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HOWARD UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

SEMI-ANNUAL STATUS REPORT

May 16, 1981 - Nov. 15, 1981

NASA-NSG-1414, Suppl. 4

THE DYNAMICS AND CONTROL OF LARGE FLEXIBLE SPACE STRUCTURES

by

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Principal Investigator

R. Krishna
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A.S.S.R. Reddy
Graduate Research Assistants

Nov. 15, 1981

N82-12096

I. INTRODUCTION

The present grant represents a continuation of the research completed in the previous grant years (May 1977 - May 1981) and reported in Refs. 1-7.* The dynamics and attitude and shape control of very large, inherently flexible spacecraft systems are being investigated in this research. Increasingly more complex examples have been examined, beginning with a uniform free-free beam, next a free-free uniform plate/platform and finally by considering a thin shallow spherical shell structure in orbit. The examples considered differ from those of other investigators in that: (1) the whole structure is assumed to be flexible throughout, with no rigid hub or main part; and (2) the systems considered are assumed to be earth oriented when in equilibrium - i.e. the inertial angular rate of such systems is very small as compared with the fundamental structural modal frequency.

Once the uncontrolled dynamics has been examined, the policy has then been to include in the model the effects of control devices. For given sets of assumed actuator locations, the controllability of these systems is first established. After that, control laws for each of the actuators are developed based on some or all of the following techniques: decoupling techniques (including distributed modal control); pole placement algorithms; and an application of the linear regulator problem from optimal control theory.

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*For references cited please see list of references page 13.

For the more complex examples of the platform and shell involving many degrees-of-freedom the ORACLS numerical subroutines have been employed to develop various control laws.[8]

Figure 1 illustrates our concept for the development of the necessary system software necessary for the support of LSST dynamics analysis. Items identified with a check mark indicate computer algorithms which are at present operational. Items identified with the symbol (IP) indicate routines that are currently in the process of development.

The proposal[9] for studies to be performed during the period May 16, 1981 - May 15, 1982 called for: (1) further analysis of the environmental effects on large flexible space systems in the absence of very fine precission surface control, in order to better understand the principal expected disturbance effect on such systems; (2) inclusion of the sensor and actuator dynamics into the previously developed models of the orbiting structures where the sensors were assumed to measure each of the output variables perfectly, and the actuators were assumed to provide the desired control time histories without delay; and (3) further application of graph theoretic techniques to determining the controllability, observability, and the eigenvalues (frequencies) of large scale systems.

However, at the time of the final oral presentation in July 1981, it was indicated that a change in the scope of the work was desired by NASA-LRC in order to lend greater support to the dynamics analysis of the propsoed LSST-Hoop/Column antenna system. At this time we were provided with a copy of a letter dated March 30, 1981 from Dr. John Shipley of the Harris Corporation, Melbourne, Florida, to Dr. G. Rodriquez of JPL together with a computer printout of the eigenvalues and eigenvectors associated with a NASTRAN finite element representation (FEM) of the system.

