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NASA/HOWARD UNIVERSITY LARGE SPACE STRUCTURES INSTITUTE

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Submitted by

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Director, NASA/Howard U. LSSI

March 22, 1984

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

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OVERVIEW OF NASA/HU LSSI

The purpose of the Institute is to provide the NASA/Langley Research Center with basic research needs to support their large space structures interests. The objectives of the Institute are (1) to create a body of knowledge contingent to an understanding of the engineering behavior of large space structures; and (2) to populate the field of large space structures engineering with persons who are capable researchers and who share NASA/Langley's interests in such structures. The focus of the Institute is on methods of structural analysis, control and optimization of large flexible systems. The aim is to integrate these methods to create a center of excellence in the area of control and optimization of large structural systems modeled as continuous media. The mission of the Institute, then, is to fulfill these objectives within the framework of the mission of Howard University which is as follows:

The mission of Howard University, expanded since the establishment of the University, is two-fold. First, it is to provide quality education at a reasonable cost for any student irrespective of race, creed, or national origin, but with emphasis upon the provision of educational opportunities for those students who may not otherwise have an opportunity to acquire an education of the type provided at Howard. Second, it is to assist, through full utilization of its research resources, in the development of solutions to human and social problems.

The methodology by which the Institute can realize its mission is outlined as follows:



1. An administrative unit is organized to manage the work of the institute. This unit consists of (a) a Director who assumes responsibility for the realization of the Institute's mission, and assumes accountability for the activities of the Institute's resources - human, physical and fiscal resources. The Director also initiates the recruitment of all key personnel; (b) an Administrative Assistant who performs both office management and secretarial duties, and manages the technical typing functions as prescribed by the Institute's researchers and a secretary who performs secretarial duties for the Institute. (See Overview Appendix A: LSSI Organizational Chart).

2. An Advisory Committee which consists of Howard faculty, NASA personnel, other university and industrial scholars, has been formed. The Advisory Committee advises the Director on all matters the Committee considers within its concern, and approves of any new directions the Institute proposes to take. (See Overview Appendix B: LSSI Advisory Committee).

3. On-going research projects with NASA will be continued, but secretarial work will be pooled and physical facilities (eg. office space of graduate students, computer hardware and software, etc.) will be shared. Also, new research projects will be initiated as recommended by the Director and approved by the Advisory Committee. Each project is directed by a Principal Investigator and is supported by as many Graduate Research Assistants as approved. It is anticipated that the stipends of such assistants will be supplemented by departmental budgets. (See Part II: Organization of Research Projects).

4. Graduate Student Fellowships are made available to students who are deemed capable of making superior contributions to the creative efforts research projects. These students are recruited by the Institute Director and appointed to a project (see #3 above) with the approval of the Advisory Committee. The Fellows are U.S. citizens and full-time graduate students, and their research duties will be to write theses on topics specified by the principal investigators of the projects to which they are assigned. Each fellow will spend several weeks during the summer doing research in residence at the NASA/Langley Research Center in Hampton, Virginia. It is anticipated that at least one Fellow will be assigned to each research project. It is hoped that these Fellows, upon completion of their M.S. and/or Ph.D. studies at Howard, will join the research staff at the NASA/Langley Research Center.

5. A revolving 1-year Post-Doctoral Fellowship program has been established in order to bring special scholarly activity into residency at Howard in order to enhance the breadth and depth of the Institute's research. Such Fellows may be either young scholars who possess unique up-to-date skills which are relevant to the Institute's research plan; or senior scholars whose experience and "eye-to-the future" could enhance the quality of the Institute's research. Such Fellows are recommended by the principal investigators, through the Director, to the Advisory Committee. It is anticipated that the presence of such scholars would invite the various engineering departments to supplement the Institute's financial burden of acquiring them. The

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resumes of two candidates for this position are included in this document (see Part III: HU Human Support Plan).

6. The equipment needs of the Institute are in the area of computer graphics. These needs are described in the Physical Support Plan of this document.

7. Such a concentrated effort on the part of faculty and students in the area of large space structures would naturally impact on the engineering curriculum at Howard. Therefore, in-house resources would be used to establish new courses such as Control of Flexible Bodies, Megamechanics, etc. Such courses would be offered by one of the existing engineering departments as a regular part of their degree-granting program.

Some significant activities of the LSSI that will be continued are as follows:

1. SEMINARS. The HU Institute PI's meet weekly to (a) present technical seminars aimed at achieving a truly interdisciplinary effort focused on control and optimization of large lattice systems using -- in part -- the LCM; and (b) to conduct business. The RPI and MIT PI's are kept informed of these seminars and a mailing list of other interested parties (ie. HU students and faculty from other universities, etc.) has been formulated. The Institute sponsored a seminar on Wednesday, November 16, 1983 by Dr. K.C. Park, Senior Scientist, Lockheed Missiles and Space Corp. who spoke on the topic "Computational Issues in Large Space Structures Technology. (See Overview Appendix C: Institute Lectures).

2. LECTURE/RECRUITING TOUR. Between February 22, 1984 and March 2, 1984 the HU PI's conducted a nation-wide lecture/recruiting tour. The purposes of the tour were (a) to make scholarly contacts with persons who are involved in research work of interest to the Institute; and (2) to recruit qualified graduate students, including minority students, to the Institute. Nine universities were visited including Stanford, Prairie View A&M, and Southern University. Whereas results of the recruiting effort of the tour are as yet forthcoming, the PI's agree that the tour was a success and another tour is planned for the Fall of 1984. (See Overview Appendix D: 1st LSSI Lecture/Recruiting Tour).

3. DOD PROPOSAL. On behalf of the LSSI and other Howard faculty, the Institute Director submitted a proposal to AFOSR entitled "DOD/HU Interactive Computer Graphics Facility for Space Research - December 15, 1983. This proposal was for computer hardware dedicated to computer graphics for space research. The amount of the proposal was \$350K and, if awarded, would establish the LSSI Director as PI for the implementation and use of this equipment. Notification of acceptance is expected on on about April 15, 1984.

4. ADVISORY COMMITTEE MEETINGS. The first Advisory Committee meeting was on Monday, October 17, 1983 in Washington, D.C. at Howard Univesity. The second meeting is scheduled for March 23, 1984 at the NASA/Langley Research Center in Hampton, Virginia.

5. **STUDENT TOURS AT NASA/LANGLEY.** A tour was conducted on January 26, 1984 for two Institute research students at NASA/Langley. The two LSSI fellows, Cheryl McKissack and Stanley Woodard, will spend several weeks each in residence at the Center this summer. Other tours are planned for the Fall of 1984.

6. **NEW LSSI PROJECT.** A new project has been added to the LSSI. The PI of this project is Dr. I.W. Jones. The project is in the area of deployable dynamics and Dr. K.C. Park of Lockheed will consult with Dr. Jones (See Organization of Research Projects). It is expected that by the Fall of 1984 Dr. Jones and Dr. Park will generate an HU-LSSI/Lockheed proposal to support their work.

7. **OFFICE SPACE UTILIZATION.** The office space needs of the LSSI are driven by (1) needs of the LSSI Administrative Assistant; (2) needs of the LSSI Secretary; (3) work space for LSSI terminals, printer, xerox machine, etc.; and (4) storage requirements. The present situation is illustrated by the diagram in Overview Appendix E.1. The renovation plan is illustrated in Overview Appendix E.2. The costs of effecting this plan are borne by the LSSI, the Civil Engineering Department and the Office of the Dean of the School of Engineering. (Note: Though this plan was initiated in September, 1983, the HU Physical Plant did not respond with an estimate until January, 1984. However, the Physical Plant has responded to a memorandum from the President directing it to place research needs on a high priority. The new Chief of Operations and Maintenance of the Physical Plant, Mr. Hight, has been designated as the person responsible

to the Director for expediting research requests. Relations with the Physical Plant have since been very good and responsive to our needs).

8. LSSI PRODUCTIVITY TO DATE. The means suggested for measuring the output of the LSSI are (1) presentations made at conferences; (2) papers in scholarly journals; and (3) student acquisitions of graduate degrees. A status report of progress toward producing this output is described in Overview Appendix F in bibliographic form.

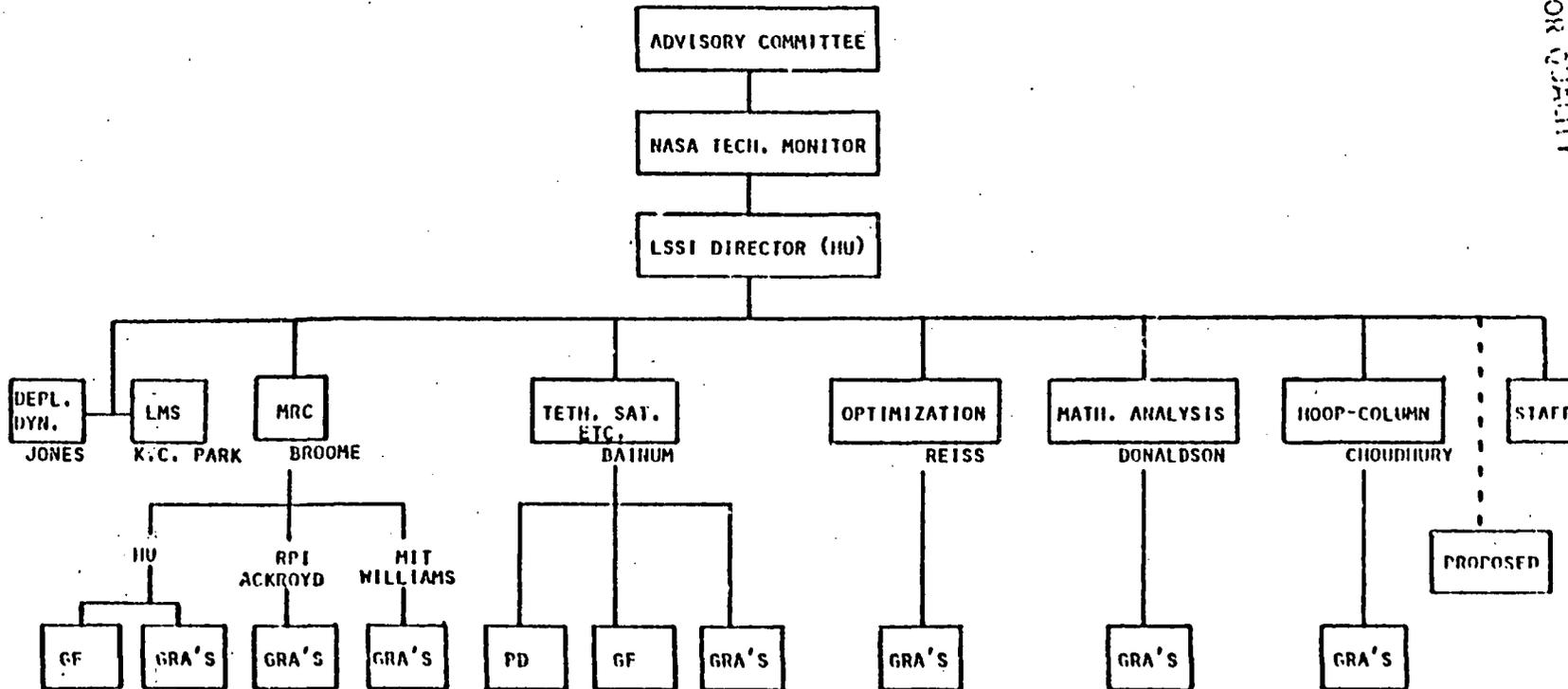
9. PROGRESS TOWARD LSSI FOCUS. As mentioned earlier, the aim of the LSSI is to form a truly interdisciplinary approach to the control and optimization of large lattice systems using continuum modeling methods. Though we will maintain interest in large space structures that do not consist of lattice systems (e.g., the tethered satellite), focus is directed upon creating expertise - on the part of each HU Principal Investigator - in the use of the continuum modeling approach to the optimization and control of large lattices. The measures taken to achieve this focus are listed in Overview Appendix G.

OVERVIEW APPENDIX

- A. LSSI Organizational Chart
- B. LSSI Advisory Committee
- C. Institute Lectures
- D. 1st LSSI Lecture/Recruiting Tour
- E. Office Space Utilization
 - 1. The Present Situation
 - 2. The Renovation Plan
- F. LSSI Research Productivity Status
- G. LSSI Progress Toward Its Focus

A. LSSI ORGANIZATIONAL CHART

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LEGEND: GF GRADUATE STUDENT FELLOW
 GRA GRADUATE RESEARCH FELLOW
 LMS LOCKHEED MISSILES & SPACE
 MIT MASSACHUSETTS INSTITUTE OF TECHNOLOGY
 MRC MEGAMECHANICS RESEARCH CONSORTIUM
 PD POST-DOCTORAL FELLOW
 RPI RENSSELAER POLYTECHNIC INSTITUTE

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B. LSSI ADVISORY COMMITTEE

Dr. Melvin Anderson
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Hampton, VA 23665

Mr. John Young
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* Director, LSSI
** Technical Monitor

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C. INSTITUTE LECTURES

1. IN-HOUSE: Howard University Principal Investigators, graduate students, guests.

September 14, 1983	Dr. T.H. Broome	Introduction to LSSI
September 21, 1983	Dr. T.H. Broome	Introduction to Megamechanics -1
September 28, 1983	Dr. T.H. Broome	Introduction to Megamechanics -2
October 5, 1983	Dr. R. Reiss	Elasticity: A Review
October 19, 1983	Dr. R. Reiss	Variational Methods in Elasticity
October 26, 1983	Dr. R. Reiss	Self-Adjoint Boundary Value Problems
November 2, 1983	Dr. R. Reiss	Optimum Structural Design
November 9, 1983	Dr. P.M. Bainum	Introduction to Spacecraft Dynamics: Modelling of Disturbance Torques - Gravity Gradient Torques - Moments Due to Solar Pressure - Magnetic Torques

November 22, 1983 Dr. P.M. Bainum Development of Equations of Motion:
- Earth Pointing Gravity Stabilized Systems
- Spin and Dual Spin Systems
- Double Gimbal Reaction Wheel Systems

November 30, 1983 Dr. P.M. Bainum Modelling of Large Flexible Systems in Orbit

March 13, 1984 Dr. J. Donaldson PDE Formulation of Control Problems -1

2. INVITED SCHOLARS; Howard University Engineering Community

November 16, 1983 Dr. K.C. Park* Computational Issues in Large Space Structures Technology

3. SIGMA XI: Howard University Research Community

December 8, 1983 Dr. T. H. Broome Introduction to NASA/HU LSSI

4. PLANNED

a. IN-HOUSE: Donaldson, Choudhury (weekly)

b. INVITED SCHOLAR; To be arranged.

