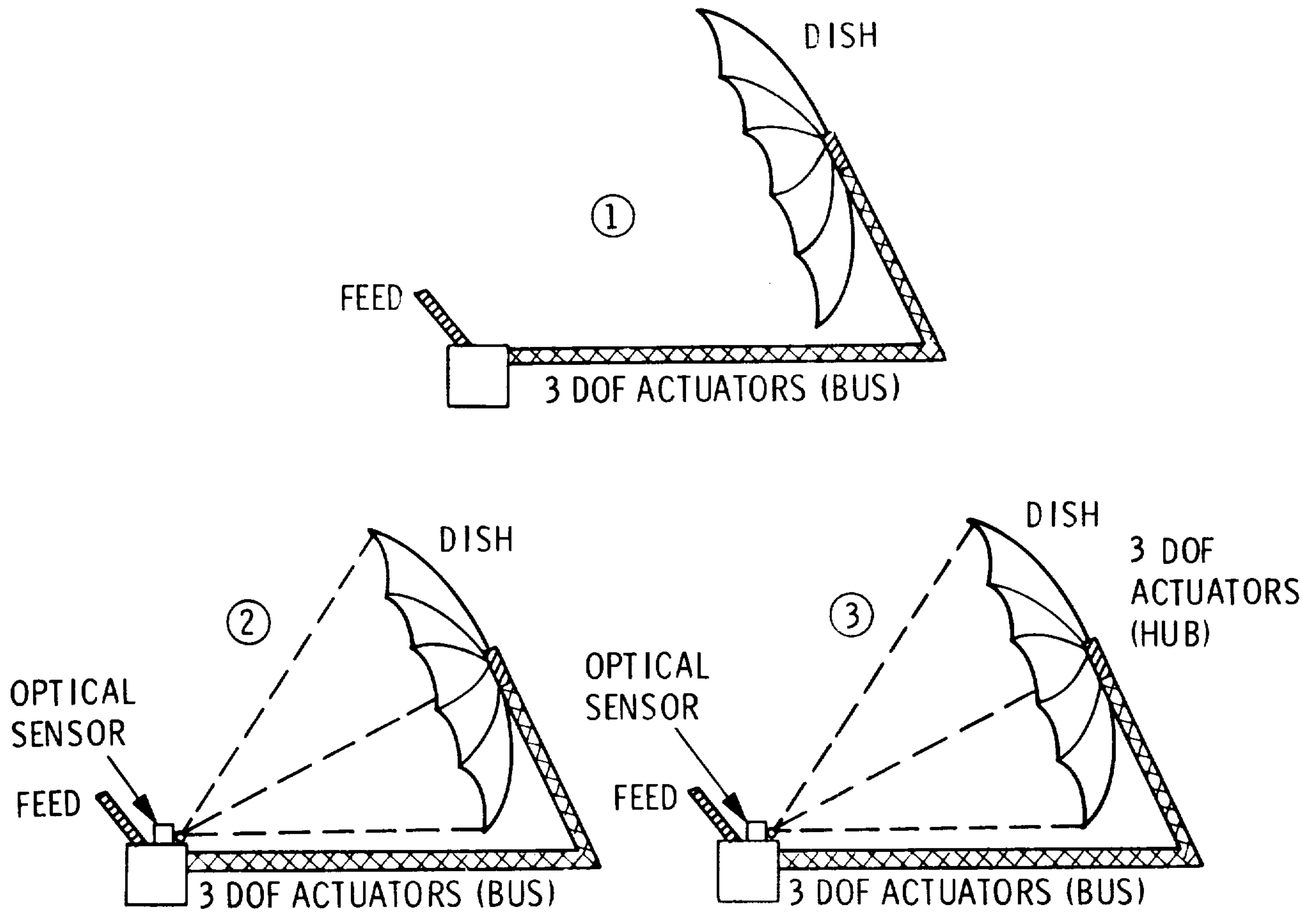


Figure 21

THE FINITE-ELEMENT STRUCTURAL MODEL

(WRAP-RIB)

Before presenting results of these control systems, a description is given here for the antenna models on which control performance is evaluated.

Part of the model development work has been geared to capture the characteristics of the LMSS as much as possible. Therefore, a finite-element model (fig. 22) was developed to represent the wrap-rib configuration of the LMSS. The details of this work are contained in the presentations by R. Freeland and M. El-Raheb of JPL (refs. 1 and 2). It is noted that lowest system vibration frequencies in this model involve boom distortions as indicated in modes 1, 2, and 3. In particular, the first flex mode is associated with the short boom twist with a frequency of about 0.087 Hz.