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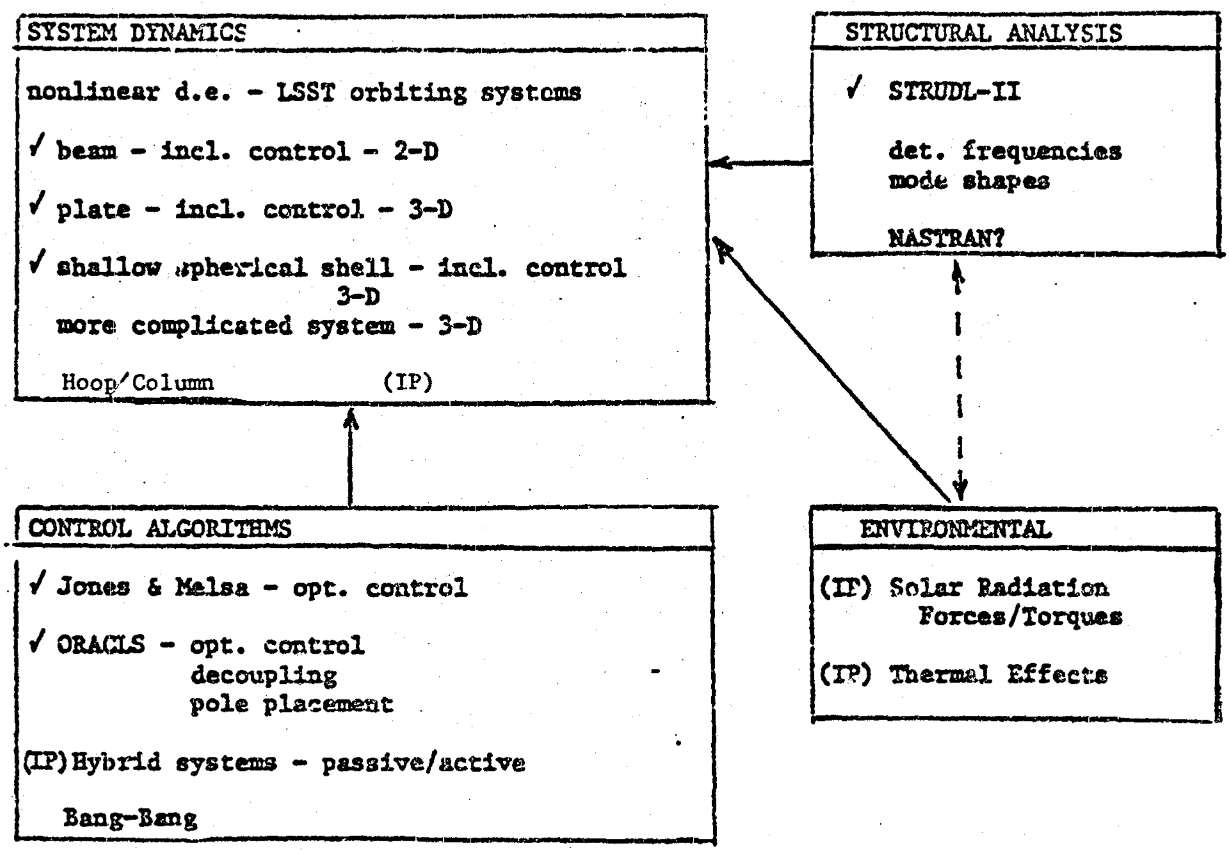
Fig. 1 DEVELOPMENT OF SYSTEM SOFTWARE FOR LSST DYNAMICS ANALYSIS



✓ operational

IP- in progress

We were asked to begin to look at the design of possible control laws for this system and then to determine whether the surface control stringers could, indeed, provide the required tensions. It should be noted that the FEM model does not include the effects of gravity-gradient torques and gyroscopic coupling effects due to the orbital motion.

II. REVIEW OF RESULTS OBTAINED IN THE PERIOD MAY 16, 1981 - NOV. 15,1981

In accordance with the redirection of our effort after mid July 1981, a period was spent to familiarize ourselves with the data provided us. As a result, we prepared a list of ten points of information that we felt would be helpful in the completion of our controls analysis of the LSST Hoop/Column System as documented in our letter to the Technical Monitor dated July 21, 1981 (please see Appendix A). Through the efforts of Dr. Suresh M. Joshi, NASA-LRC modified this request to include not only our questions but some of Dr. Joshi's as well (please refer to letter from Mr. Hamer dated Aug. 5, 1981, with attached request for information as forwarded to the Harris Corporation, Appendix A). The response from the Harris Corp. was transmitted to us via Mr. Hamer's letter dated August 28, 1981 (also contained in Appendix A).

To this date, we have proceeded with the following tasks in preparation for our analysis:

(1) Calculation of the cartesian coordinates of the nodal points on the outer hoop and the four inner circles using a computer routine. There are 24 such points on the hoop and each of the four inner circles for a total of 120 nodal points. The data provided by the Harris Corporation indicated only the radius of each circle and the polar angular coordinate of the node, whereas the direction cosines of the modal shape function are provided in a cartesian system of coordinates for each of the twelve modes to be considered in the truncated model for preliminary controls analysis.

