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ON THE ACCURACY OF MODELLING THE DYNAMICS OF LARGE SPACE STRUCTURES

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ON THE ACCURACY OF MODELLING THE DYNAMICS OF LARGE SPACE STRUCTURES*

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Several recently sponsored NASA workshops[1,2,3] have discussed proposed new space missions which would require large-scale, light weight space-based structural subsystems. Four representative proposed future missions utilizing such systems are: ocean data systems; electronic mail systems; large multi-beam antenna systems; and space-based solar power systems.

It is evident that a complete new technology must be considered and developed so that these structures can be delivered into orbit (based on the Shuttle Transportation System), deployed, and then fully assembled in a space environment. Because of their inherent size, modeling techniques and scaling algorithms must be developed so that system performance can be accurately predicted prior to launch and assembly. In many cases it will be necessary to control the shapes of the antenna or collector surfaces to within centimeters or even millimeters (RMS) by using a variety of sensor-actuator systems properly positioned throughout the system.

The steps involved in the development of mathematical models that can be used to simulate the in-orbit dynamics of large flexible systems together with some aspects of simulation requirements were reviewed in a recent session at the 10th IMACS World Congress on System Simulation and Scientific Computation, most notably the reviews presented in Refs. 4 and 5. Fig. 1[5] illustrates a conceptual

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plan of development of a system software capability for use in the analysis of the dynamics and control of large space structures technology (LSST) systems. The most fundamental component is that of the modelling of the (open-loop) system dynamics of such systems in orbit.

When the size and weight to area ratio of such proposed LSST systems dictate that the entire system must be considered to be flexible there are two basic modelling methods which can be used. Santini[5] has developed a mathematical formulation for predicting the motion of a general orbiting flexible body using a continuum approach. Elastic deformations are considered small as compared with characteristic body dimensions. Equations are developed for both the rigid and elastic (generic) modes. This development is based on an a priori knowledge of the frequencies and shape functions of all modes included within the truncated system model.

As an alternative, finite element techniques can be used to model the entire structure as a system of lumped masses connected by a series of (restoring) springs and possibly dampers. Within the linear range, the coupling terms between the rigid and flexible modes and between the different flexible modes themselves are usually neglected. Such coupling terms are seen to depend on volume integrals whose integrand functions depend on the various components of the different modal shape functions together with the coordinates of the differential mass elements.[6]

The controllability and control law synthesis based on a finite element model of the proposed Hoop/Column orbiting antenna system (Fig. 2) was the subject of a recent IAF presentation.[7] Subsequently, the environmental disturbance effects were included in the closed-loop model of this system, where it was seen that these disturbances affect predominantly the system rigid modes.[8]

In response to questions concerning the accuracy of the model used in Refs. 7 and 8, it is the object of the present paper to develop a computational algorithm to evaluate the coefficients of the various coupling terms in the equations of motion as applied to the finite element model of the Hoop/Column system. In order to make this comparison, the volume integrals appearing in these coefficients have now been discretized, where the integrals have been replaced by summations over the total number of discrete mass points corresponding to the finite element output data. Based on this information it was possible to arrive at the following mass distribution, as assumed to be distributed at the final (reduced) number of grid points (Table 1).

With this information together with the modal shape function components at the same grid points, it was possible to implement a computer algorithm to evaluate the magnitudes of the various coupling coefficients. A flow diagram of this algorithm is shown in Fig. 3.

Table 2 illustrates the comparison between the magnitudes of the components of the rigid rotational modal coefficients with the components of the largest (flexible) coupling coefficients (Qn) for assumed displacements of 1m and 1mm, respectively, for all seven flexible modes contained in the model. (The diameter of the Hoop/Column in deployed configuration is about 122m.) It appears that when the system is operating within the mission specifications (deflections of the order of mm at the antenna mesh supports), the finite element assumptions are valid; when the deflections are of the order of meters, the coupling between the flexible and rigid modes should be included in the mathematical model.

In Table 3 a comparison of the pertinent terms in the generic modal equations is presented, where $R_n/1\ w_7^2$ and $P_n/1\ w_7^2$ represent the main terms (harmonic oscillators) and the principal coupling terms, appropriately normalized, respectively. This comparison shows that the time dependent amplitude of the modes can be approximated as an harmonic oscillator, at least for the ranges of modal amplitudes considered.