*Dr. K. C. Park, Lockheed Missiles and Space Company, Inc., Applied Mechanics Lab., Palo Alto, California

D. 1st LSSI LECTURE/RECRUITING TOUR

FEBRUARY, 1984

DATE	PLACE	TIME	ACTIVITIES	LSSI PERSONNEL	CONTACT PERSON
Wednesday February 22	LEAVING: Washington, DC National Airport	3:30 pm	GOING TO: Denver, CO	T.H. Broome	Continental Air- lines, Flight #467
Thursday February 23	University of Colorado at Denver, Colorado 80202 School of Engineering East Classroom #15	9:00 am	Meet with Dean Thomas	T.H. Broome	Dean G. Thomas
		11:00 am	Structural Analysis Seminar	T.H. Broome	Prof. Judy Stlan- ker
		12:00 pm	Lunch: With Engineering Chairmen of Departments ● Metropolitan State Col- lege ● Vice President of MSC ● University of Denver ● University of Colorado ● Martin Marietta Corp.	T.H. Broome	Dean G. Thomas
		4:00 pm	Lecture: With Engineering Students Dr. Xing	T.H. Broome/ C. McKissack	Dean R. Anne School of Eng'g
Friday February 24	South High School Denver, Colorado	10:00 am	Lecture	T.H. Broome/ C. McKissack	Mrs. B. Deline
	Metropolitan State College St. Cajetans Bldg., Denver, Colorado 80204	11:30 am	Second Black World Con- ference	T.H. Broome	Dr. Akbarali Thobhani

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1st LSSI LECTURE/RECRUITING TOUR

FEBRUARY, 1984

DATE	PLACE	TIME	ACTIVITIES	LSSI PERSONNEL	CONTACT PERSON
Friday February 24			<ul style="list-style-type: none"> ● Announcement of the LSSI: T.H. Broome <p>"Role of Minorities in the Space Program"</p>	T.H. Broome	ORIGINAL PAGE IS OF POOR QUALITY
		12:00 pm	lunch		
Saturday February 25	LEAVING: Denver, CO	6:36 pm	GOING TO: Stanford Univ.	T.H. Broome	United Airlines Flight #825
	ARRIVING: San Francisco, CA	8:01 pm	Travel to lodging	T.H. Broome	
	Note: C. McKissack returns to Washington, DC				
Saturday Evening February 25	LODGING: Ricky's Hyde House 4219 El Camino Real Palo Alto, CA	9:00 pm	Picked up mail and telephone messages from front desk and replied. Forwarded response back to Howard University	T.H. Broome	Lodging: (415) 493-8000
Sunday February 26	Note: P.M. Bainum arrived	3:25 pm			
Monday February 27	Stanford University	8:00 am	Meetings with	T.H. Broome/ P. M. Bainum	Dr. Michael L. Jackson, Director Stanford Overseas Studies (415) 497-3555
	Durand Building Room 369		<ul style="list-style-type: none"> ● Prof. Holt Ashley Aero-Astro & Mechanical 		
	Durand Building Room 206	9:00 am	<ul style="list-style-type: none"> ● Prof. Peter Banks, Head NASA Task Force 		

1st LSSI LECTURE/RECRUITING TOUR

FEBRUARY, 1984

DATE	PLACE	TIME	ACTIVITIES	LSSI PERSONNEL	CONTACT PERSON		
Monday February 27	Durand Building Room 113	10:00 am	<ul style="list-style-type: none"> ● (Prof. John Breakwell Orbital Mechanics - Cancelled) 	ORIGINAL PAGE IS OF POOR QUALITY	Dr. M.L. Jackson Prof. Thomas Kane		
	Durand Building Room 262-A	11:00 am	<ul style="list-style-type: none"> ● Prof. Arthur Bryson 				
	Tresidder Room 271	12:00 pm	Luncheon with (15 people) <ul style="list-style-type: none"> ● Administrators of Minority Programs ● Vice President Boyd ● Faculty, and ● Students 				
	Stanford University Tresidder Room 132	2:30 pm	ISSI Symposium Faculty/Students			T.H. Broome/ P. Bainum	Prof. Thomas Kane
	LEAVING: San Francisco, CA	5:25 pm	GOING TO: Arizona State University			T.H. Broome/ P. Bainum	Republic Airlines Flight #19
Tuesday February 28	Arizona State University Department of Mechanical and Aerospace Engineering Room G-325	10:00 am	Meet with and conduct Interview <ul style="list-style-type: none"> ● Dr. Kailash C. Pande Mechanical and Aerospace Engineering Discuss: LSSI Candidacy for potential Post Doctoral Fellow/Consulting	T.H. Broome/ P. Bainum	Dr. Kailash C. Pande (602) 965- 4115 Dr. Mahosh Rayan Dr. K.C. Pande		

1st LSSI LECTURE/RECRUITING TOUR

FEBRUARY, 1984

DATE	PLACE	TIME	ACTIVITIES	LSSI PERSONNEL	CONTACT PERSON
Tuesday February 28		1:30 pm	Seminar: With ASU Graduate Students and Faculty		
	LEAVING: Phoenix, AZ	6:40 pm	GOING TO: Prairie View A&M University	T. Broome/ P. Bainum	Republic Airlines
	ARRIVING: Houston, TX Lobby Airport	9:51 pm	Travel to lodging	T. Broome/P. Bainum	
Wednesday February 29	Prairie View A&M University Office of the President Main entrance on Campus Avenue-A, 2nd Bldg. on left	9:00 am	Meet with o Dr. John Hill, Vice President for Development and University Relations	T. Broome/P. Bainum	Dr. John Hill
	President's Conference Room	9:15 am	o Meet with Administrators	T. Broome/P. Bainum	
	College of Engineering Dean's Conference Room	10:00 am	Meet with o Dr. Decatur Rogers, Dean College of Engineering o Faculty	T. Broome/P. Bainum	
		11:30 am	Tour of Facilities	T. Broome/P. Bainum	
		12:30	Lunch		
		1:30 pm	Meet with o Dr. Percy A. Pierre President Prairie View A&M	T. Broome/P. Bainum	

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1st LSSI LECTURE/RECRUITING TOUR

FEBRUARY, 1984

DATE	PLACE	TIME	ACTIVITIES	LSSI PERSONNEL	CONTACT PERSON
Wednesday February 29	Prairie View A&M	2:00 pm	Lecture/Graduate Students and Faculty	T. Broome/P. Bainum	
			Introduction by Dr. Percy A. Pierre, President		
	ARRIVE: Memorial Student Center- Texas A&M University Campus	6:30 pm			
	The Confederate House	7:30 pm	Dinner: With Dr. Cress	T. Broome/P. Bainum	
Thursday March 1	Texas A&M University Engineering Room 215 College Station, TX	9:30 am	Meeting with o Dr. E. James Cross, Jr.	T. Broome/P. Bainum/ R. Reiss	Dr. E. James Cross, Jr. (409) 845- 7541
			Meeting with	T. Broome/P. Bainum/ R. Reiss	
		10:00 am	o Dr. Allen o Dr. Kinra		
		12:00	LUNCH: Dr. Cross		
	Engineering Research Center Room 324	2:00 pm	Seminar: Faculty/Graduate Students	T. Broome/P. Bainum/ R. Reiss	
		3:30 pm	Tour, Engineering Research Center		
		4:00 pm	Depart for Easternwood Airport	T. Broome/P. Bainum/ R. Reiss	

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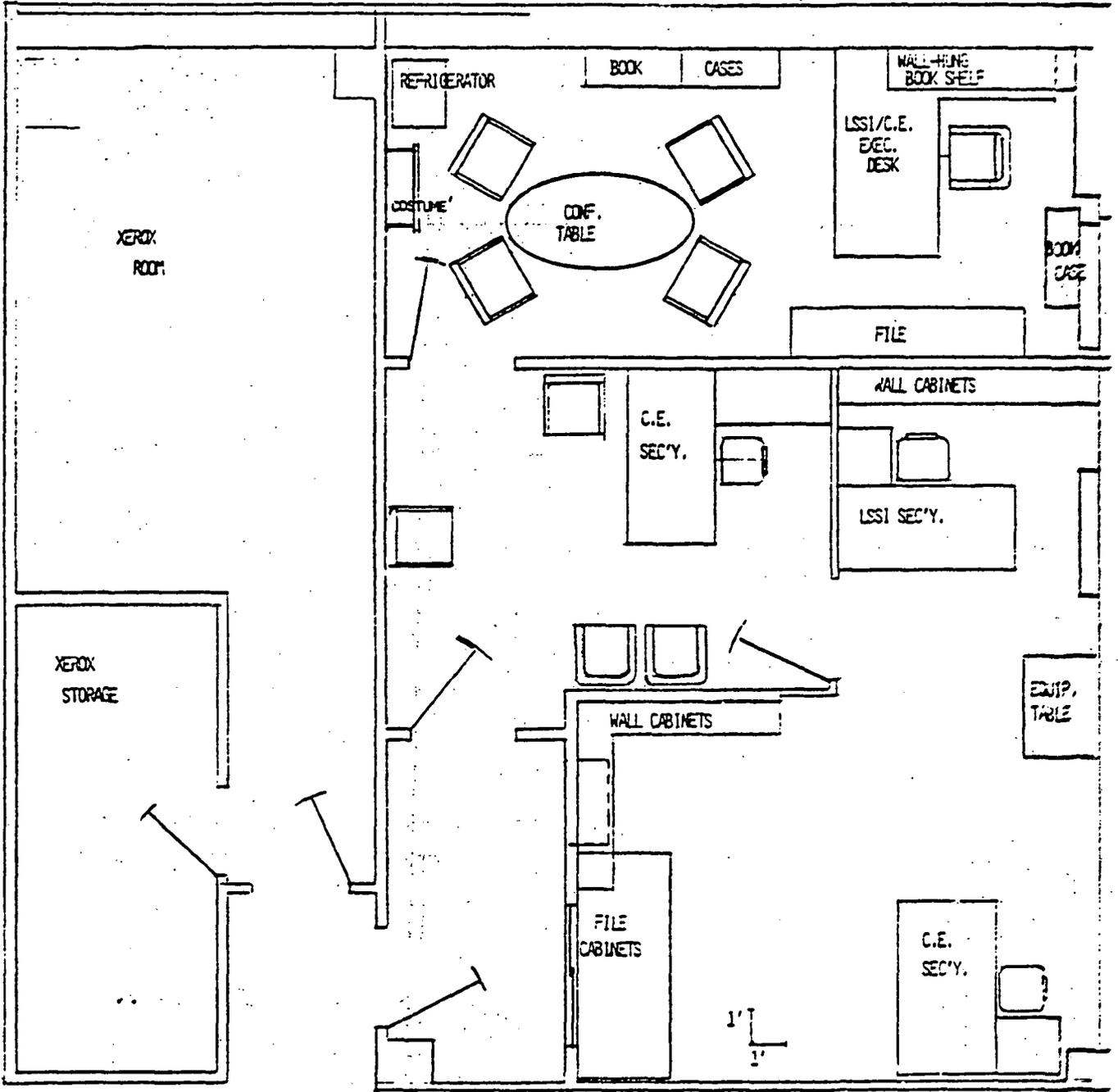
1st LSSI LECTURE/RECRUITING TOUR

FEBRUARY, 1984

DATE	PLACE	TIME	ACTIVITIES	LSSI PERSONNEL	CONTACT PERSON
Friday March 2	ARRIVING: Baton Rouge, LA	9:08 pm	Bainum returns to Washington A.K. Choudhury arrives in Baton Rouge, LA	T.Broome/R.Reiss	American Airlines Flight #595
	Southern University Baton Rouge, LA	10:00 am	Meet with: -Dr. M.Q. Burrell, Dean School of Engineering -Seminar: Faculty/Student	T.Broome/R. Reiss A.K. Choudhury	Dean M.Q. Burrell 504/771-5290
		11:00 am	Seminar	T.Broome/R.Reiss	
		12:00 pm	Lunch		
		1:00 pm	Two-hour Interview with Students	Broome/Reiss/Choudhury	
	LEAVE: Baton, Rouge, LA	4:00 pm	Return to Washington, D.C.	Broome/Reiss/Choudhury	