(2) Calculation of the direction cosines for each of the control stringers; first this was done assuming that each such stringer was attached at nodal point number 2 (as shown in the schematic on Enclosure 3, provided to us on July 15, 1981) on the lower mast. A further study of the computer input/output of the FEM program revealed that a circular ring represented by the 700-series of nodes also contains 24 nodal points, and suggests the possibility that the control stringers may actually be attached at the corresponding nodal points on the circle (701^-, 702^-, --- 724^-). The direction cosines were recalculated with the greatest differences observed for those stringers assumed to connect the 500- series of nodes to the 700- series, respectively, as expected.

(3) Using computer assisted logic, we are now in the process of determining the non-zero elements in the control influence matrix (B) whose dimensionality is 1236 rows x 96 columns, assuming that there are 24 lower control stringers connected to each of the four circles represented by the nodes: 201^-,--- 224^-, 301^-, --- 324^-, --- , 501^-, ---, 524^-, and that the FEM is based on a total of 216 nodal points.

(4) Further clarification of some of the questions raised in (3) has been requested together with a request for the tape containing the elements of the modal "ϕ" matrix of dimensionality, 1236x12. We understand NASA-LRC will provide this information on tape compatible with the Howard IBM system in the near future.

In addition to the tasks described above in direct support of the LSST Hoop/Column Controls Analyses the following additional efforts have been initiated:

(5) At the suggestion of NASA-LRC, we have re-examined the models of the orbiting plate and shell to determine the effects of the gravity-gradient and orbital dynamics on the closed loop poles of these models where the control law was initially developed based on models vibrating out-of-orbit. The control laws thus developed, primarily for vibration control, were then inserted into our previously developed models which contain both first order gravity-gradient and orbital dynamic coupling effects. Changes in the location of the closed-loop poles and in the required force-time histories were noted. In all cases there is a general tendency for some of the rigid modes to shift toward the imaginary axis (which could cause instability for the less robust systems) when the gravity-gradient and orbital effects are superimposed. In general, there is no noticeable shift in the poles corresponding to the flexible modes. Furthermore, for the cases of the controlled shell, some of the peak forces and total force impulses are increased when the gravity-gradient and orbital effects are included. When the time constant of the least damped mode is comparable to the orbital period in magnitude, the shift in the closed loop poles is more pronounced. As expected, for the more robust systems, the relative effect of this shift is less noticeable, but at the expense of greater control forces.

(6) The evaluation of the coefficients of the coupling terms in both the rigid rotational equations and the elastic generic modal equations has been initiated. These terms account for coupling between the rigid and flexible modes due to both gravity and orbital gyroscopic effects as well as intramodal coupling.

For the FEM provided by the Harris Corp., these terms involve the calculation of certain volume integrals[2,4], dependent on both the modal shape functions and the mass distribution, which now must be approximated by a summation of discrete terms taken at each of the nodal points in the FEM simulation. For these purposes, it is necessary to know the mass distribution at each of the nodal points in the model and this information has been requested. By comparing the magnitude of these coefficients with the other coefficients in these equations, one can assess the need for incorporating the effects of orbital coupling and gravity-gradient into the previously developed FEM, before designing control algorithms. In connection with this effort, the tape containing the elements of the "ϕ" matrix referred to in (4), will also be required.

(7) Following our original proposal[9], preliminary work has been initiated in developing expressions for the forces and torques on flexible orbiting structures. For the case of a completely absorbing free-free beam the expressions involved can be integrated analytically whereas for a completely reflecting surface an approximate expression is developed under the assumption of small slopes as compared with over-all beam lengths.

III. PRESENTATION AND PUBLICATION OF RESULTS

A final presentation of last year's grant was given at Langley on July 15, 1981 and a final report was published: The Dynamics and Control of Large Flexible Space Structures IV, by P.M. Bainum, V.K. Kumar, R. Krishna, and A.S.S.R. Reddy, August 1981. It is our understanding that the Technical Officer plans to issue this document as a NASA Contract Report (CR). A visit to Langely during the period Nov. 16-18 is planned in response to an invitation to attend the Third Annual Technical Review - Large Space Systems Technology. During this time a brief informal exchange with the Technical Officer is planned. A mid-term presentation of the current year's progress is planned, tentatively on Dec. 10-11, 1981.

During the six month reporting period two papers based on last year's grant were present at professional society meetings:

(1) "Graph Theory Approach to the Eigenvalue Problem of Large Space Structures," by A.S.S.R. Reddy and Peter M. Bainum, Third VPI & SU/AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, Blacksburg, Va., June 15-17, 1981.