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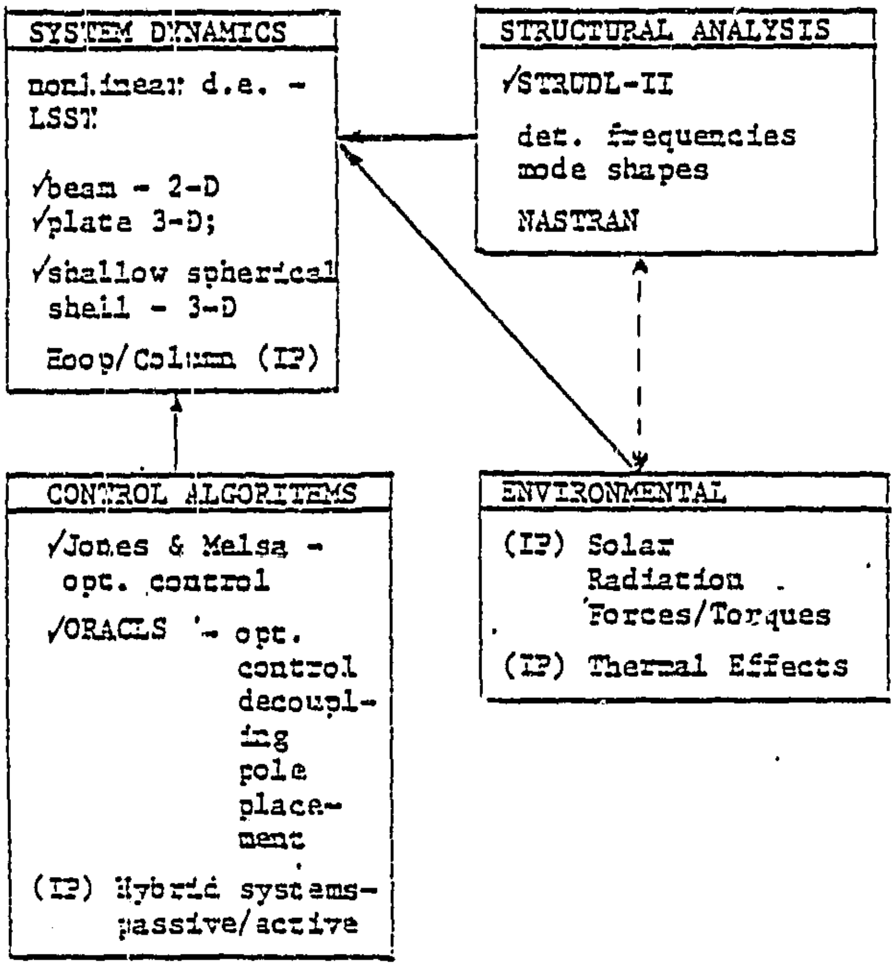