FLEX MODE	FREQ (Hz)	DESCRIPTION
1	0.0872	SHORT BOOM TORSION
2	0.1473	DISH TORSION, LONG BOOM TWIST
3	0.1965	DISH TORSION, LONG BOOM BENDING
4	0.2062	DISH BENDING
5	0.2201	DISH BENDING, LONG BOOM BENDING
6	0.2906	DISH TORSION
7	0.6644	DISH ROTATION, LONG BOOM BENDING

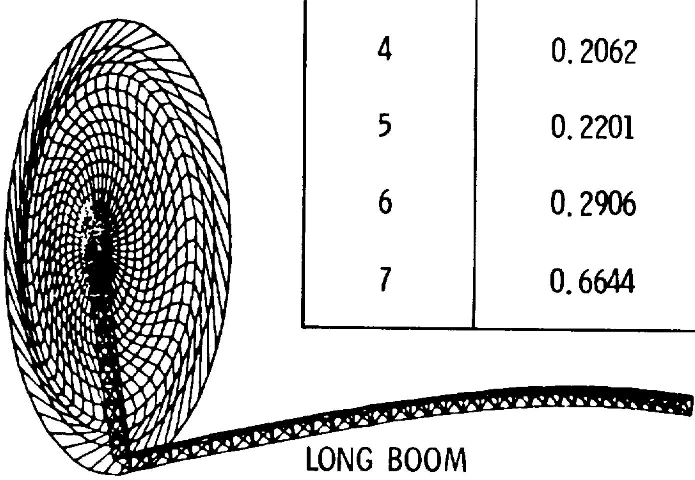
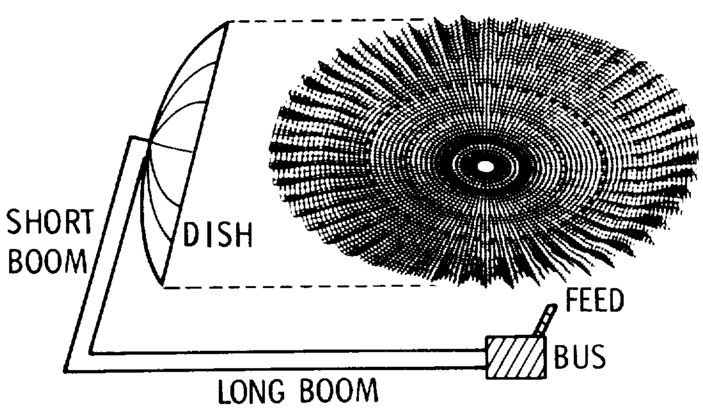


Figure 22

PARAMETRIC MODELS FOR CONTROL STUDIES

(WRAP-RIB)

To undertake control studies for the antenna system, parametric models (fig. 23) of the wrap-rib antenna system were also developed. It is noted that in the nominal case where there are no parameter errors, the mode frequencies and mode shapes of the parametric model are very close to those in the finite-element model. However, the development of parametric models is intended to have the following advantages. It allows easy and inexpensive change in model parameters, such as modal damping, boom stiffness, and mass of dish, bus, or feed, so that it can predict changes in system behavior as a result of model parameter change. It also permits simulation of different control concepts such as distributed sensing of dish and actuations at bus, at hub, or at both locations. Therefore, this capability is vital to control designs and sensitivity analyses.



MODE	NOMINAL FREQ (Hz)	DESCRIPTION
1	0.0874	SHORT BOOM TORSION
2	0.1493	DISH TORSION, LONG BOOM TWIST
3	0.1826	DISH TORSION, LONG BOOM BENDING
4	0.2117	DISH BENDING
5	0.2285	DISH BENDING, LONG BOOM BENDING
6	0.4250	DISH TORSION
7	0.7575	DISH ROTATION, LONG BOOM BENDING

- VERY GOOD MATCH WITH THE F. E. MODEL IN THE NOMINAL CASE
- VERY EASY TO CHANGE MODEL PARAMETERS
- VERY EASY TO SIMULATE DIFFERENT CONTROL MECHANIZATION CONCEPTS
- NECESSARY FOR CONTROL DESIGNS AND SENSITIVITY ANALYSES