(2) "The Dynamics of Large Flexible Earth Pointing Structures with a Hybrid Control System," by Peter M. Bainum, R. Krishna, and V.K. Kumar, AAS/AIAA Astrodynamics Specialist Conference, Lake Tahoe, Nevada, August 3-5, 1981, Paper No. 81-122.

The following papers previously presented at professional society meetings have been accepted for journal publication:

(3) "Control of a Large Flexible Platform in Orbit," by A.S.S.R. Reddy, P.M. Bainum, H.A. Hamer, and R. Krishna, to appear, Journal of Guidance and Control, Nov. - Dec. 1981.

(4) "On the Dynamics of Large Orbiting Flexible Beams and Platforms Oriented along the Local Horizontal," by Peter M. Bainum and V.K. Kumar, to appear, Acta Astronautica.

Another paper has been tentatively accepted, pending a minor revision:

(5) "On the Motion of a Flexible Shallow Spherical Shell in Orbit," by V.K. Kumar and P.M. Bainum, tentatively accepted for publication in the AIAA Journal.

The Principal Investigator has also participated in the following invited lectures and panel discussions:

(6) Invited Panelist, Third VPI & SU/AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, Blacksburg, Va., June 15-17, 1981.

(7) "The Dynamics and Control of Large Flexible Earth Pointing Orbiting Systems," Catholic University of Louvain, Applied Mechanics Unit, Louvain, Belgium, Sept. 14, 1981.

(8) "The Dynamics and Control of Large Flexible Space Systems," Rice University, Departments of Mechanical and Civil Engineering, Houston, Texas, October 30, 1981.

IV. PLANS FOR THE NEXT REPORTING PERIOD

Under the assumption that the IBM compatible tape containing the elements of the ϕ matrix will be supplied by NASA-LRC in the near future, we will proceed with the controls analyses of the LSST Hoop/Column System. It is anticipated that some preliminary numerical results for the case where the number of control stringers is equal to the number of modes in the truncated model (12) would be completed during the period Nov. 16, 1981 - May 15, 1982. For this special case control laws can be developed based on decoupling techniques as well as the pole placement algorithm using the ORACLS[8] routines. For each control law and sets of arbitrary (small) initial displacements, the required control (tension) force time histories will be obtained to determine if all tension levels are within the maximum allowable. This study will also include the variation in the location(s) of those stringers that can be assumed to provide surface control.

Depending on the results of this initial effort, a number of control stringers different from the number of modes in the truncated model can be assumed with control laws based on the ORACLS numerical techniques. It is anticipated that this effort could continue into the next grant year, where an attempt could be made to optimize both the number and location of active control stringers. As an alternative to using the tape containing the elements of the ϕ matrix, it would be necessary to prepare hand-punched input cards of this data requiring of the order of 1000 input cards, each of which would need to be verified to avoid numerical error.

It is hoped that the evaluation of all the coefficients in the coupling terms in the rigid modal equations and the generic modal equations for one of the twelve modes can be completed during the next reporting period, including at least one of the series of coefficients involving coupling of that mode with one of the other modes. Depending on these results, selected coefficients corresponding to the other modes will be evaluated. If it appears that the magnitudes of some of these coefficients are the same order as those of the remaining terms in the equations, it may be necessary to completely evaluate all of the coupling coefficients for each of the twelve modes. It is anticipated that this effort would also continue into the 1982-83 grant year.

Numerical evaluation of the effect of solar radiation torques on the flexible orbiting beam should be completed during the next six months and should provide insight into the treatment of solar radiation torques on the more complex structures.

REFERENCES

1. Bainum, P.M. and Sellappan, R., "The Dynamics and Control of Large Flexible Space Structures," Final Report NASA Grant: NSG-1414, Part A: Discrete Model and Modal Control, Howard University, May 1978.

2. Bainum, P.M., Kumar, V.K., and James, Paul K., "The Dynamics and Control of Large Flexible Space Structures," Final Report, NASA Grant: NSG-1414. Part B: Development of Continuum Model and Computer Simulation, Howard University, May 1978.