✓operational
IP- in progress

Fig. 1 Development of system software for LSST dynamics analysis

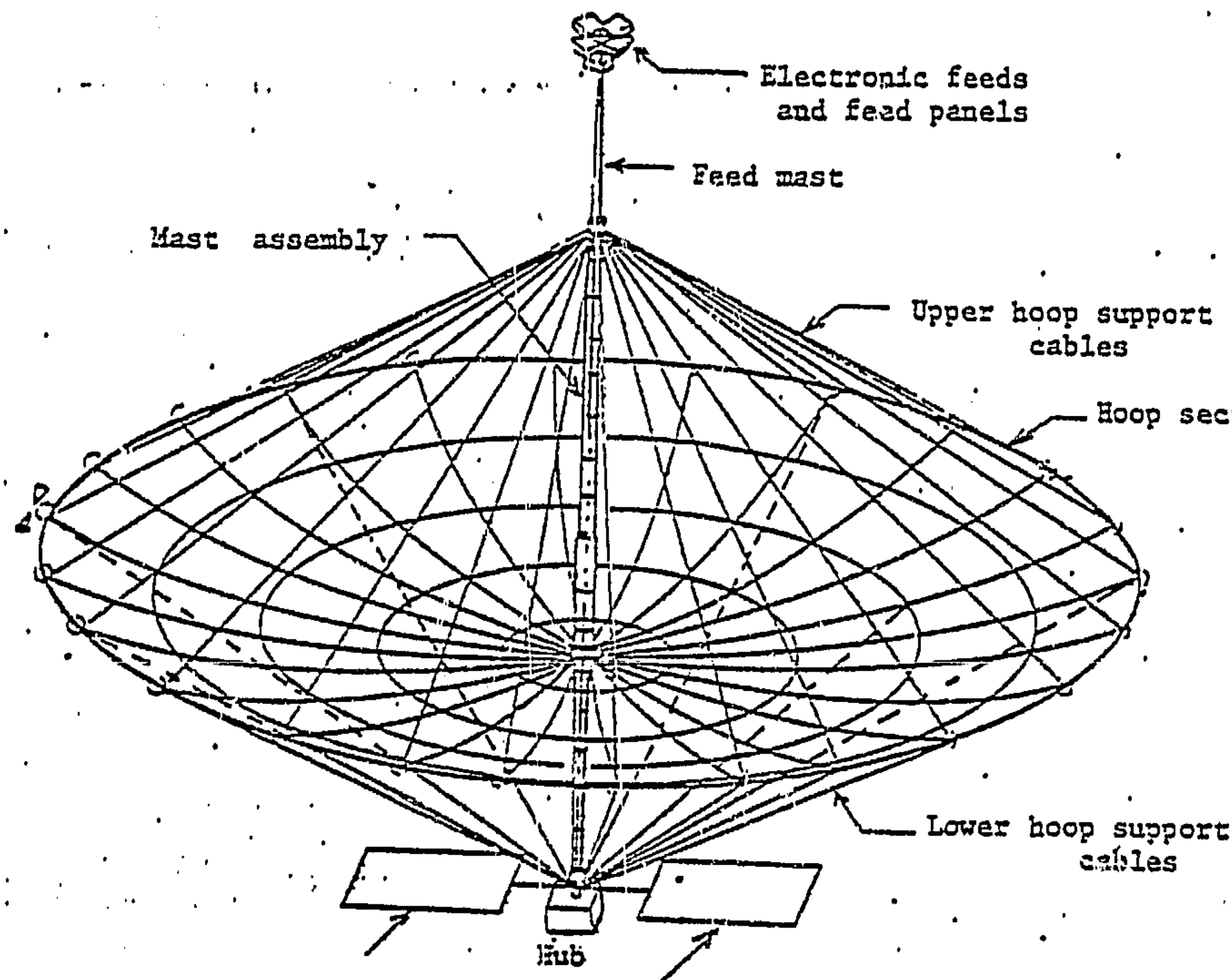

Fig. 2 The Hoop/Column Antenna System

Grid points I.D. No.	Hat Assemb.	Feed Hat Page 77	Lower Solar Panels Page 85	Upper Solar Panel Page 81	Feed Panels Page 82	S band Feed Page 86	S band Reflector Page 82	Lower Electronics Page 84	Upper Electronics Page 84	Hoop Assemb. & Mesh Reflector	Sub. Total at grid points in lbs.
98	320.00	30.00									350.00
99	320.00							1953.00			2273.00
100			144.50								144.50
101			144.50								144.50
109	320.00										320.00
118	320.00										320.00
127		30.00		327.50					1898.00		2255.50
128					548.13						548.13
129					481.87						481.87
130					548.13						548.13
131					481.87						481.87
133						255.00					255.00
134							130.00				130.00
135				327.50							327.50
1100 series										1027.00	1027.00
1200 series										49.00	49.00
1300 series										49.00	49.00
1400 series										49.00	49.00
1500 series										49.00	49.00
										TOTAL	9803.0

* Hoop assembly at grid points 1101, 1107, 1113, 1119; 244.5lbs/point

Table 1 Approximate Mass Distribution at Final Grid Points (Pounds)