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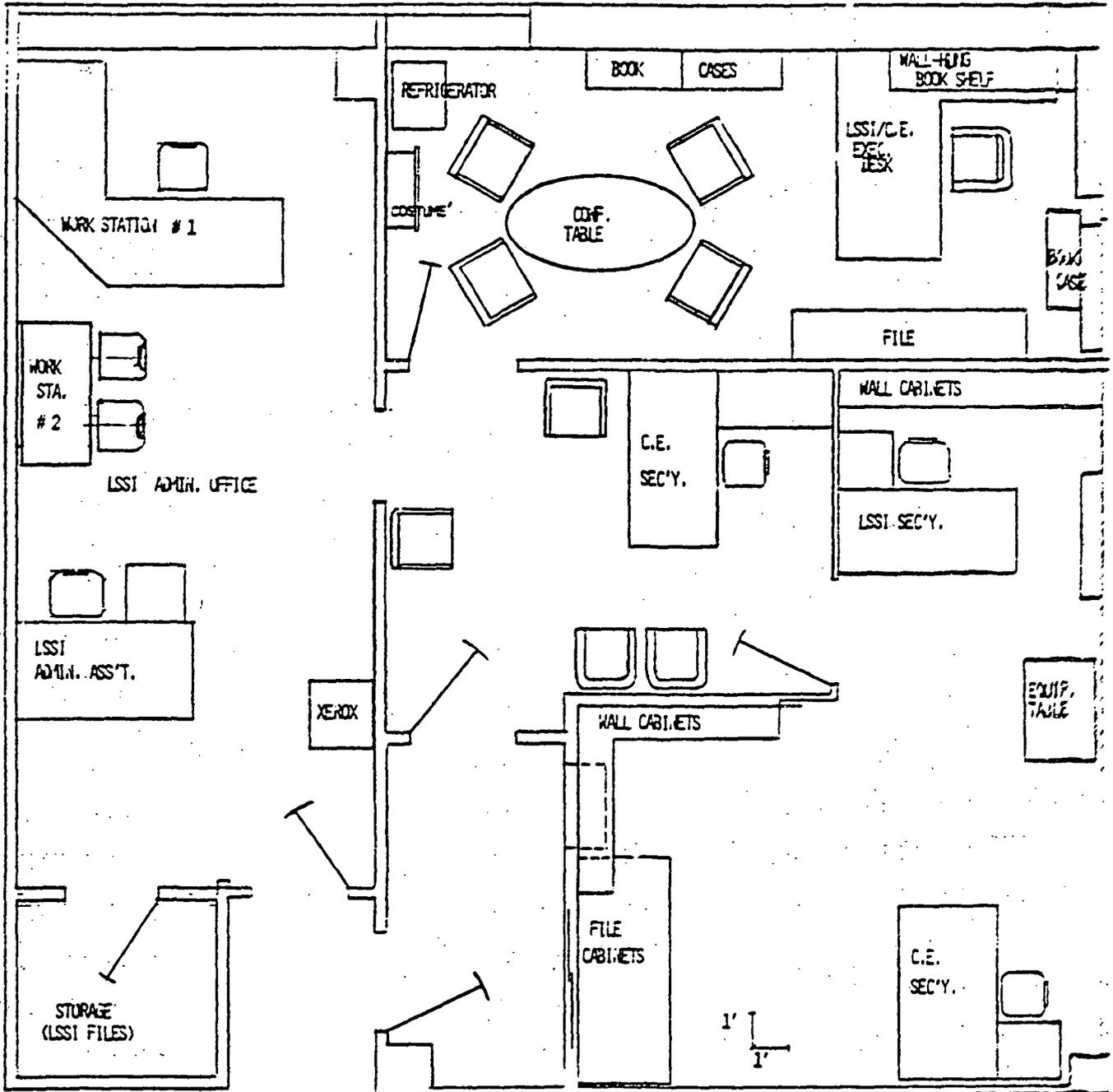
E.1 OFFICE SPACE UTILIZATION: THE PRESENT SITUATION



← TO LSSI ADMINISTRATIVE ASSISTANT'S OFFICE

E.2 OFFICE SPACE UTILIZATION: THE RENOVATION PLAN

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- WORK STATION # 1 = TECHNICAL WORK STATION (TERMINAL, PRINTER, ETC.)
- WORK STATION # 2 = ADMINISTRATIVE WORK STATION (WORD PROCESSOR, ETC.)

F. LSSI RESEARCH PRODUCTIVITY STATUS

1. Reiss, R., "Structural Optimization With Constraints on Transient Response", to be presented at the NASA Symposium on Recent Experiences in Multidisciplinary Analysis and Optimization, April 24-26, 1984.
2. Ananthakrishnan, S., "Analysis of a Control System for a Large Space Antenna System in the Presence of Plant and Measurement Noise", to be presented at the AIAA Mid-Atlantic Regional Student Conference, University of Maryland, College Park, Maryland, April 27-28, 1984.
3. Bairum, P. and Krishna, R., "Control of an Orbiting Flexible Square Platform in the Presence of Solar Radiation", to be presented at the Fourteenth International Symposium on Space Technology and Science, Tokyo, Japan, May 28-June 3, 1984.
4. Krishna, R. and Bairum, P., "Dynamics and Control of Orbiting Flexible Beams and Platforms Under the Influence of Solar Radiation and Thermal Effects", tentatively accepted for presentation at the AIAA/AAS Astrodynamics Conference, Seattle, Washington, August 20-22, 1984.
5. Krishna, R. and Bairum, P., "Environmental Effects on the Dynamics and Control of an Orbiting Large Flexible Antenna System", under review for presentation at the 35th International Astronautical Congress, Lausanne, Switzerland, October 7-13, 1984.
6. Miller, A.F., Interactive Computer-Aided Design and Analysis of Large Space Structures, M.S. Thesis, R.P.I., February, 1984.

7. Broome, T.H., The POWER Analysis Program. Solves the LCM problem for plane trusses and frames. A power series representation of the displacement field is used. The thermal module from a previously written program is added. Operational at HU and R.P.I. and was used to generate the results presented in ref. #6 above.
8. Ackroyd, M., the FOURIER Analysis Program. Extends the POWER analysis program (ref. #7 above) by the use of Fourier series representation of the displacement field. Operational at R.P.I.
9. Miller, A. and Ackroyd, M., The LCM Preprocessor. Computes, interactively, the load corrections for general (i.e., 3D) truss and lattice frames. Operational at R.P.I. and used to generate the results presented in ref. #6 above.
10. Cordiero, J., Dynamic Analysis of Large Lattice Booms via the Load Correction Method, M.S. Thesis, M.I.T., in preparation for May, 1984.

The following is the publication plan for the MRC (i.e., Broome, Ackroyd and Williams). The MRC is in its second year of funding and has identified its publication challenges. Whereas the MRC is ready to present the view that the LCM is (1) a correct formulation of a continuum modeling strategy; (2) is independent (theoretically) of existing strategies; and is (3) computationally efficient or comparable to existing strategies; the challenges are to formulate a literature in which the LCM is proved to be advantageous - in some respects - to existing modeling strategies and/or present solutions to problems which have as yet been

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3. New MRC Reference Set

Broome, T.H., "The Load Correction Method", invited for presentation at the ASCE Structural Engineering Congress, Chicago, 1985 (Session sponsored by the Elasticity Committee, Engineering Mechanics Div., ASCE).

Ackroyd, M. and Williams, J., "Advances of the Load Correction Method", invited for presentation at the ASCE Structural Engineering Congress, Chicago, 1985 (see #11 above).

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4. New Optimization Reference

Reiss, R., "Quadratic Extremum Principles: A Unified Approach", submitted to 16th International Congress of Theoretical and Applied Mechanics, Lyngby, Denmark, August, 1984. (Includes discussions of weighted variational principles (see Item 6, Appendix G).

studied. To meet these challenges, the MRC resolved to (1) construct a computer software system that would enable the PI's to solve a wide variety of LCM problems quickly; (2) identify a set of candidate problems that have promise of being instrumental in meeting these challenges; and (3) solve this set of candidate problems and incorporate the appropriate solutions into a literature that is in progress. These software systems have been constructed (see #7, #8 and #9 above), have been verified (see for example #6 above) and are being improved. The literature that is in progress will be finalized in May, 1984 and is as follows:

11. Broome, T.H., "A New Method of Modeling Lattice Structures by Continua". This paper presents the LCM formulation and was used as the theoretical basis for #6 above and all of the papers below. This paper has been completed and will be released to NASA and the literature in May, 1984.
12. Broome, T.H. and Ackroyd, M., "LCM Solutions for Complex Structures". The LCM is applied to plane trusses and frames, and 3D beams. Both POWER And FOURIER analysis codes will be applied and compared. To be released in May, 1984.
13. Miller, A. and Ackroyd, M., "Interactive Computer-Aided Design Using the LCM". The software in #6 above, together with other software designed by M. Ackroyd, will be presented in the form of a design procedure for large lattice systems. To be released in May, 1984.
14. Cordiero, J., Williams, J. and Broome, T., "Dynamic Analysis via the LCM". To be released in June, 1984.
15. Williams, J., "On the LCM". An analysis of #11 above for

the purpose of placing the LCM on firm theoretical grounds.
To be released in June, 1984.

16. Broome, T., "Extension of the Boussenesq Problem Into the Lattice Domain". To be released in September, 1984.

G. LSSI PROGRESS TOWARD ITS FOCUS

1. The central point about which the HU/LSSI PI's continue to acquire knowledge about one another's work and to identify areas for collaboration are the In House Seminars (see Overview Appendix C: Institute Lectures).
2. In order to begin to acquire expertise in the area of controls, T. Broome attended the one-week short course "Dynamics and Control of Large Flexible Structures", by R. Skelton and P. Hughes at UCLA (August 22-26, 1983).

Interactions among the research projects are as follows:

3. Broome/Donaldson. Investigations into the special type of boundary value problems arising from the load correction method (LCM) have begun.
4. Bainum/Donaldson. Control problems of interest involving partial differential equations have been identified.
5. Broome/Reiss. A problem of optimizing the stress distribution in a lattice half-plane is being formulated. Broome and Reiss will collaborate on this portion of the proposed new work of the MRC.
6. Reiss/Broome. A problem involving the desirability of a weighted variational principle for the solution of elasticity problems has been identified and discussed. Investigations into this problem will continue but on a low priority basis.
7. Bainum/Choudhury. There exists a mutual interest in the control aspects of the hoop-column. Bainum will extend work done on deterministic controls into the stochastic regime.



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Choudhury will complement this work with the consideration of delayed controls.

8. Reiss/Broome. Reiss has proposed the problem of optimal design of truss beams with attached vibration absorbers. Broome will follow Reiss' progress with interest in extending the problem by an LCM analysis for large one-way and two-way beams (i.e., two repeating element bays in the thickness direction).

9. Reiss/Bainum. Reiss has proposed to optimally design truss-beams with prescribed passive controls. Bainum is interested in designing controls for specified space structures. Although the important problem of simultaneously designing the structure and control system is not specifically addressed, it is anticipated that Reiss' proposed research will be a first step in this direction.

5. New FOCUS Problem

Reddy/Bainum/Choudhury. Reddy has proposed to set up a lab to implement control laws using a microprocessor and data acquisition systems. Bainum and Choudhury can use this lab to test the control laws developed by them either on the scale models or using simulators to mimic the actual space structures.

II. ORGANIZATION OF RESEARCH PROJECTS

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MEGAMECHANICS RESEARCH CONSORTIUM
(MRC)

by

Taft H. Broome, Jr.
Associate Professor and Director
Large Space Structures Institute

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2. PROGRESS TO DATE
3. PROPOSED RESEARCH PLAN
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 - C. LCM Problem #6
 - D. Lattice Half-Space Problems
 - E. MRC Student Management Plan
 - F. MRC Fiscal Requirements

1. INTRODUCTION

The purpose of the Megamechanics Research Consortium (MRC) is to develop a body of knowledge of the mechanical behavior of large space lattice systems. The aim of the MRC is to solve structural analysis problems defined by the grantors. The concepts to be developed derive from various continuum modeling methods with particular emphasis placed on a new continuum modeling approach developed by the Consortium Director, called the "load correction method (LCM)".

The primary objective of the LCM is to map a lattice structure into a topologically identical, and kinematically similar continuum model. The LCM derives its modeling capabilities from two special attributes: (1) local (as opposed to global) implementation of familiar finite element operations; and (2) the a priori specification of any advantageous material model which both lends itself to a more ready solution of the continuum problem and enables the injection of intuition into the solution process. The first attribute admits a broader domain of solution strategies for the analyst while eliminating the need for solution of large systems of equations. The second attribute facilitates interpretation of results and formulation of design alternatives for the designer, and admits a simpler set of governing differential equations within the domain of the material body at the expense of a more complicated loading as compared with existing techniques. However, these two attributes allow for very

simple expressions for the variation of work done on the model by this loading.

A fundamental attribute of current techniques is that the mapping from the lattice to the equivalent continuum is contained in the constitutive properties of the continuum, while the loads and boundary conditions are left unchanged. In many cases, however, the resulting continuum exhibits quite complex and exotic constitutive properties giving rise to a continuum problem which can be more difficult to solve than the original lattice problem. In such cases, a technique which does not possess this fundamental attribute is desirable. Thus, an alternative to, but not a replacement for, these techniques is a new continuum modeling method proposed herein which circumvents the possibility of confronting unusual constitutive properties by housing all the mapping transformations in the structural loading rather than in the material properties. This is the essence of the LCM. The main features of the LCM are as follows:

- o The constitutive equations for the continuum model can be specified a priori, (e.g., isotropic) regardless of the lattice properties and whether its joints are pinned or rigid.
- o Matrix dimensions are dependent upon the geometry of the repeated lattice pattern only, and are independent of the number of repeating elements in the structure.
- o The matrices are the familiar matrices used in the finite element method, but solution of large systems of equations is avoided.
- o The LCM accommodates a wide variety of lattices (e.g., beams,

reticulated plates and shells), is apparently adaptable to a large range of structural responses (e.g., static, dynamic, thermal and materially and geometrically non linear), and accounts for edge effects.

2. PROGRESS TO DATE

The LCM has been extended from the static analysis of trusses to include (1) static analysis of frames; (2) dynamic analysis of trusses; (3) a computer code to do static analyses of plane frames and trusses subject to mechanical and thermal loads; and (4) a preprocessor to generate the load corrections for 3D complex geometries.