Figure 23

AUTOMATION OF CONTROL DESIGN AND SENSITIVITY ANALYSIS

(WRAP-RIB)

To perform control and sensitivity analysis requires handling a large amount of data. To eliminate major manual operations and human errors, a software program was developed. Similar to the one for hoop/column studies this program consists of three major elements (fig. 24), one of which is the antenna model with parameters at selected values. The second block is the control and estimation element which simulates mechanizations of control systems 1, 2 and 3 as described earlier. The last element consists of all subroutines for computing antenna performance parameters such as dish surface RMS errors, dish pointing errors, and feed/dish relative displacements.

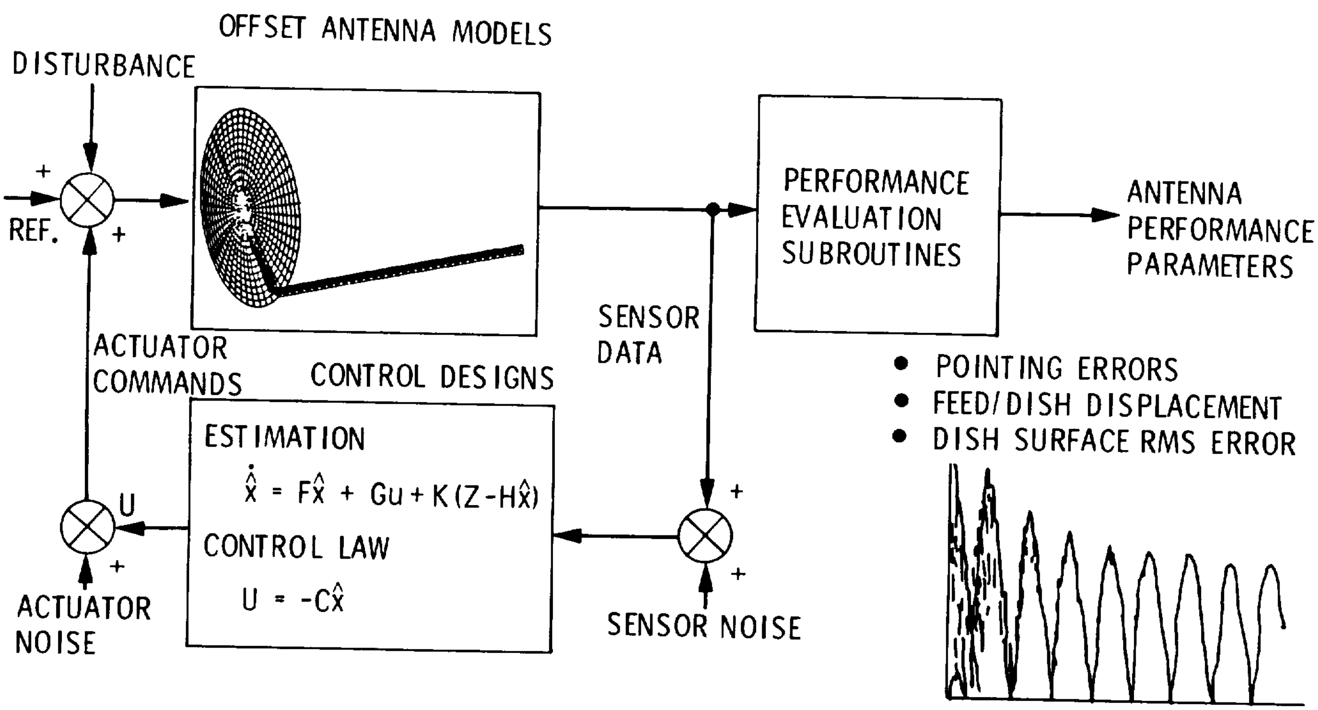


Figure 24

ANTENNA CONTROLLER DESIGNS BASED ON RF PERFORMANCE

(WRAP-RIB)

This simulation program (fig. 25) is currently being updated to include an RF model for the prediction of RF performance such as RF gain, sidelobe levels, and RF pointing. The purpose of the RF model is to permit antenna control designs based on RF performance, which should be the ultimate parameter to be optimized.