3. Bainum, P.M. and Reddy, A.S.S.R., "The Dynamics and Control of Large Space Structures II," Final Report, NASA Grant NSG-1414, Suppl. 1, Part A: Shape and Orientation Control Using Point Actuators, Howard University, June 1979.

4. Bainum, P.M., James, P.K., Krishna, R., and Kumar, V.K., "The Dynamics and Control of Large Flexible Space Structures II," Final Report, NASA Grant NSG-1414, Suppl. 1, Part B: Model Development and Computer Simulation, Howard University, June 1979.

5. Bainum, P.M., Reddy, A.S.S.R., Krishna, R., and James, P.K., "The Dynamics and Control of Large Flexible Space Structures - III," Final Report, NASA Grant NSG-1414, Suppl. 2, Part A: Shape and Orientation Control of a Platform in Orbit Using Point Actuators, Howard Univeristy, June 1980.

6. Bainum, P.M., and Kumar, V.K., "The Dynamics and Control of Large Flexible Space Structures - III," Final Report, NASA Grant NSG-1414, Suppl. 2, Part B: The Modelling, Dynamics, and Stability of Large Earth Pointing Orbiting Structures, Howard University, Sept. 1980.

7. Bainum P.M., Kumar, V.K., Krishna, R., and Reddy, A.S.S.R., "The Dynamics and Control of Large Flexible Space Structures-IV," Final Report, NASA Grant NSG-1414, Suppl. 3, Howard University, August 1981.

8. ORACLS - A System for Linear-Quadratic-Gaussian Control Law Design, by Ernest S. Armstrong, NASA Technical Paper 1106, April 1978.

9. Bainum, P.M., "Proposal for Research Grant on: The Dynamics and Control of Large Flexible Space Strucures - V," Howard Unversity, (Submitted to NASA), Jan. 15, 1981.

Appendix A

Correspondence Related to Request for Information on the LSST Hoop/Column System.

THE SCHOOL OF ENGINEERING / HOWARD UNIVERSITY
Washington, D. C. 20059

MECHANICAL ENGINEERING
Telephone (202) 636-6600

July 21, 1981

Mr. H.A. Hamer, Technical Officer NASA Grant NSG-1414
402 Woodroof Road
Newport News, Va. 23606

Dear Mr. Hamer:

In accordance with our telephone conversation today I am writing to request additional information in connection with our future controls analysis of the LSST Hoop/Column System as modelled by a finite element structural model.

The following information we feel is absolutely necessary to help us in the completion of this task:

1. The exact coordinates, with system of units defined, which represent the location of the points on the ring(s) where the surface control stringers are attached. Do some or all of these points correspond to the nodal points on the radius used in connection with the finite element computer analysis as generated by the Harris Corp.? If not, we would need both the coordinates of the stringer attachment points as well as the coordinates of the NASTRAN nodal points.

2. We understand that there are either 16 or 24 surface control stringers attached to each of the five rings, for a total of 80 or 120 control members. Can we assume that the tension in each of these members be controlled separately and independently of the tension in any other member? If not, which of the surface control stringers are controlled dependent on the control in other members? The answer to this question will help us to ascertain the total number of independent tension control devices.

3. What is the normalizing factor relating the frequencies to the eigenvalues - i.e. for the seventh mode, $\omega_7 = 0.101$ Hz and the eigenvalue is 0.04057837., etc.?

The following information would be helpful but not absolutely necessary for the completion of this task:

4. A knowledge of the elements contained in the mass and stiffness matrices. Presumably this was calculated prior to the eigenvalue-eigenvector calculations. This information could help as a check in our calculations.

5. Any preliminary or final reports issued by the Harris Corp., particularly in the area of the structural dynamics analysis.

6. A description (users' manual) of the NASTRAN MSC-60A version used in this study.

7. Is the center of the X,Y,Z coordinate system taken at element number 10 on the mast, or slightly above this element? (Enclosure 3)

8. Are the generalized masses, damping ratios (on page 20 handout), and the computer listed eigenvalues for the twelve modes given in a consistent system of units? We note the generalized masses are given in the English system of units, whereas the outer radius of the structure is apparently 64 meters.

9. Later on in the study we will need to know the nominal tension in the control stringers when in the nominal (unstretched) position as well as the maximum tensile strength of these elements.