The extension of the LCM to include frames was accomplished by extending the cluster stiffness equations in the form:

$$\{F\} = [K_{FU}] \{U\} + [K_{FO1}] \{O_1\} + [K_{FO2}] \{O_2\} + [K_{FT}] \{T\} \dots (1)$$

$$\{M\} = [K_{MU}] \{U\} + [K_{MO1}] \{O_1\} + [K_{MO2}] \{O_2\} + [K_{MT}] \{T\} \dots (2)$$

where F and M are known external forces and moments; U and O are translational and rotational displacements, O_1 being rotations at external joints and O_2 being rotations at internal joints; T are temperatures at the joints; and the K-matrices are constants. Since K_{MO1} is always invertible, O_1 can be eliminated from (1), and U and O_2 can be approximated using a Ritz procedure as was done in the case of the truss. Some results are presented in the Appendix to this section.

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The specific functions carried out by the preprocessor fall into three general areas:

1. Standard structural definition
2. LCM structural definition
3. Generating the load corrections

Within each of these areas, individual functions are grouped by task. Tasks which must be controlled by the user are made available as modes of operation. Tasks which can be automated are directly incorporated as features which are transparent to the user.

The computer model of a conventional latticed structure includes four groups of data:

1. Geometry (including both joint locations and member connectivity)
2. Material and member properties
3. External loads
4. Boundary conditions

These four groups of information are created by the preprocessor using five different modes of operation. Two modes are used to describe the structural geometry (GEOM and VLSS). Material and member properties, external loads, and boundary conditions are each produced using one mode (MEMBS, LOADS, and DISPL).

One of the advantages of using the Load Correction Method of continuum modeling is that mapping to the continuum is carried out using repetitive sub-domains (clusters). Defining the appropriate clusters requires two steps. The first step is to specify the geometry and material properties of the lattice

clusters. Because of the way geometry is interactively generated in the preprocessor, this step is completely automated.

The second step is to define the geometry and material properties of the corresponding continuum clusters. This process must be user controlled, and a mode of operation (ELEM) has been created with the appropriate functions.

After both the lattice and the continuum clusters have been defined, the load correction coefficients can be calculated as described earlier. Load corrections are automatically generated by the preprocessor and saved on file for later use by LCM analysis packages.

The six modes (GEOM, VLSS, LOADS, ELEM, MEMBS, and DISPL) are used in the definition of the structural model and are described in the RPI Masters Thesis entitled "Interactive Computer-Aided Design and Analysis of Large Space Structures" by A. Miller (February, 1984). The other two modes (I/O and CLUST) provide preprocessor support functions which do not directly affect the model data base. The I/O mode is described in "Support Functions in Mode I/O". A description of the CLUST mode is found in the thesis section "Displaying Clusters Using Mode Clust".

Dynamic analysis using the LCM has been completed and results will be available in approximately three weeks.

3. PROPOSED RESEARCH PLAN

The proposed research plan is to use the finite element method and the LCM to extend Saint-Venant's principle via the

Boussinesq problem into the regime of large repetitive lattice systems. Since it is apparently difficult to justify Saint Venant's principle in all cases purely on mathematical grounds, specific instances can be studied.

J. Boussinesq, in *Applications des potentiels a l'etude de l'equilibre et du mouvement des solides elastiques* (1885), has shown that if the external forces act normally to the plane surface of a semi-infinite solid, and if they are confined to lie in a circle of radius e , then the stresses at a fixed interior point at a distance greater than e from the center of the circle are of the order of magnitude e when the resultant of the external forces is zero and of the order e^2 when the resultant moment is zero. R.v. Mises has shown that these results need not be valid when the external forces are not normal to the surface. In a paper entitled "On Saint Venant's Principle", Bulletin of the American Mathematical Society, Vol. 51 (1945), pp. 555-562, v. Mises proposed a modification of the Saint-Venant principle, concerned essentially with the relative rather than absolute orders of magnitude of applied forces and the resulting internal stresses. E. Sternberg, Quarterly of Applied Mathematics, Vol. 11 (1953), pp. 393-402, has also studied this problem. Sternberg supplies a general proof of Saint-Venant's principle as modified by v. Mises. Sternberg's argument is carried on for the case of piecewise continuous tractions and for the case of concentrated forces. This argument applies to finite and infinite domains of arbitrary connectivity.

The aim of this plan is to develop an understanding of the way stresses are distributed in large lattice systems due to statically equivalent loadings applied in small regions of the structures, and to develop an optimizer strategy for designing lattices to achieve the most desirable distributions.

The methodology for fulfilling this plan is as follows:

- (a) The literature on St.-Venant's principle and the Boussinesqu problem, and other similar applications, will be surveyed.
- (b) Various lattice repeating geometries will be selected for study based on their likelihoods as candidates for space applications.
- (c) The repeating geometries will be used to build up plane half spaces which will be subjected to statically equivalent loadings in small regions both on their surfaces as well as in their interiors.
- (d) The role of the LCM will be to calculate the stress distributions in the lattice half spaces. First, a variety of statically equivalent loads will be applied to lattice truss half spaces in the neighborhood of point A (see MRC Appendix D.1). Then, the stress distributions in the lattices will be computed from the strain distributions in the continuum models. Second, this process will be repeated for lattice frame half spaces using the loadings on the trusses as well as statically equivalent moment loadings (see MRC Appendix D.2). The aim is to determine whether Saint-Venant's principle applies to these lattice structures
- (e) The role of the finite element method will be to verify the

LCM calculations to the degree that computational efficiency (e.g., cost) can be justified. Since semi-infinite regions can only be approximated by finite element (FEM) models, a convergence procedure will be used to verify the LCM calculations. Associated with each problem being studied by the LCM, a series of FEM problems will be solved (see MRC Appendix D.3). If the solutions of these problems are observed to converge to the LCM solutions, then the LCM results will be taken as correct.

- (f) A design parameter will be formulated that measures the degree to which the stress distributions are uniform, and this parameter will be minimized subject to the relative cross-sectional areas of the lattice cords-to-diagonals (i.e., A_C/A_D). For example, the degree to which the first strain invariant, I_e , of the LCM continuum model can provide information about the state of stress in the lattice will be investigated. If this investigation suggests that the distribution of stress in the lattice can (somehow) be characterized by the distribution of I_e over the LCM model, then we will seek to formulate the argument that the most uniform distribution of stress in the lattice is achieved when the ratio A_C/A_D corresponds to the minimum value of B where:

$$B = \iint (I_{e,x^2} + I_{e,y^2}) dx dy$$

Thus, B will be called the design parameter for the stress distribution analysis.

- (g) The plan for managing the work of the student researchers is illustrated in MRC Appendix E. The graduate thesis students are actively engaged in producing thesis work described in

(d) and (f) above. The graduate non-thesis students are actively engaged in performing the FEM analysis as described in (e) above as their special project requirements. The MRC/HU PI (T. Broome) has established an elaborate training program for these students to assure the quality of their research productivity.

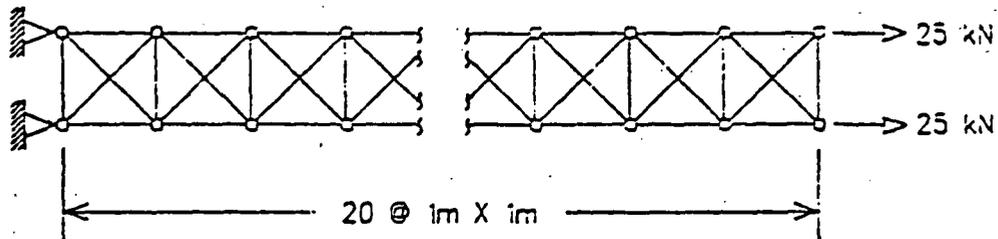
(h) Extensions of Calvin's problem and Lamb's problem into the large lattice domain will be studied if time permits.

Of significance is that studies will be made to incorporate the effect of damping into the LCM. If such an incorporation appears at anytime to be promising, the project aims will be modified under the concurrence of the NASA monitor.

MRC APPENDIX

- A. LCM Problem #1: Symmetric, Lattice Truss - Extension Loads.
- B. LCM Problem #2: Symmetric, Lattice Frame - Extension Loads.
- C. LCM Problem #6: Symmetric, Lattice Frame - Cantilever Boom.
- D. Lattice Half-Space Problems
 - 1. Truss Half-Space Problems
 - 2. Frame Half-Space Problems
 - 3. Finite Element Approximations
- E. MRC Student Management Plan
- F. MRC Fiscal Requirements

1. SYMMETRIC, LATTICE TRUSS - EXTENSION LOADS



Material Properties

$$E = 2500 \text{ kN/cm}^2$$

Member Properties

$$A = 10.00 \text{ cm}^2$$

Notes

- All joints are pinned connections
- Bracing is not attached at midpoint
- All members have identical properties

Case Number	Continuum Mapping		POWER Results		
	Element Type	Displacement Field Codes		Percent Error in Tip Displacement	
		U(x,y)	V(x,y)	U(x,y)	V(x,y)
1	LRBE	I	I(a)	-3.03	151.34
2	LRBE	I	III(a)	-1.15	7.75
3	LRBE	I	VI	-0.73	83.77
4	LRBE	II	III(a)	-1.09	15.18
6	LRBE	I	I(b)	-3.03	151.20
9	LRBE	I	III(b)	-1.15	7.61
7	LRBE	I	V	-1.15	7.67
8	LRBE	I	IV	-1.15	7.67
10	LRBE	II	VIII	-0.36	15.66

U-Displacement Field Codes	
I	A_1x
II	$A_1x + A_2x^2$
V-Displacement Field Codes	
I(a)	$B_1x(y - h/2)$
I(b)	$B_1x + B_2xy$
III(a)	$(B_1x + B_2x^2)(y - h/2)$
III(b)	$B_1x + B_2x^2 + B_3xy + B_4x^2y$
IV	$B_1x + B_2xy + B_3x^2 + B_4x^2y$
V	$B_1x + B_2xy + B_3x^2 + B_4x^2y + B_5xy^2$
VI	$(B_1x + B_2x^2 + B_3x^3)(y - h/2)$
VIII	$(B_1x + B_2x^2 + B_3x^3 + B_4x^4)(y - h/2)$

Figure 26. POWER Results for Example Number 1

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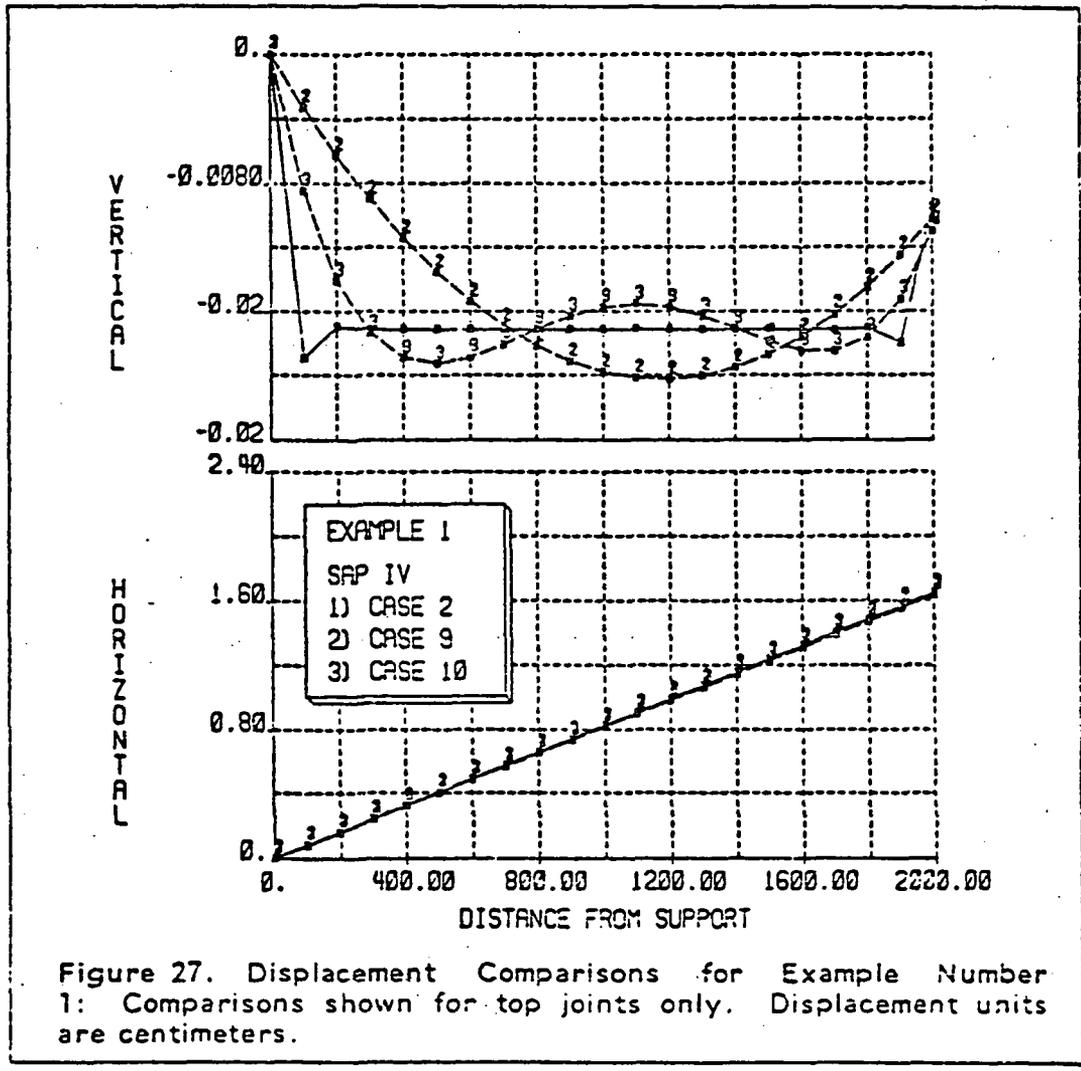
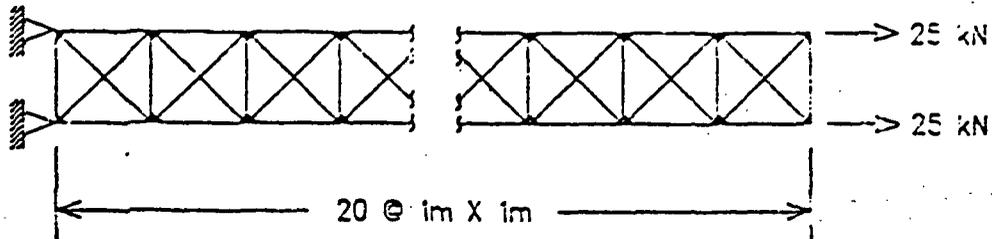


Figure 27. Displacement Comparisons for Example Number 1: Comparisons shown for top joints only. Displacement units are centimeters.