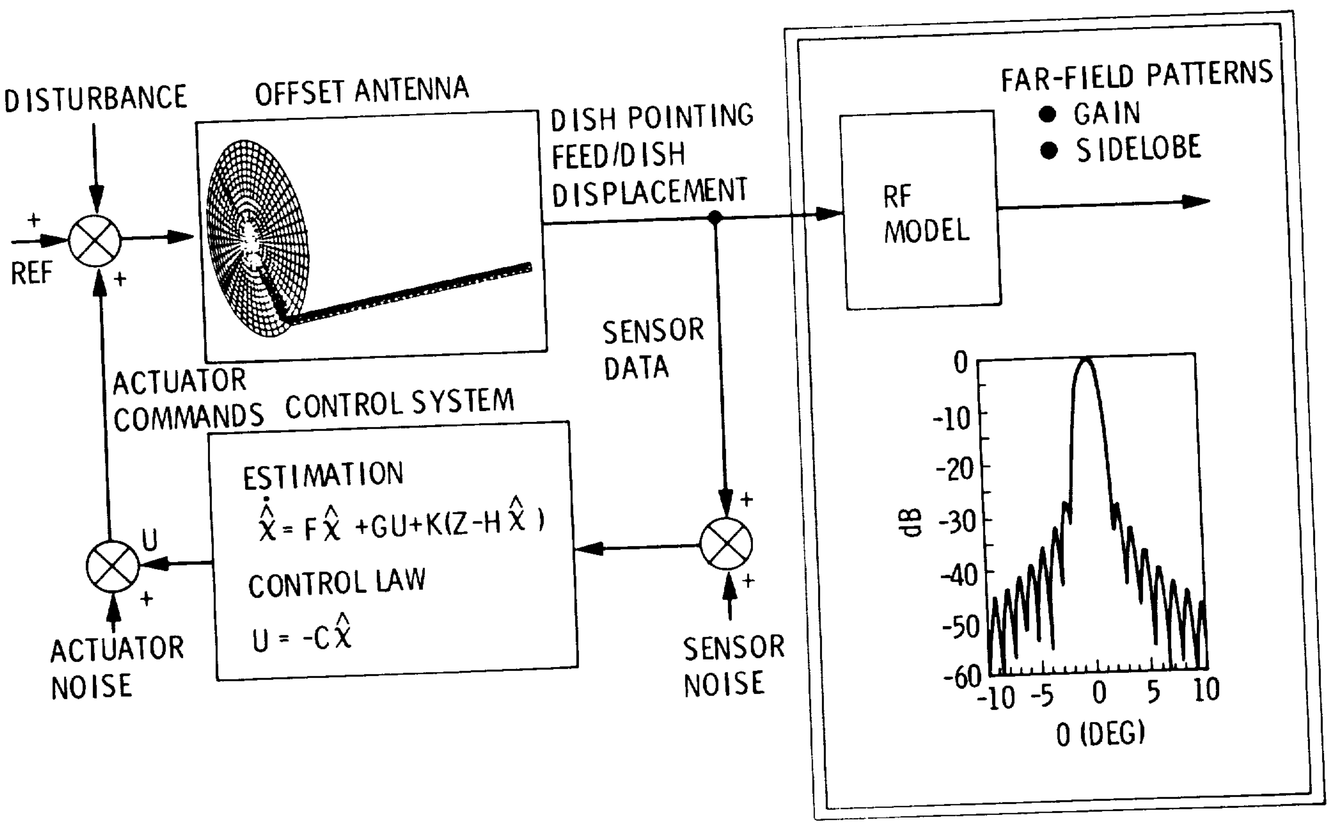


Figure 25

DISH LINE-OF-SIGHT STABILITY

(WRAP-RIB)

Consider the first case where actual boom frequencies are the same as the boom frequencies used in the control designs. Figure 26(a) shows the dish LOS stability error as a result of having 1 newton-meter sinusoidal disturbance torque applied to the antenna. For example, in cases where the disturbing sinusoidal torque has the same frequency as the first vibration frequency of the antenna at 0.55 rad/sec, the dish LOS error will be 0.03° for control system 1, 0.015° for control system 2, and 0.002° for control system 3. This means that having capabilities of optical sensing and extra control at dish hub, system 3 is able to bring peak errors down by an order of magnitude and distribute the errors in a harmless manner.