10. A knowledge of the overall area/mass ratio and surface element reflectivities would enable us to perform a preliminary analysis of the solar radiation pressure effects.

We understand that our task is first to determine the control influence matrix for the truncated 12 mode system which could have a dimensionality as large as 804x120 or (804x80) and then proceed with the development of control laws using the ORACLS algorithms. While we are waiting for the requested necessary information we will proceed with the final phases of our final report, and also with computer simulations of the control of the plate model based on the exclusion of the orbital and gravity-gradient effects and then compare these results with our previous results. When these computer results are available I ill contact you again.

Thank you for your kind attention to this matter.

Sincerely yours,

Peter M. Bainum

Peter M. Bainum
Professor of Aerospace Engrg.
Director, Graduate Studies
Principal Investigator

cc: Mr. V.K. Kumar
Mr. R. Krishna
Mr. A.S.S.R. Reddy

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia
23665

NASA

AUG 5 1981

Reply to Attn of 152E

Howard University
School of Engineering
Attn: Professor Peter M. Bainum
Mechanical Engineering
Washington, DC 20059

Dear Prof. Bainum:

Through the efforts of Dr. Suresh M. Joshi, we have revised your recent letter of request for additional information on the model of the LSST Hoop/Column System. We believe that this will give you most of the information needed for control analyses of this antenna. I am enclosing a copy of this revised letter. Richard Russell of the LSS Project Office has sent this letter by datafax to the Harris Corporation. Personnel from Langley will visit the Harris Corporation on Thursday, August 6, 1981, and, hopefully, will be able to bring back most of this information. In any event, I will call you upon their return and bring you up-to-date on your request.

In reference to your question in item number (3) of your letter, the eigenvalue 0.4057837 is the frequency squared in radians/second.

Sincerely,

Harold A. Hamer

Harold A. Hamer
Aero-Space Technologist,
Stability and Control Branch,
FDCD

Enclosure

Reference: Letter and data sent by Dr. John Shipley to Dr. G. Rodriquez, Jet Propulsion Laboratory, March 30, 1981.

The following information is necessary for two separate investigations to be conducted by NASA Langley on control analyses of the LSST Hoop/Column System.

1) A clearer definition of the coordinate system and origin is needed. For example, is the center of the X,Y,Z coordinate system taken at element number 10 on the mast, or slightly above this element? (Enclosure 3). We need the manner in which the elements and nodes are numbered, and how does one find out the coordinates of any nodal point. Do some or all of the points on the ring(s) where the surface control stringers are attached correspond to the nodal points on the radius used in connection with the finite element computer analysis as generated by the Harris Corp.? Which ones are the control stringers and has their interaction against the mast (caused by pulling them) been incorporated in the model? We need the numbering and coordinates of points of attachment of the stringers (both ends).
2) We understand that there are either 16 or 24 surface control stringers attached to each of the five rings, for a total of 80 or 120 control members. Can we assume that the tension in each of these members can be controlled separately and independently of the tension in any other member? If not, which of the surface control stringers are controlled dependent on the control in other members? The answer to this question will help us to ascertain the total number of independent tension control devices.
3) We need an explanation of the printout of modal data (symbols, units, etc).
4) How does one calculate displacement (translations and rotations) at any node from the data provided?

The standard modal model used by control engineers is of the form:

$$\ddot{q} + D\dot{q} + \Lambda q = \Phi^T f$$

It would be immensely helpful if the printout were explained with the help of an example which would demonstrate how to obtain the row of the Φ^T matrix corresponding to a certain mode. Also, the units of f, and of displacements (defined by)

$$y = \Phi q$$

should be explained. More than one example may be necessary in order to accomplish this. (An NASA sample report on a plate model will be sent next week, which shows the type of information needed.)

5) In the "Structural Model Elastic Modes" summary sheet (page 20), it seems that Mode No. 16 should be 17 and 17 should be 18, because in checking the Plot Module printouts (as well as the Real Eigenvector printouts), Mode No. 16 should have a frequency of 3.357 Hz. Is this current and , if so, what does the 4.616 value in the summary sheet relate to?