Observations About the Results

- Forcing symmetry in displacements has negligible advantage over using simple series approximations (case 1 vs 6 and 2 vs 9).
- Displacement fields with terms which do not contribute to the actual displacement of the continuum do not influence the results (cases 7, 8, and 9).
- Many terms are needed to increase the order of the solution (case 10).
- Simple displacement behavior is modeled accurately by the power series approximation (see horizontal displacements in Figure 27).

2. SYMMETRIC, LATTICE FRAME - EXTENSION LOADS



Material Properties

$$E = 2500 \text{ kN/cm}^2$$

$$\nu = 0.25$$

Member Properties

$$A = 10.00 \text{ cm}^2$$

$$J = 50.00 \text{ cm}^4$$

$$I_y = 30.00 \text{ cm}^4$$

$$\lambda_y = 2.00$$

$$I_z = 30.00 \text{ cm}^4$$

$$\lambda_z = 2.00$$

Notes

- All joints are framed connections capable of transferring moment (except to supports)
- Bracing is not attached at midpoint
- All members have identical properties

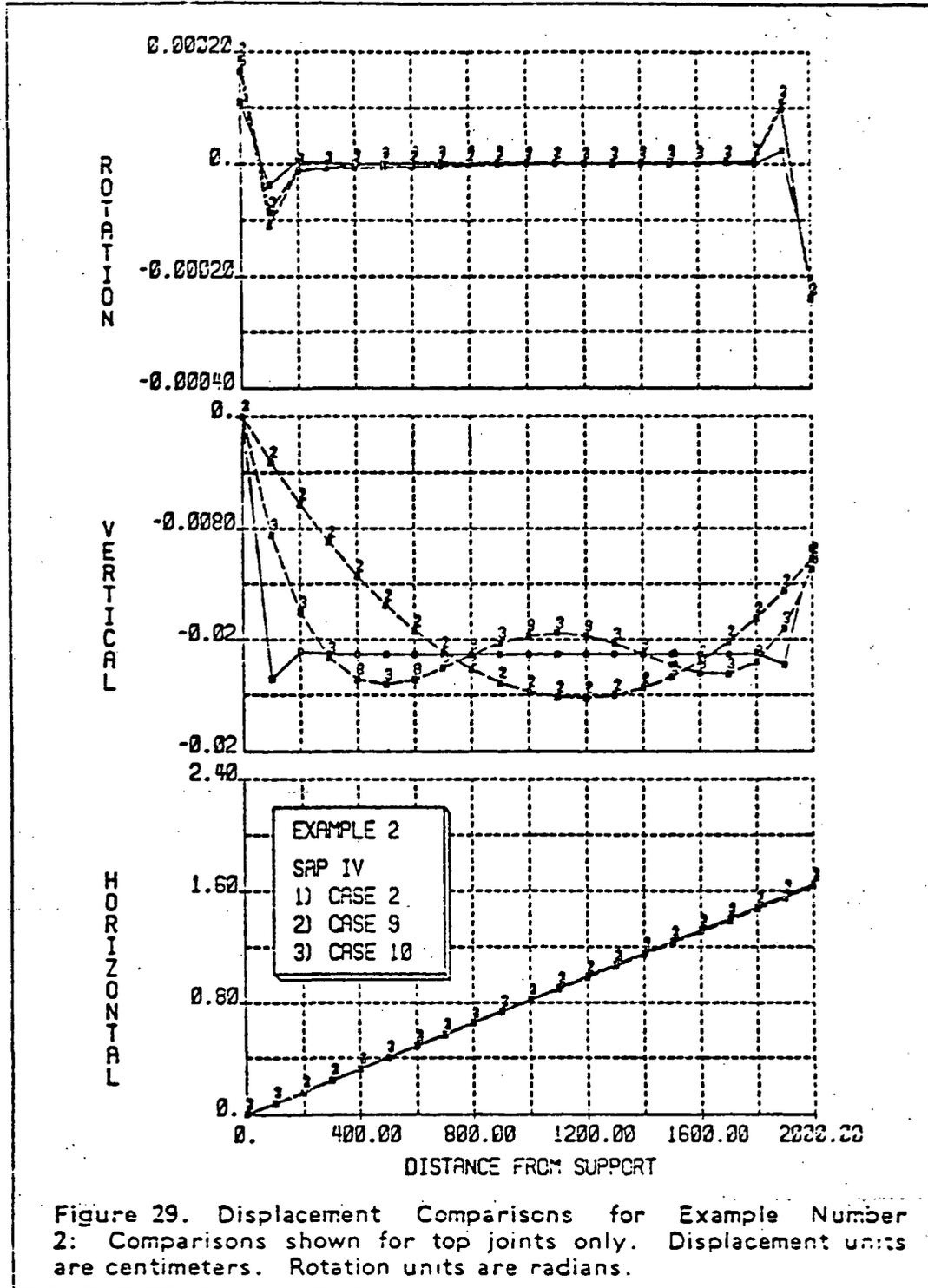
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Case Number	Continuum Mapping		POWER Results		
	Element Type	Displacement Field Codes		Percent Error in Tip Displacement	
		U(x,y)	V(x,y)	U(x,y)	V(x,y)
1	LRBE	I	I(a)	-2.91	150.90
2	LRBE	I	III(a)	-1.03	7.52
3	LRBE	I	VI	-0.61	83.37
4	LRBE	II	III(a)	-1.03	14.92
6	LRBE	I	I(b)	-1.03	150.73
9	LRBE	I	III(b)	-1.03	7.34
7	LRBE	I	V	-1.03	7.24
8	LRBE	I	IV	-1.03	7.24
10	LRBE	II	VIII	-0.24	15.39

U-Displacement Field Codes	
I	A_1x
II	$A_1x + A_2x^2$
V-Displacement Field Codes	
I(a)	$B_1x(y - h/2)$
I(b)	$B_1x + B_2xy$
III(a)	$(B_1x + B_2x^2)(y - h/2)$
III(b)	$B_1x + B_2x^2 + B_3xy + B_4x^2y$
IV	$B_1x + B_2xy + B_3x^2 + B_4x^2y$
V	$B_1x + B_2xy + B_3x^2 + B_4x^2y + B_5xy^2$
VI	$(B_1x + B_2x^2 + B_3x^2)(y - h/2)$
VIII	$(B_1x + B_2x^2 + B_3x^2 + B_4x^2)(y - h/2)$

Figure 28. POWER Results for Example Number 2

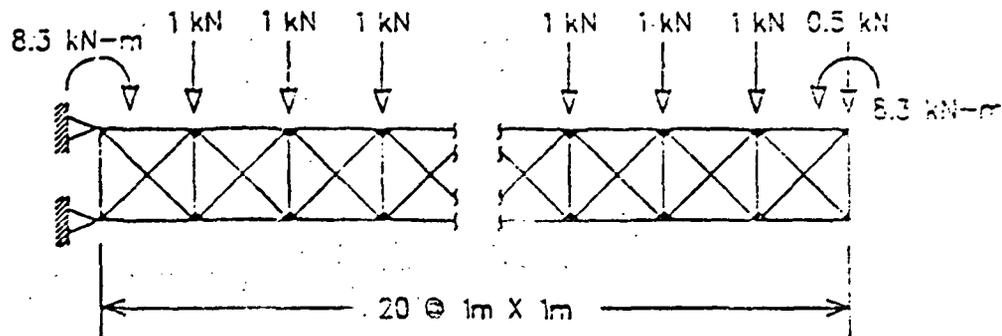
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Observations About the Results

- Results are comparable to the corresponding trussed example (number 1).
- Local rotation behavior is modeled well by the condensation and recovery procedure.

6. SYMMETRIC, LATTICE FRAME - CANTILEVER BOOM



Material Properties

$E = 2500 \text{ kN/cm}^2$

$\nu = 0.25$

Member Properties

$A = 10.00 \text{ cm}^2$ $J = 50.00 \text{ cm}^4$

$I_y = 30.00 \text{ cm}^4$ $\lambda_y = 2.00$

$I_z = 30.00 \text{ cm}^4$ $\lambda_z = 2.00$

Notes

- All joints are framed connections capable of transferring moment (except to supports)
- Bracing is not attached at midpoint
- All members have identical properties

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Case Number	Continuum Mapping		POWER Results		
	Element Type	Displacement Field Codes		Percent Error in Tip Displacement	
		U(x,y)	V(x,y)	U(x,y)	V(x,y)
11	LRBE	III	VII	36.94	-12.34
12	LRBE	IV	VII	6.38	7.64
13	LRBE	IV	IX	6.25	7.69
14	LRBE	V	VII	5.91	6.72

U-Displacement Field Codes	
III	$A_1x + A_2x^2 + A_3xy$
IV	$A_1x + A_2x^2 + A_3xy + A_4x^3 + A_5x^2y + A_6xy^2$
V	$A_1x + A_2x^2 + A_3xy + A_4x^3 + A_5x^2y + A_6xy^2 + A_7x^4 + A_8x^3y + A_9x^2y^2 + A_{10}xy^3$
V-Displacement Field Codes	
VII	$B_1x + B_2x^2 + B_3xy + B_4x^3 + B_5x^2y + B_6xy^2 + B_7x^4 + B_8x^3y + B_9x^2y^2 + B_{10}xy^3$
IX	$B_1x + B_2x^2 + B_3xy + B_4x^3 + B_5x^2y + B_6xy^2 + B_7x^4 + B_8x^3y + B_9x^2y^2 + B_{10}xy^3 + B_{11}x^5 + B_{12}x^4y + B_{13}x^3y^2 + B_{14}x^2y^3 + B_{15}xy^4$

Figure 36. POWER Results for Example Number 6

Observations About the Results

- Simple cantilever displacements are modeled well by a power series. However, these frame results are not as good as those for the corresponding truss example (number 5).
- Rotations are recovered accurately when displacements are accurate.