In addition, system 3 provides performance more stable and robust than the other two systems as actual boom frequencies decrease. This is illustrated in figures 26(b) and (c). As actual boom frequencies decrease to 62.5% of the design frequencies, the peak LOS errors for system 3 is about 2.5 times better than that of system 2, whereas system 1 is already unstable. Similarly, in the last case where actual boom frequencies are 60% of the design boom frequencies, the peak LOS error for system 3 is at about 0.02°, and both system 1 and system 2 are unstable.

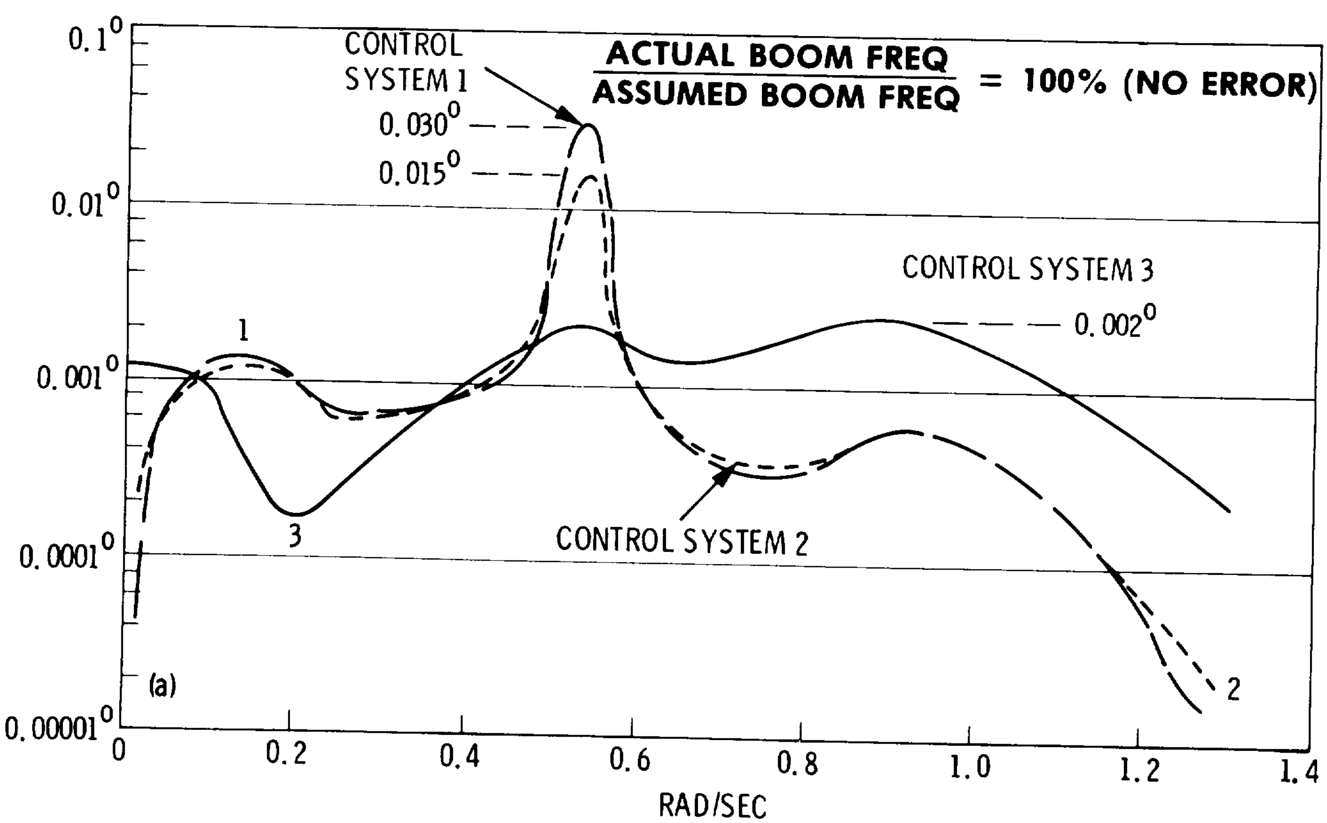


Figure 26

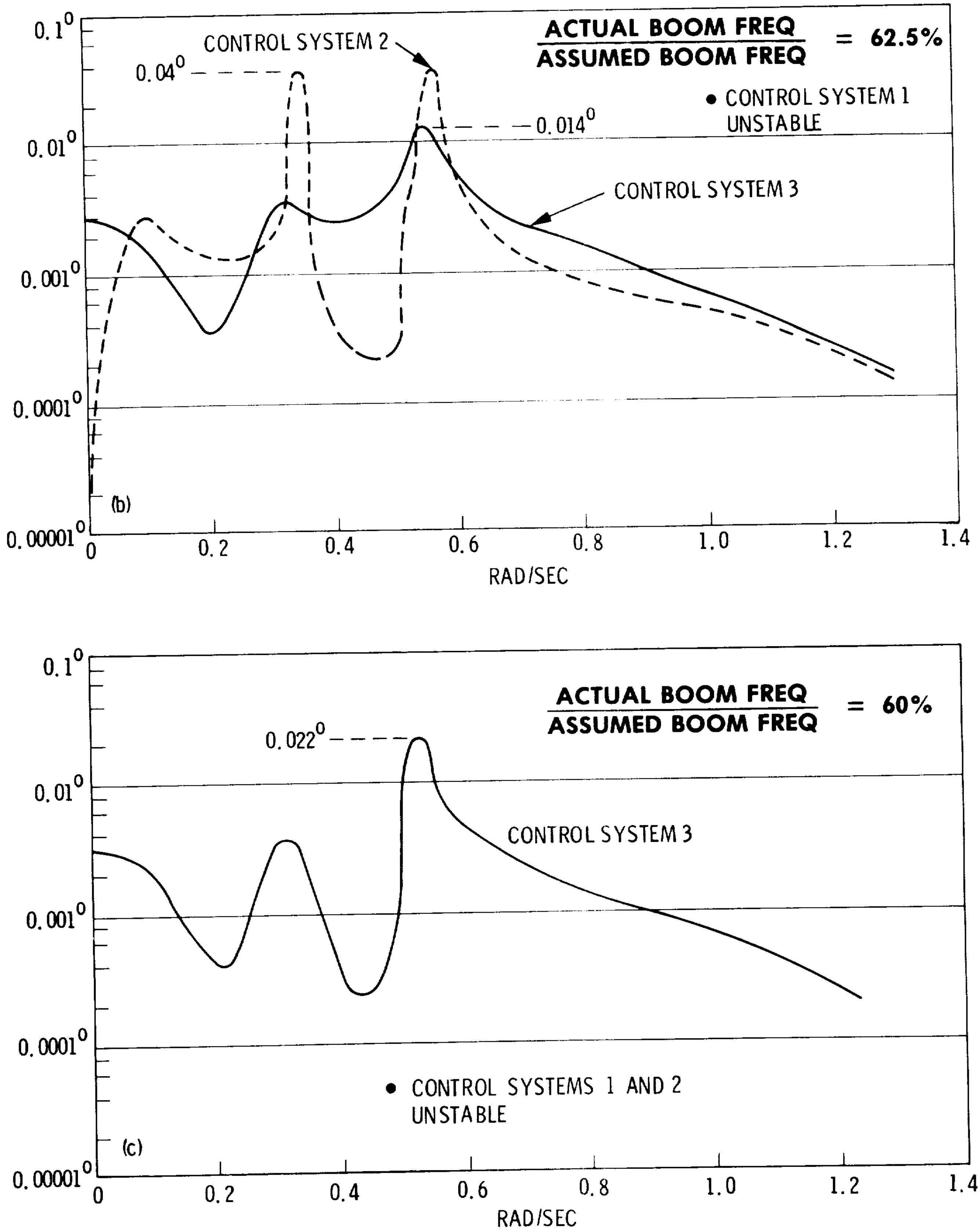


Figure 26.- Concluded.

SUMMARY OF RESULTS (DISH LINE-OF-SIGHT

STABILITY: PEAK ERROR)

(WRAP-RIB)

To summarize results obtained to date, dish LOS stability error is again used as an example in figure 27 to show performance and sensitivity results of three control designs. It is noted that performance of system 3 is much better than the performance of the other two systems as mentioned earlier. Furthermore, as boom frequency reduces, system 3 is more stable and robust than the other two systems.

From these results, it appears that uncertainties in boom dynamics and its stiffness (frequency) are very critical to the definition of control systems for the wrap-rib antenna systems.