6) We need to know the nominal tension in the control stringers when in the nominal (unstretched) position as well as the maximum tensile strength of these elements. Are there any nonlinearities in the stringers, or can they be assumed to be linear force-producing devices for surface control? For example, does the slack caused by loosening a stringer appear as a nonlinearity, or are the stringers normally in tension, and therefore can be considered linear around the nominal operating tension point?

The following information would also be helpful:

7) A knowledge of the elements contained in the mass and stiffness matrices. Presumably this was calculated prior to the eigenvalue-eigenvector calculations. This information could help as a check in our calculations.

8) Are the generalized masses, damping ratios (on page 20 handout), and the computer listed eigenvalues for the twelve modes given in a consistent system of units? We note the generalized masses are given in the English system of units, whereas the outer radius of the structure is apparently 64 meters.

9) We would appreciate plots of the mode shapes. Also, any preliminary or final reports issued by the Harris Corp., particularly in the area of the structural dynamics analysis.

10) A knowledge of the overall area/mass ratio and surface element reflectivities would enable us to perform a preliminary analysis of the solar radiation pressure effects.

Thank you

July 31, 1981

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia
23665

NASA

INFORMAL LETTER

Reply to Attn of 152E

August 28, 1981

Professor Peter M. Bainum
The School of Engineering
Department of Mechanical Engineering
Howard University
Washington, DC 20059

Dear Dr. Bainum:

I am sending you the results of our request for information on the LSST Hoop/Column System. Dr. Joshi and I think that most of our questions have been answered. I still have not been able to obtain the NASTRAN user's manual. We are attempting to get answers to the following three questions:

1) While simulating a control stringer force "F" at a hoop node, should a force "-F" be applied to the mast node No. 1 to represent the reaction force?

2) How do you use a "two-for-one" model for the whole antenna?

3) Are there any <u>upper</u> control stringers?

If you have any questions, please do not hesitate to call me.

Sincerely,

Harold A. Hamer

Harold A. Hamer
Aero-Space Technologist,
Stability and Control Branch, FDCD

Enclosure

P.S. In reference to question 10, I will get you this data from Richard Russell (he is now on leave).

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(Enclosure 1)

RESPONSES TO MESSAGE NUMBER 233 LaRc TO HARRIS

1. A) A clearer definition of the coordinate system and origin is needed. For example, is the center of the X,Y,Z coordinate system taken at element number 10 on the mast, or slightly above this element? (Enclosure 3).

(Response) The reference is on the mast in the plane of the hoop.

B) We need the manner in which the elements and nodes are numbered, and how does one find out the coordinates of any nodal point.

(Response) The elements and nodes are listed in the NASTRAN listing (transmitted to JPL on 3-30-81) of BULK DATA. The coordinates of each node are listed on the GRID cards.

C) Do some or all of the points on the ring(s) where the surface control stringers are attached correspond to the nodal points on the radius used in connection with the finite element computer analysis as generated by the Harris Corp.?

(Response) Question is not clear. I believe answer is all.

D) Which ones are the control stringers and has their interaction against the mast (caused by pulling them) been incorporated in the model?

(Response) Elements 101-124, 201-224, 301-324, 401-424, 501-524. Yes.

E) We need the numbering and coordinates of points of attachment of the stringers (both ends).

(Response) Hoop nodes: 101-124, 201-224, 301-324, 401-424, 501-524.
Mast nodes: 701-724.

2. A) We understand that there are either 16 or 24 surface control stringers attached to each of the five rings, for a total of 80 or 120 control numbers.

(Response) The model is a two-for-one model of a 48 gore antenna. There are 24 gores in this model, and it would be possible to have 24x5 adjustments on control cords.

B) Can we assume that the tension in each of these members can be controlled separately and independently of the tension in any other member? If not, which of the surface control stringers are controlled dependent on the control in other members? The answer to this question will help us to ascertain the total numbe of independent tension control devices.

(Response) Yes.

3. A) We need an explanation of the printout of modal data (symbols, units, etc.).

(Response) The modes are printed out one at a time six degrees of freedom at each node. The symbols are Arabic numerals and modern English letters. Units for the mode shapes are inches for translations and radians for rotations.