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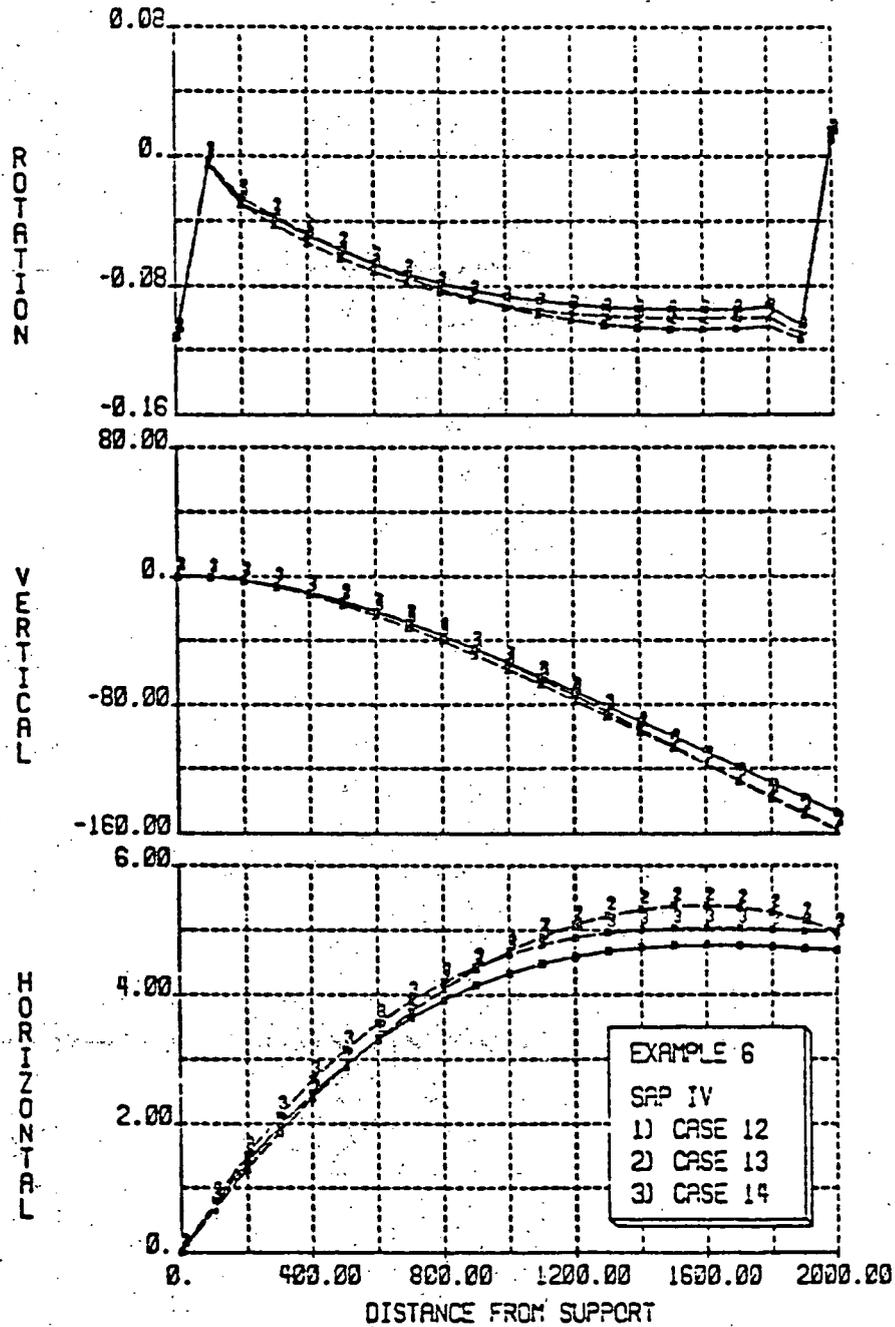
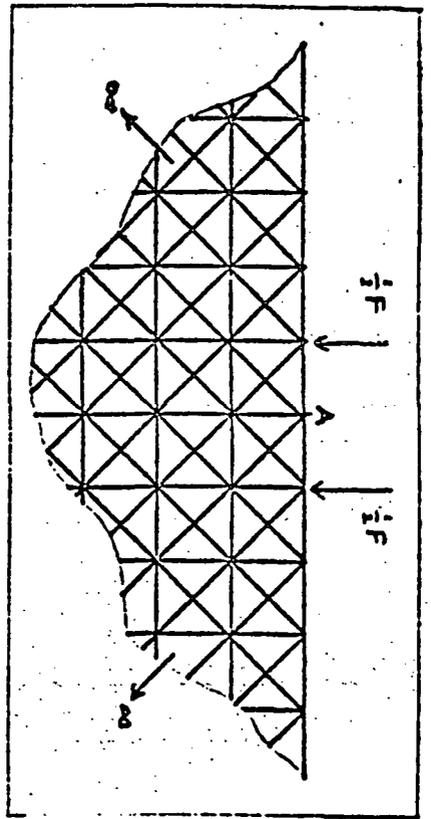
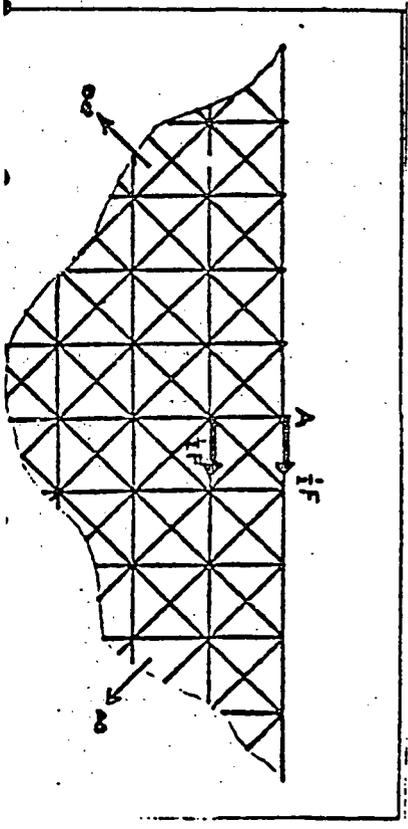
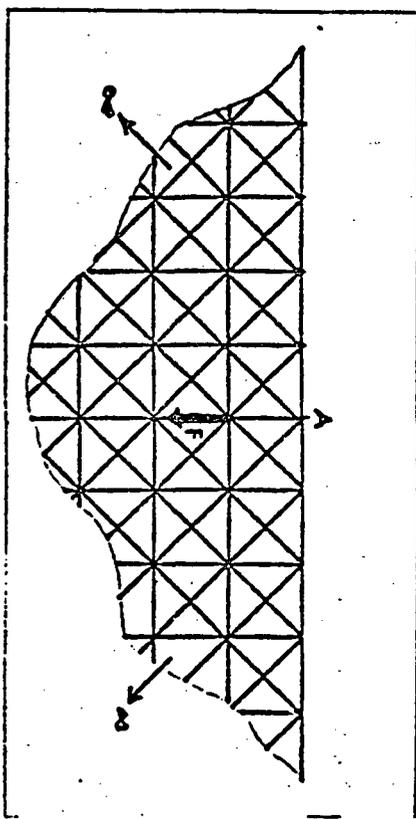
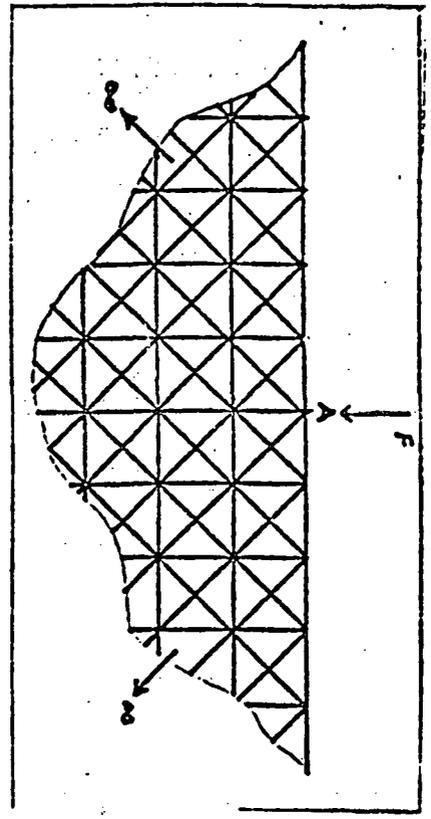
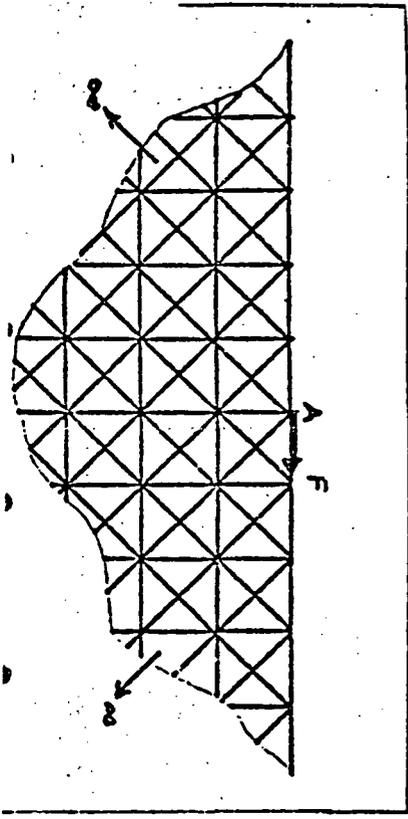


Figure 37. Displacement Comparisons for Example Number 6. Comparisons shown for top joints only. Displacement units are centimeters. Rotation units are radians.

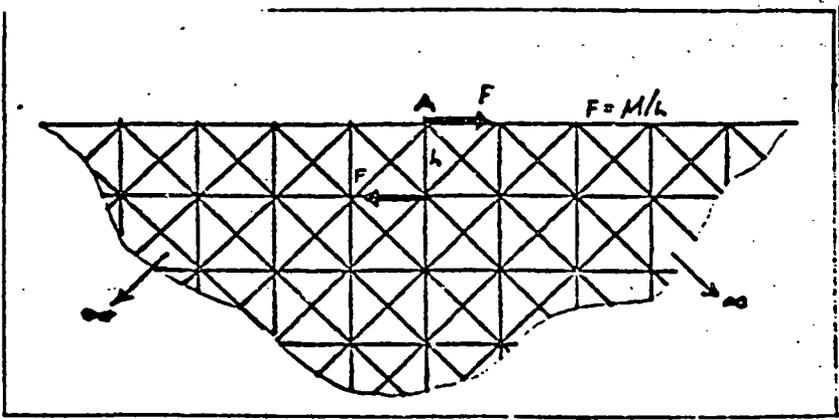
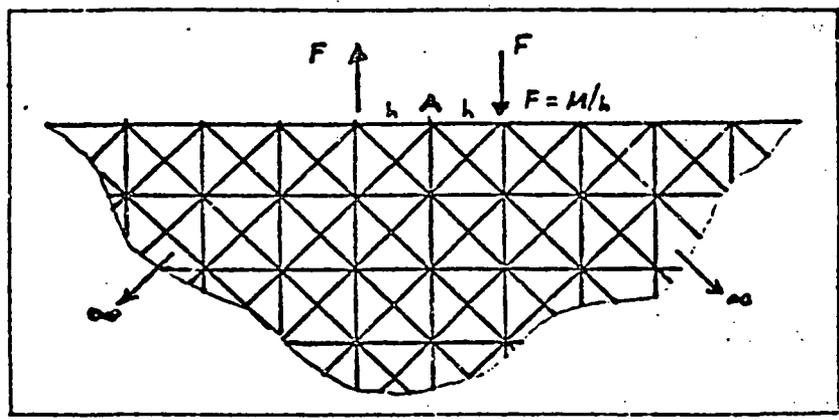
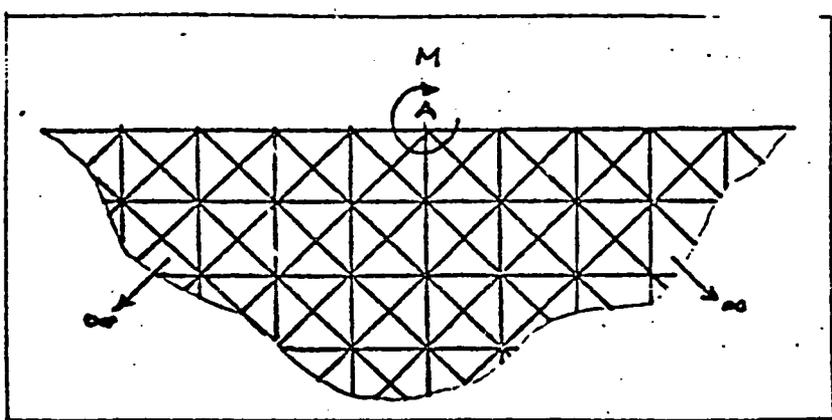
D.1. TRUSS HALF-SPACE PROBLEMS

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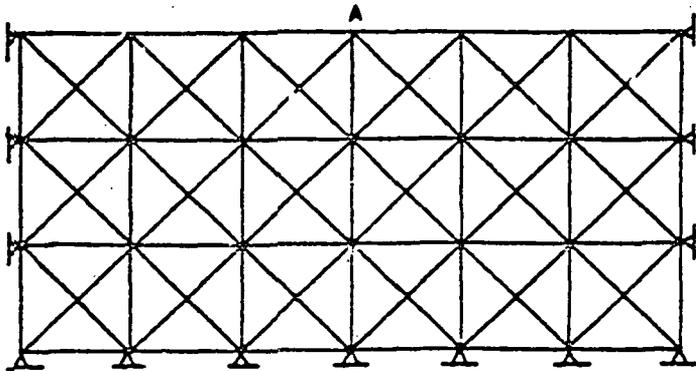
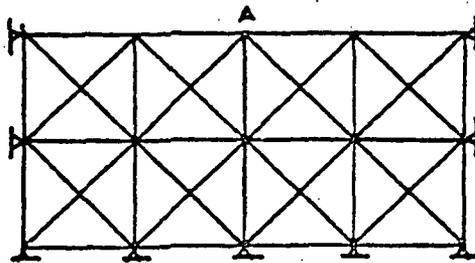
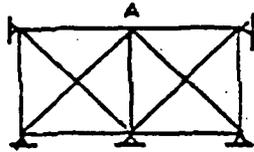


D.2. FRAME HALF-SPACE PROBLEMS

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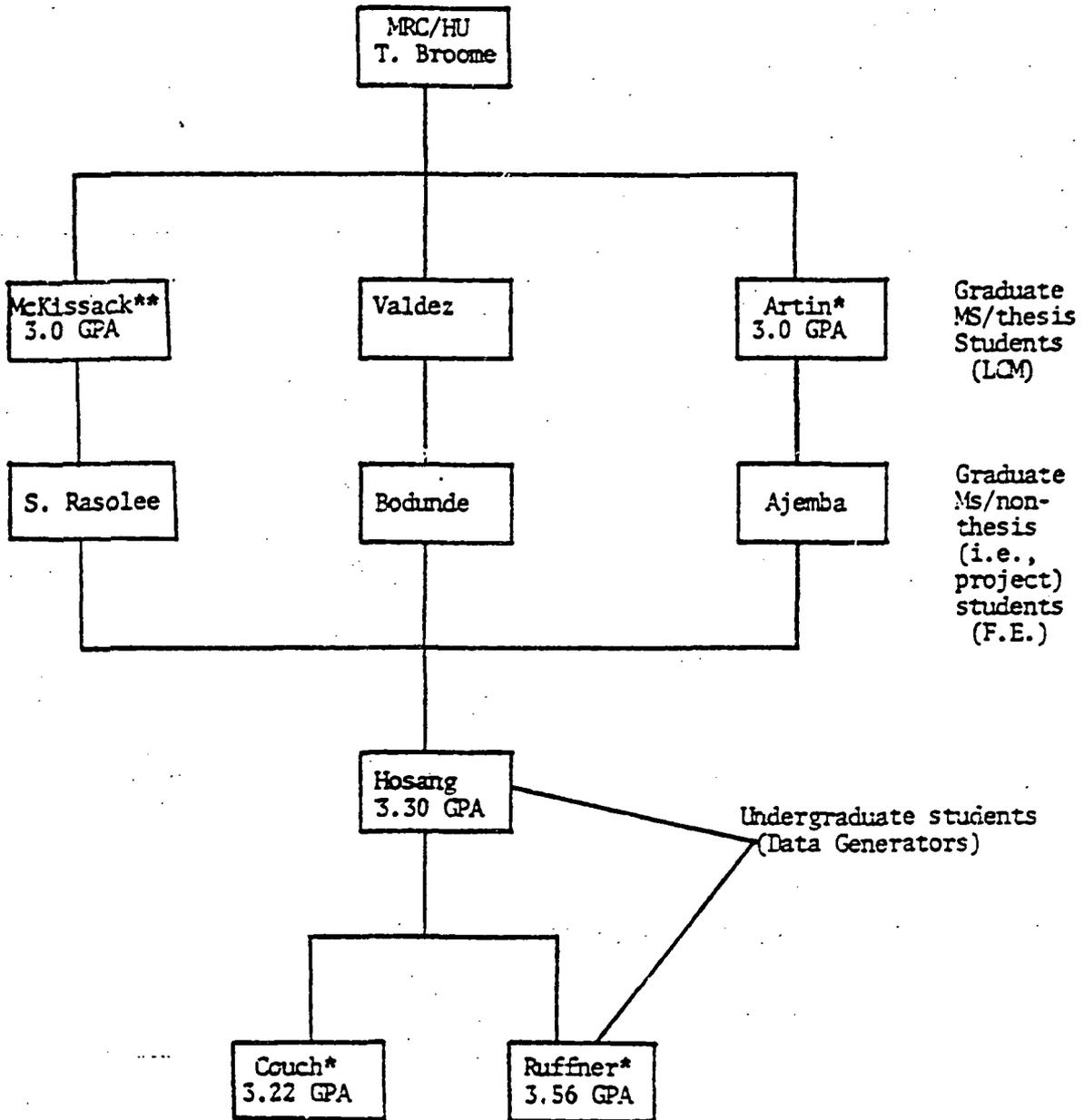