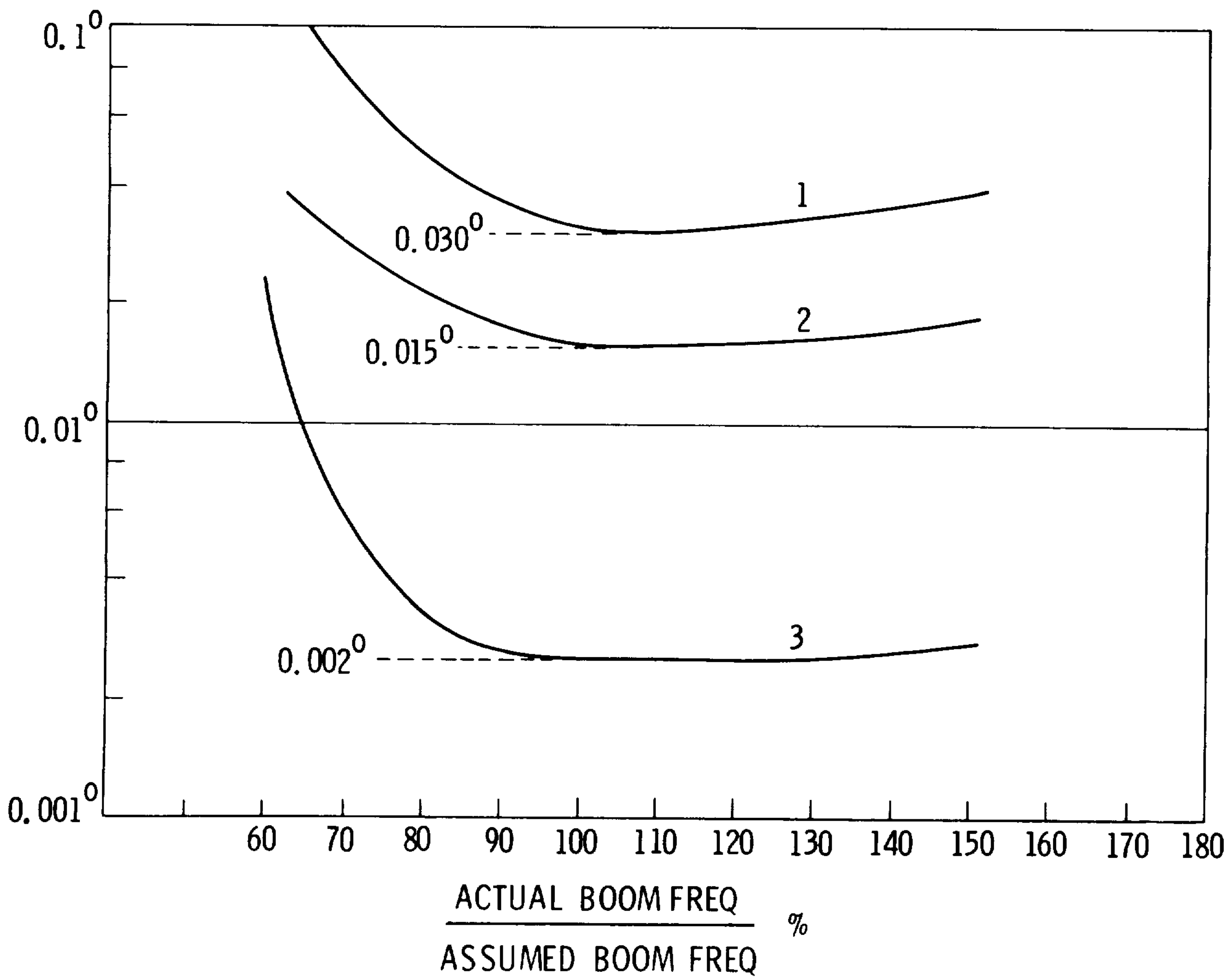


Figure 27

SUMMARY

(WRAP-RIB)

Figure 28 is a summary of what has been presented on the control of wrap-rib antenna systems:

1. First, the system drivers are the following:

The inevitable errors or discrepancies between the on-board controller design model and the real structure. The most critical vibration of the wrap-rib antenna appear to be the short boom twist and the torsion about antenna line of sight.

2. Control System 3 appears effective in stabilizing the short boom twist, which is the most critical of all vibrations. As system 3 is applied to the LMSS mission, it results in an average power requirement of 260 watts and ACS weight of about 1000 lb. which are considered very reasonable. Again, the details of this work will be presented as part of the LMSS control subsystem definition by A. F. Tolivar (ref. 3).