4. A) How does one calculate displacement (translations and rotations) at any node from the data provided?

(Response) Given numerical values for dimensionless nodal coordinates $\begin{Bmatrix} q_1 \\ \vdots \\ q_n \end{Bmatrix}$, physical rotations are by given the matrix equation

$$\left\{ y \begin{pmatrix} \text{In-Trans} \\ \text{Rad-Rotations} \end{pmatrix} \right\} = \left[\phi \begin{pmatrix} \text{In-Trans} \\ \text{Rad-Rotations} \end{pmatrix} \right] \begin{Bmatrix} q_1 \\ \vdots \\ q_n \end{Bmatrix}$$

The max value in any column of $[\phi]$ is unity.

B) The standard modal model used by control engineers is of the form:

$$\ddot{q} + D\dot{q} + \Lambda q = \Phi^T f$$

It would be immensely helpful if the printout were explained with the help of an example which would demonstrate how to obtai the row of the Φ^T matrix corresponding to a certain mode.

(Response) See 3 above.

C) Also, the units of f, and of displacements (defined by)

$$y = \Phi q$$

should be explained. More than one example may be necessary in order to accomplish this. (An NASA sample report on a plate model will be sent next week, which shows the type of informatic needed.)

(Response) The units of f would be Lbs. to be consistant with the NASTRAN run. Displacements are defined in 4A above.

5. A) In the "Structural Model Elastic Modes" summary sheet (page 20), it seems that Mode No. 16 should be 17 and 17 should be 18, because in checking the Plot Module printouts (as well as the Real Eigenvector printouts), Mode No. 16 should have a frequency of 3.357 Hz.

(Response) The correct frequency for mode 16 is 3.357 Hz.

B) Is this current? correct

Response) This is current.

C) And if so, what does the 4.616 value in the summary sheet relate to?

Response) 4.616 Hz is the frequency of mode 19. The mode shapes were not calculated for modes 19 up.

6. A) We need to know the nominal tension in the control stringers when in the nominal (unstretched) position as well as the maximum tensile strength of these elements.

Response) Information in attached table.

B) Are there any nonlinearities in the stringers, or can they be assumed to be linear force-producing devices for surface control? For example, does the slack caused by loosening a stringer appear as a nonlinearity, or are the stringers normally in tension, and therefore can be considered linear around the nominal operating tension point?

Response) The control cords are linear elastic elements when near their nominal tension value. I do not know what the term "linear forces-producing devices" means.

The following information would also be helpful:

7. A knowledge of the elements contained in the mass and stiffness matrices. Presumably this was calculated prior to the eigenvalue-eigenvector calculations. This information could help as a check in our calculations.

Response) The structural input is contained in the NASTRAN list of BULK DATA (transmitted to JPL on 3-31-81). The printout of mass and stiffness matrices would be rather large, but could be obtained by making another computer run. This data is on the tape sent to JPL on 3-9-81.

8. Are the generalized masses, damping ratios (on page 20 handout), and the computer listed eigenvalues for the twelve modes given in a consistent system of units? We note the generalized masses are given in the English system of units, whereas the outer radius of the structure is apparently in meters.

Response) All units are in the (IN, LBS, SEC) system.

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9. We would appreciate plots of the mode shapes. Also, any preliminary or final reports issued by the Harris Corp., particularly in the area of the structural dynamics analysis.

(Response) JPL was given plots of the mode shapes for this model at the LSST Program Review in Feburary and the LMSS Presentation in May.

10. A knowledge of the overall area/mass ratio and surface element reflectivities would enable us to perform a preliminary analysis of the solar radiation pressure effects.

(Response) This data was transmitted to R.A. Russell LaRc on July 6, 1981.

Pretensions and Tensile Strengths
for the Two-for-One Dynamic Model

lement No.*	101-124	201-224	301-324	401-424	501-524
ominal Tension (LBS)**	10.03	49.41	6.22	10.82	13.33
ensile Strength F_{TU}) in LBS.**	184	920	184	184	184

Element numbers are per enclosure 3 of letter Shipley to Rodriques, Jet Propulsion Laboratory, 3-30-81.

Because this is a two-for-one model (24 gore's), these values are twice the actuals for a 48 gore antenna. Also, because the dynamic model has a single surface representing both the front surface and the rear drawing surface of the actual antenna, the tensions differ somewhat from those of the actual antenna because of the model approximation.

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