D.3. FINITE ELEMENT APPROXIMATIONS

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E. MRC STUDENT MANAGEMENT PLAN

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* Black Americans
 GPA = Grade Point Average on 4.0 system
 ** LSSI Fellow

2. BUDGET

F. MRC FISCAL REQUIREMENTS (BROOME)

ITEM

NASA

1. Salaries

Consortium Director (Broome)

- Summer (FT)

- Winter (30%)

TOTAL-A

Fringe Benefits @ 28%

TOTAL SALARIES

2. Wages

Secretarial (1/2T)

Fringe Benefits @ 28%

TOTAL WAGES

3. Travel

4. Supplies

SUBTOTAL

5. INDIRECT COST @ 90%

6. Graduate Student Assistants (4)

7. Equipment

8. Sub-Contractor (MIT)

Principal Investigator (Williams)

- Summer (1/2T)

- Winter (1/10T)

TOTAL-B

Research Associates (1/10T)

SUBTOTAL

Employee Benefits @ 27.9%

Computing

Materials and Services

SUBTOTAL

Overhead @ 51.5%

TOTAL-C (MIT)

9. Sub-Contractor (RPI)
Principal Investigator (Ackroyd)
- Summer (3/4T)
- Winter (1/4T)
TOTAL-D
Fringe Benefits @ 16%
Supplies
SUBTOTAL
Overhead @ 62%
TOTAL-E (RPI)

GRAND TOTAL

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Stabilization of a Flexible Body (Hoop-Column) Antenna by
Feedback Control Law

by

Dr. Ajit Choudhury
Department of Electrical Engineering
Howard University
Washington, DC 20059

Stabilization of a flexible Body (Hoop-Column)
Antenna by Feedback Control law.

1. Introduction

There are several models of the Hoop-Column antenna ,such as the finite element model used in [1]. All of these models can be described by the finite dimensional state-space equation of the form

$$\dot{X}(t) = A X(t),$$

where the dimension of the model depends on the degree of sophistication and the number of modes retained.

2. Nonlinear Feedback Control for Stabilization by Receding Horizon Method.

Linear state feedback control laws have been used by many authors to control and stabilize linear systems. However, linear control laws suffer from the deficiency that they cannot react fast enough to large errors. The object is to find easily computable nonlinear controllers with desirable properties, such as fast response to large errors and, closed-loop asymptotic stability. In a classical paper by Lewis [2], the improvement in the transient response of a second-order linear position servomechanism achieved by using nonlinear feedback control law is reported. The feedback is arranged so that the system has a small damping ratio during early part of the transient response, and thus a high initial velocity results. As the output approaches the steady state position, the damping ratio becomes large and the overshoot is minimized. The inherent difficulty in extending this method to higher order systems is the need to guarantee closed-loop stability. Also, in the past

nonlinear damping, odd power law feedback devices were attempted [3]. However, except for low order systems these techniques fail to guarantee asymptotic stability of the closed-loop system. Design of nonlinear regulators was first considered by Rekasius [4] who formulated the problem as a minimization of a nonquadratic integral performance index. More recently, in the regulator problem considered by Moylan and Anderson [5], where the plant is considered controllable and suitably observable with respect to the performance index. In [6,7] Sander and Williamson consider the problem of designing a stable nonlinear controller for an n-th order plant. The design is formulated as the solution of an inverse optimal control problem, and it is shown that the nonlinear controllers result from the constrained minimization of an integral performance index which is quadratic in controls and nonquadratic in the system states. The solution is obtained directly by solving a system of linear equations and leads to a feedback control law $U_{NL}(x)$ which is a nonlinear function of the states of the plant. The general nonlinear feedback control law $U_{NL}(x)$ may prove to be impractical due to the complex computational effort required to solve a large number of linear equations. In [8] Shaw considers the design of a nonlinear feedback controller by modifying the linear control law of that of receding horizon method [9,10] by making the horizon time dependent on the states of the system. These control laws, less complex than [6,7], are computable with a microprocessor and assure closed-loop stability. The method is briefly explained below.

Consider the linear plant

$$\dot{X}(t) = A X(t) + B u(t); \quad X(t_0) = X_0$$

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which is the model of the flexible hoop-column antenna

The performance index to be minimized is

$$J = \int_{t_0}^T u^T(\tau) R u(\tau) d\tau$$

subject to the constraint

$$X(t_0 + T) = 0.$$

Assume that the pair (A,B) is completely controllable, then it is straightforward to show that the optimal controller is of the form

$$u^0(t) = R^{-1} B^T e^{A^T(t-t_0)} W^{-1}(T) X_0$$

$$t_0 \leq t \leq t_0 + T$$

in which the horizon dependent matrix $W(T)$ is the solution at time T of the Lyapunov equation

$$\frac{dW}{dT} = B R^{-1} B^T - A W - W A^T; W(0)=0$$

In the receding horizon method, the above time-varying controller is made time-invariant controller by imagining that at every instant t , the controller acts as if it were beginning a T seconds performance interval. That is, in the above control law, we set $t = t_0$, and the new control law becomes

$$u^0(t) = R^{-1} B^T W^{-1}(T) X(t)$$

In the above control law, T is a design parameter and is proportional to the effective settling time, although it no longer represents the

OPTIMAL CONTROL
OF PATH STABILITY

the solution to an optimal control problem. The stability property of the above controller is shown by proving that indeed

$$V(X,T) = X(t)^T W^{-1}(T) X(t)$$

is a Lyapunov function

Upto this point, T is a design parameter. Now we want to make T a function $T(X)$ which decreases as the size of X increases. The desired $T(X)$ behavior could be induced via an implicit definition of $T(X)$, resulting from the additional constraint

$$V(X,T) = F(T)$$

with F a monotonically decreasing function of T .

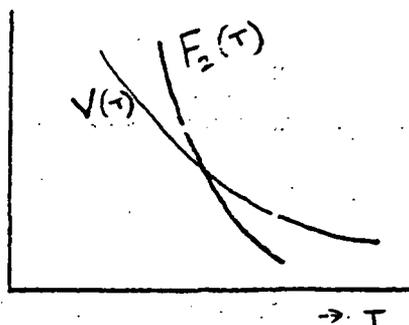
Possible forms of $F(T)$ are

$$F_1(T) = c^2 (h^T W^{-1}(T) h)^k$$

where h is a given vector, and c, k are design parameters.

$$F_2(T) = c^2 \left(\frac{T_M - T}{T - T_m} \right)^k$$

where $T_m \leq T \leq T_M$ and c, k are again design parameters.



It is clear from the shape of these F_2 functions, and the bounded positive nature of V , that there will always exist at least one T in (T_m, T_M) which satisfies

$$V(X,T) = F_2(T).$$

For each $F(T)$, there will be a different control law. The response will be computed for the hoop-column antenna model and the result will be compared with a linear control law model [1].

3. Delayed Feedback Stabilization of the Hoop-Column Antenna Model by the Receding Horizon Method.

This part of the proposal will be addressed if there is enough manpower. Otherwise it will be addressed in the next fiscal year.

As was mentioned before, most of the models of the hoop-column antenna can be posed as a finite-dimensional model of the form

$$\dot{X}(t) = A X(t)$$

where A is a constant matrix. It is desired to stabilize the system with a feedback control law. In space applications there is some delay between the estimation of the state variables and the application of feedback control laws. So the model we consider is of the form

$$\dot{X}(t) = A X(t) + B_0 u(t) + B_1 u(t-h),$$

where h is the delay. $X(t)$ represents the state of the system at time t and $u(t)$ is the control law. A , B_0 , B_1 are constant matrices of appropriate dimensions. We follow here the formulation of W.H. Kwon and A.E. Pearson [11]. Historically, a constant stable feedback control law has been obtained in a general way from the infinite-time quadratic cost problem. In [12], it is shown that the steady state optimal control law for the quadratic cost problem is of the form

$$u(t) = - (B_0^T L_{00} + B_1^T L_{01}) X(t) + \int_{-h}^0 [B_0^T L_1(\theta) + B_1^T L_2(\theta) B_1 u(t+\theta)] d\theta$$

where the nxn matrices L_{00} , L_{01} , $L_1(\theta)$, and $L_2(\theta)$ are obtained from operator Riccati equations which are extremely difficult to compute owing to their representation by partial differential equations.

Stabilization by Receding Horizon Method.

We define

$$u_t(s) = u(t+s), \quad -h \leq s \leq 0$$

and consider the fixed terminal control energy problem, which is to find the optimal control of the system which minimizes the cost functional

$$J(u) = \int_{t_0}^{t_1-h} u^T(t) u(t) dt$$

subject to the control segment pairs

$$u_{t_0} = v_0 \text{ and } u_{t_1} = 0 \text{ and}$$

state vector pairs

$$X(t_0) = X_0 \text{ and } X(t_1) = 0$$

We assume that the system is completely controllable. It can be shown, using calculus of variations, that the optimal control law is given by

$$u^*(t) = -H^T(t-t_0)W^{-1}(t_1-h-t_0) \left[X(t_0) + \int_{t_0-h}^{t_0} e^{-A(s-t_0)} e^{-Ah} B_1 u(s) ds \right]$$

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where

$$\begin{aligned}
 W(t_1 - t_0) &\triangleq \int_{t_0}^{t_1} H(\tau - t_0) H^T(\tau - t_0) d\tau \\
 &= \int_0^{t_1 - t_0} H(s) H^T(s) ds
 \end{aligned}$$

and

$$H(t - t_0) \triangleq e^{-A(t-t_0)} B_0 + e^{-A(t-t_0)} e^{-Ah} B_1$$

The above control function is an open-loop control and u_{t_0} is a given initial condition. By replacing t_0 by t in the open-loop control, we obtain the closed-loop control

$$u^*(t) = - (B_0 + e^{-Ah} B_1)^T W^{-1}(t_1 - h - t) \left[X(t) + \int_{-h}^0 e^{-A\tau} e^{-Ah} B_1 u^*(t+\tau) d\tau \right]$$

By the receding horizon concept, t_1 above is replaced by $t+T$ resulting in the new control law

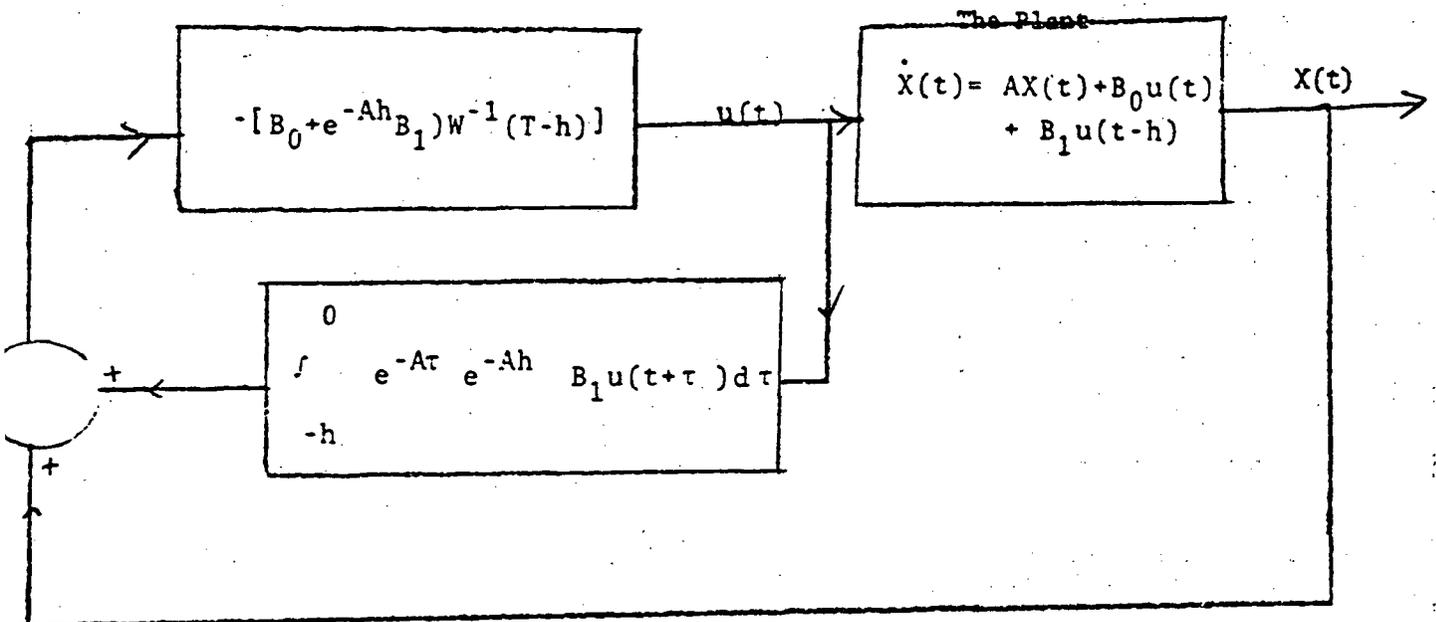
$$\hat{u}(t) = - (B_0 + e^{-Ah} B_1)^T W^{-1}(T-h) \left[X(t) + \int_{-h}^0 e^{-A\tau} e^{-Ah} \hat{u}(t+\tau) d\tau \right]$$

It may be mentioned that

$$H(t-t) = H(0) = B_0 + e^{-Ah} B_1$$

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and the upper limit in the cost functional together with the constraint $u_{t_1} = 0$ have been deliberately chosen to give the system closed-loop stability.