3. As in the hoop/column case, identification of critical modes can allow a control design to achieve its best performance possible.

- SYSTEM DRIVERS
  - STRUCTURAL UNCERTAINTIES/MODEL ERRORS
  - LOW FREQUENCIES OF BOOM
    - SHORT BOOM TWIST
    - TORSION ABOUT ANTENNA LINE-OF-SIGHT
- CONTROL SYSTEM 3
  - EFFECTIVE IN STABILIZING BOOM MOTIONS
  - RESULTING IN REASONABLE HARDWARE REQUIREMENTS WHEN APPLIED TO THE LMSS MISSION
    - AVG POWER 260 WATTS
    - ACS HARDWARE & PROPELLANT 1010 LB
- IN-ORBIT IDENTIFICATION OF CRITICAL MODES INSURES BEST CONTROL PERFORMANCE

Figure 28

CONCLUSIONS

Conclusions (fig. 29) that can be drawn for the control of large space antenna systems are the following:

1. Important control system drivers for the hoop/column configuration are dynamics associated with hoop rotations, and for the wrap-rib configuration are dynamics associated with the boom.

2. Model uncertainty as defined in this presentation results in control performance degradation. This has been established quantitatively for both antenna systems.

3. System instability can occur if uncertainties are sufficiently large.

4. Because flight data base for large space systems is nonexistent, large uncertainties will occur.

5. To demonstrate technology and to increase flight data base, in-flight experiments are necessary.

- BOOM AND HOOP DYNAMICS ARE IMPORTANT CONTROL SYSTEM DRIVERS
- UNCERTAINTY IN CONTROL/STRUCTURE INTERACTIONS RESULTS IN CONTROL PERFORMANCE DEGRADATION
- INSTABILITY OCCURS IF UNCERTAINTIES ARE SUFFICIENTLY LARGE
- LARGE UNCERTAINTIES WILL OCCUR BECAUSE FLIGHT DATA BASE IS NONEXISTENT
- IN-FLIGHT EXPERIMENTAL IDENTIFICATION OF CONTROL/STRUCTURE INTERACTIONS WILL DEMONSTRATE TECHNOLOGY AND INCREASE DATA BASE

Figure 29

PLANNED WORK

The planned work is summarized in figure 30 as follows:

1. Control Synthesis

Control design and evaluation for both antenna concepts are to be directed toward specific point designs in order to achieve maximum results. In particular, additional system drivers will be identified. Control performance sensitivity to uncertainties such as truncation errors, non-linearities, and hardware constraints will also be determined.

2. Control Experiment Definition

Definition tasks for such a flight experiment involve the following areas. First, control goals and requirements must be defined. Then control hardware mechanization and requirements for the experiment are to be defined so that the experiment implementation can proceed.

The experiment can be designed to have its own control system or to utilize the reaction control system on board the shuttle. For either case, dynamics interactions between the shuttle and the experiment must be carefully examined to ensure the safety of shuttle/experiment.

Instrumentation for modal sensing and excitation is to be identified, selected, and integrated into the experiment. This will allow the proper implementation of sensing and actuation of experiments.

CONTROL SYNTHESIS

- COMPLETE EVALUATION OF SYSTEM DRIVERS
- DETERMINE SENSITIVITY TO UNCERTAINTIES
- ESTABLISH NEW CONTROL TECHNOLOGY PERFORMANCE BOUNDS

CONTROL EXPERIMENT DEFINITION

- DEFINE CONTROL GOALS AND REQUIREMENTS
- ESTABLISH MECHANIZATION APPROACHES
- DETERMINE EXPERIMENT/SHUTTLE CONTROL INTERACTIONS
- IDENTIFY INSTRUMENTATION FOR MODAL SENSING AND EXCITATION
- PERFORM PRELIMINARY DESIGN AND IMPLEMENTATION APPROACHES

Figure 30

REFERENCES

1. Freeland, R. E.: JPL Antenna Technology Development. Large Space Systems Technology - 1981, NASA CP-2215, Pt. 2, 1982, pp. 429-438.

2. El-Raheb, M.: Analytical Performance Prediction for Large Antennas. Large Space Systems Technology - 1981, NASA CP-2215, Pt. 2, 1982, pp. 471-477.

3. Tolivar, A. F.: LSS Control Technology. Large Space Systems Technology - 1981, NASA CP-2215, Pt. 1, 1982, pp. 241-247.