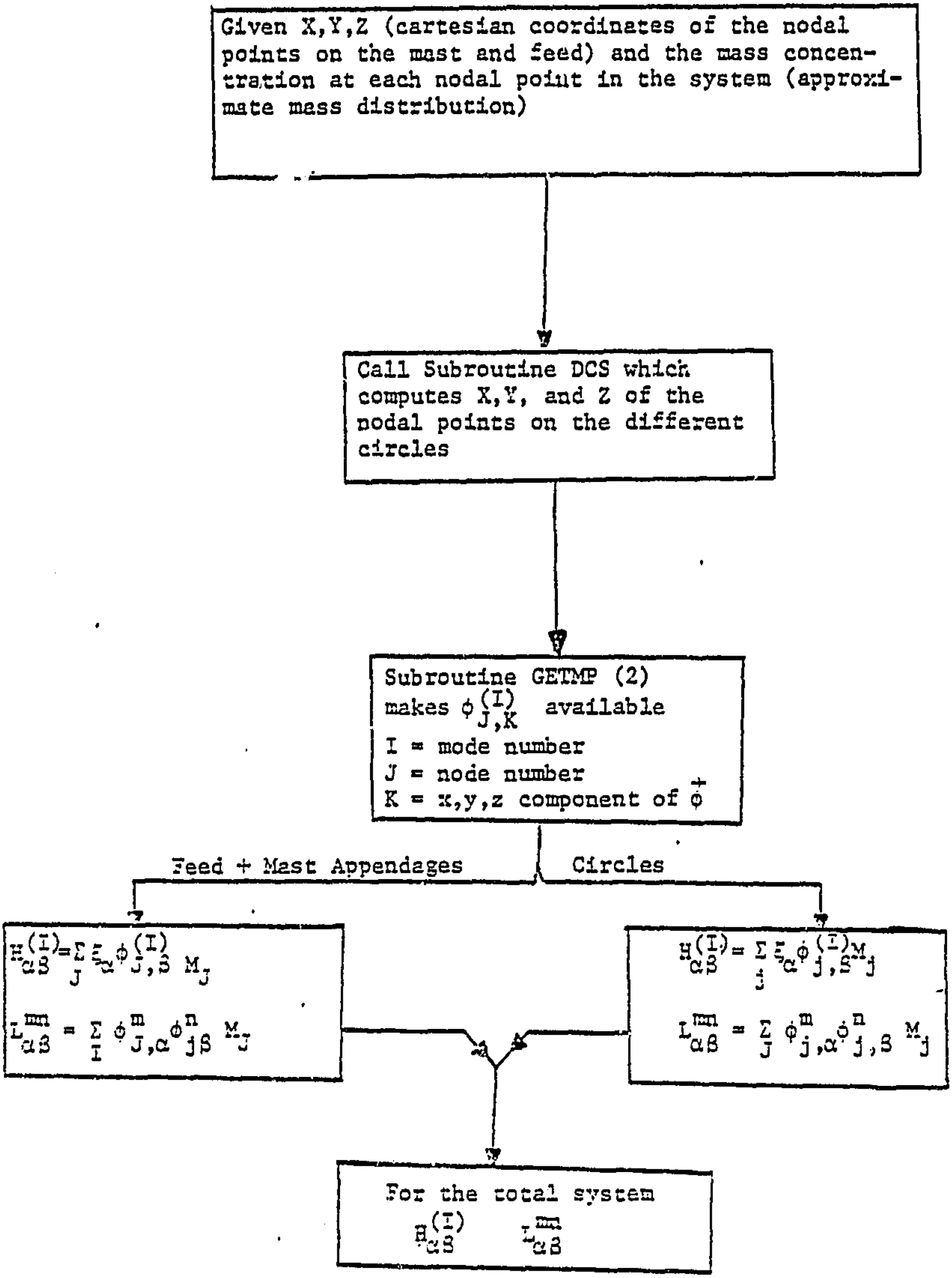

Fig. 3 Flow Diagram Describing the Algorithm Used in the Evaluation of the Coupling Coefficients.

Table 2 Comparison of Pertinent Terms in the Rigid Modal Equations

Direction	R	$\sum_{n=7}^{13} Q_n$
$A_n = 1m$		
X	1.48922 E-01	2.642388 E+00
Y	1.49854 E-01	-8.816196 E+00
Z	9.26317 E-02	-1.480150 E+00
$A_n = 1mm$		
X	1.48922 E-01	2.642388 E-03
Y	1.49854 E-01	-8.816196 E-03
Z	9.26317 E-02	-1.480150 E-03

Table 3 Comparison of Pertinent Terms in the Genetic Modal Equation

A = 1mm

Mode Number	Frequency rad/sec	Modal Mass	$R_n/\ell\omega_7^2$	$P_n/\ell\omega_7^2$
7	0.7489559	153.157	$.629344\text{x}10^{-5}$	$1.9543\text{x}10^{-8}$
8	1.3692409	5.232954	$.210346\text{x}10^{-4}$	$-2.10287\text{x}10^{-10}$
9	1.7471481	3.232954	$.34248\text{x}10^{-4}$	$8.7299\text{x}10^{-7}$
10	3.2148494	0.3046446	$.115957\text{x}10^{-3}$	$-4.901252\text{x}10^{-5}$
11	4.535031	1.992988	$.230747\text{x}10^{-3}$	$-3.46559\text{x}10^{-5}$
12	5.3926659	723.5216	$.350924\text{x}10^{-3}$	$3.226\text{x}10^{-8}$
13	5.7942225	0.6561203	$.376674\text{x}10^{-3}$	$4.678578\text{x}10^{-7}$

A = 1m

Mode Number	Frequency rad/sec	Modal Mass	$R_n/\ell\omega_7^2$	$P_n/\ell\omega_7^2$
10	3.2148494	.3046446	.115957	$.4901252\text{x}10^{-4}$
11	4.535031	1.992988	.230747	$.337854\text{x}10^{-4}$
12	5.5926659	723.5216	.350924	$3.2362\text{x}10^{-8}$