Feedback structure of the delayed feedback
receding horizon control law.

The above control law will be computed for the hoop-column model and compared with linear and nonlinear control laws. With the advent of microprocessors, the implementation of the above

control laws are within the realms of possibility and computer simulation and, comparison of the effect of different control laws are a worthwhile investment for NASA before embarking on the construction of large antenna and large space structures.

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BUDGET

Dr. Ajit Choudhury, Principal Investigator

Stabilization of a Flexible Body (Hoop-Column) Antenna Non-Linear
Feedback Control

Year 1984 - 1985

1. Salaries
Principal Investigator
(2 months)
Fringe Benefits @ 28%
TOTAL SALARIES

2. Wages
Fringe Benefits @ 28%
TOTAL WAGES

3. Travel

4. SUBTOTAL

5. INDIRECT COST (90%)

6. Graduate Students
Research Assistants
TOTAL STUDENTS

GRAND TOTAL

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MATHEMATICAL ANALYSIS

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Professor and Chairman

Department of Mathematics

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Washington, D.C. 20059

The section on Mathematical Analysis serves the following role in the NASA Langley/HU Large Space Structures Institute.

- It provides mathematical support to other sections of the Institute. (Direct mathematical assistance is given when requested.), and
- identifies and investigates mathematical problems thought to be of interest to the Institute and NASA.

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Background

During weekly seminars of the LSSI and discussions with participants of LSSI several areas requiring further mathematical analysis were identified. Of special interest for further investigation are two areas:

1. Boundary Value Problems arising in the Professor Taft Broome's Load Correction Method for analyzing large space structures.
2. Control Problems involving partial differential equations. (This area was suggested in part by work of Juang and Sun (7) and others (14) who have introduced simple continuum models in the study of large space structures, and in part by remarks of Professor Peter Baimum of LSSI).

The problems in each of these areas are governed by a partial differential equation, or a system of partial differential equations.

Reports abound in the literature of analyses of large space structures where the system is first approximated by a discrete model at the finite element or the modal level. The approximate model is then truncated and a control system is designed for the truncated model. For large numbers of degrees of freedom this approach is computationally expensive, and it is common that the accuracy of the results decreases as the number of degrees of freedom increases. Furthermore, important properties of stability of the system are often obscured and certain desired tasks (for example, updating parameters on-line, a necessary task because of uncertainties in most models) can not be performed efficiently by this approach.

In contrast, some researchers believe that the simple continuum model is superior to other models in analyzing large structures for several important reasons:

1. the simplicity of the model,
2. the greater efficiency of estimating parameters of the simple continuum model governed by a partial differential equation over estimating all the modes and modal frequencies of other models, and
3. the capability of estimating only those parameters that affect the controls.

Progress to date:

A boundary value problem arising in the Load Correction Method approach of Professor Broome has been studied. This problem involves a system of two second order partial differential equations in a region Ω . Various methods have been used to obtain explicit representations of solutions.

For the second problem involving control problems for partial differential, only preliminary work has been done. Some literature (1, 2, 3, 4, 7, 9, 10, 11, and 15) on control problems for differential equations (ordinary, and partial) and the application of these problems in large space structures has been surveyed. Out of these efforts have come material for a series of lectures for delivery in the NASA Langley - HU LSSI weekly seminar series, and the identification of a problem for further study.

Specifically, we propose to employ partial differential equations to model a large space structure, base the design of an optimal controller on this model, approximate the resulting optimal control model, and compare the results with those obtained from other methods.

Proposed Research Plan:

Work will be continued in the two areas: (1) boundary value problems arising in the Load Correction Method, and (2) control problems involving partial differential equations. It is proposed to produce a complete mathematical analysis of the boundary value problem involving

$$\begin{cases} 2u_{xx} + (1 - \nu) u_{yy} + (1 + \nu) v_{xy} = 0 \\ (1 - \nu)v_{xx} + 2v_{yy} + (1 + \nu)u_{xy} = 0 \end{cases}$$

in a general region where u, v and/or its derivatives are given on $\partial\Omega$, the boundary of Ω . Here mixed conditions are prescribed on the boundary. We hope to find an explicit representation for the solution. Also, numerical methods will be employed to obtain an approximation to the solution.

Simple continuum models governed by partial differential equations appear to have been under-utilized in the analysis of large space structures largely because of the incorrect perception that they are mathematically less tractable. This perception grows out of the misunderstanding that it is necessary to solve the partial differential equation in order to solve the

optimal control problem. We propose to construct simple continuum models which may be used in the design, analysis and control of large space structures. Initially, an analysis will be completed for a simple continuum model for a space antenna.

In order to gain a broader overview of the application to large space structures of optimal control theory for partial differential equations, it is hoped that a visit (4-6 weeks) to Langley can be arranged this summer.

Justification:

Simple continuum models governed by partial differential equations have a potentially important role in accomplishing one of NASA's goals, namely, the analysis, design and control of large flexible structures (platforms in space) placed in orbit about the earth. The simplicity of the models, and fewer structural parameters contribute to more accurate predictions of natural frequencies and mode shapes, and appear to be important in treating the question of system identification after deployment of large space structures. In order for this method to become a tool which will be used to obtain in an efficient manner designs of and controls for large flexible structures, it would be desirable to demonstrate through a detailed mathematical analysis of several examples the superiority of the simple continuum model approach over others (finite elements, etc.). It is also important to give considerable attention to the task of delineating a class of problems where the simple continuum method is better than other methods.

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1. BUDGET

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Dr. James A. Donaldson, Principal Investigator

Mathematical Analysis

Year 1984 - 1985

Salaries

Principal Investigator
(two months)

Fringe Benefits @26%

TOTAL SALARIES

Wages

Fringe Benefits @ 26%

TOTAL WAGES

Travel

Page Charges and Reprints

Supplies

SUBTOTAL

INDIRECT COST (90%)

Student Stipends

One Research Assistant (includes tuition)

Undergraduate Students

TOTAL

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OPTIMIZATION OF SPACE STRUCTURES

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INTRODUCTION

Background

Investigations into problems of optimal structural design generally proceed either computationally or by deriving and then solving the optimality criterion. The former approach consists of computer based direct methods in which the design is repeatedly changed until an apparent optimum is found. These methods include gradient projection techniques [1,2], steepest descent methods [3], reduction method [4] and penalty function techniques [5]. Much of the literature deals with applications of those direct methods, no doubt, because of the size and complexities of the problems treated.

The indirect method is often termed the "optimality criterion" approach. Here, either the methods of differential or variational calculus are employed to determine the optimality criterion. The former is used whenever the differential field equations are approximated in a finite dimensional algebraic form [6,7], otherwise, variational calculus is employed [8-11].

The development of optimality criteria pioneered by Prager and his fellow workers [11, 12] entails the development of variational representation of the relevant field equations. Moreover, the functional must be identical to the cost functional at the solution of the field equations. Thus, the design criterion for maximum plastic resistance of a structure followed directly from the upper bound theorem of limit analysis [11, 13], the design criterion for maximum elastic stiffness from the principle of

minimum potential energy [11, 12, 14], the design criterion for maximum fundamental frequency from Rayleigh's principle [11, 15], the design criterion for maximum steady state stiffness [16] from Reissner's principle [17], the design for maximum static deflection from the Shield-Prager principle of mutual stationary potential energy [12], and the design for minimum steady state deflection from the steady state counterpart to the Shield-Prager principle [10].

The optimality criterion is generally so highly non-linear that analytic solutions are obtainable only in the simplest of cases. Nevertheless, these solutions that have been obtained are sufficiently general to permit valuable insights into the nature and properties of the optimum design. Moreover, resolution of the questions of global [9, 11] or local optimality [8] and uniqueness [9, 18-19] of the optimum design necessitates a variational approach.

Rationale

In order to most efficiently utilize the capabilities of the present and expected future staff, three distinct but related problems are formulated. These are: (i) a continuation of the study to optimally design laminates; (ii) a continuation of current work to optimally design structures for specified transient response; and (iii) initiation of a project to optimally design a truss-beam with specified attached vibration absorbers.

The foregoing problems represent an initial step toward tying together some of the interdisciplinary aspects of LSSI

research. For example, in order to optimally design the stiffness distribution of truss-type beams or plates, it is necessary to know "a-priori" the mass-stiffness relationship for the equivalent continuum. Resolution of this question will ultimately be provided by the megamechanics work. When using the Load Correction Method, the stiffness is preset; accordingly the design variables become the load corrections. Similar remarks are appropriate for the optimization/Boussinesq problem mentioned elsewhere in this document.

And, finally, one of the most important but least examined issues that falls under the title "Optimization of Space Structures" is to optimally design a structure with controllability constraints. The proposed problem here represents an initial attempt at this problem; one for which the controls are specified and passive.

OPTIMAL DESIGN OF LAMINATES

Rationale/Background

Since high stiffness to weight ratios are critical to successful deployment and utilization of large space structures, it is not surprising to find many structural components of space structures designed with modern lightweight materials, including fiber-reinforced laminated composites. In view of the voluminous investigations of the mechanics of composite materials, the paucity of studies on the optimal design of these structures is strikingly noticeable.

One of the earliest investigations in this area, Housner and Stein determined, parametrically, the orientation of angle-ply laminates of prescribed thickness which maximized the shear buckling stress [20]. Slightly more general but related optimization problems were solved using direct numerically based methods by Hirano [21-22]. Bert successfully determined the optimal orientation that maximized fundamental frequency for simply supported [23] and clamped [24] rectangular laminates, symmetric about their mid-plane. Bert's method, however, required a priori knowledge of the fundamental frequency in terms of the plate's flexural and torsional rigidities. Another study maximizing eigenvalues (fundamental frequency and critical buckling) [25] assumes a continuous angle-ply variation through the laminate thickness. These eigenvalues are then maximized by mathematical programming techniques.

Tauchert [26] maximized the stiffness of a cylindrical pressure vessel. Here, global stiffness was equated with potential energy. And Obratzsov and Vasil'ev [27] maximize a laminate's strength subject to prescribed in-plane loads, assuming a Mises'-Hill strength criterion.

In a related group of optimization problems, the design variables are the constituent lamina thicknesses, and total weight is to be minimized subject to certain performance constraints. Here, the problem for plates with frequency, buckling and deflection constraints is solved using a penalty-function approach [28]. Khot, et al. [29] develop a recurrence relation based on an optimality criterion to iteratively reduce the structural weight in the presence of stress and displacement constraints. Rand and Shen [30] employ mathematical programming techniques to determine both the thickness and orientation of each ply in order to minimize the weight of a laminated shell subject to a natural frequency constraint. The variable thickness of laminated shells of revolution subject to stress constraints has also been the subject of a recent study [31].

Objectives

Continuation of a fundamental research program involving the optimal design of composite laminates for large space-structure applications is proposed. In fiscal 1984-5, the study will focus on the minimum weight design of laminates with frequency, buckling and global stiffness constraints. The design variables will be the thickness and/or orientation of each constituent lamina.

A related problem, particularly relevant for large flexible structures, concerns maximizing the stiffness of laminates undergoing large deflections (but infinitesimal strain). Stiffness will be identified with potential energy. Results will be compared to those obtained from small deflection theory. It is interesting to note that the only attention this problem appears to have received in the literature is a paper by Gierlinski and Mroz who treat the optimal stiffness design of homogeneous beams and plates for large deflections [32].

Procedure

The optimality criteria for the three small deflection problems follow directly from the principle of minimum potential energy and Rayleigh's principle for the least eigenvalue of positive definite linear operators. Indeed, it is a simple matter to show that the optimality condition for the maximum stiffness design of a symmetric laminate with prescribed constituent lamina thickness is

$$\begin{aligned} & U_2 \sin^2 \theta_k \iint (W_{,yy}^2 - W_{,xx}^2) dA \\ & + 2U_3 \sin^4 \theta_k \iint [4W_{,xy}^2 - (W_{,xx} - W_{,yy})^2] dA \\ & - 2U_2 \cos^2 \theta_k \iint W_{,xy} \nabla^2 W dA \\ & - 8U_3 \cos^4 \theta_k \iint W_{,xy} (W_{,xx} - W_{,yy}) dA = 0, \end{aligned}$$

where W is the vertical displacement of the plate under the prescribed loads, θ_k is the fiber orientation in the k -th lamina and U_2 , U_3 are specified invariant functions involving the material properties of the constituent lamina [33].

The optimality criterion associated with maximizing the critical buckling load or fundamental frequency differs from the

foregoing only in the coefficients of the sine and cosine terms. The optimality conditions, together with the governing field equations will be solved iteratively for the displacements and design angles θ_k . The iterative method shall parallel the approach in [34, 35], wherein convergence to the optimum design proved to be very rapid.

For the large deflection optimization problem, the principle of maximum potential energy is still applicable. The only difference occurs when the strains are represented by derivatives of the displacements. Since the potential energy functional may still be used as an alternative to the field equations, the optimality condition is again readily obtainable. Again, it is anticipated that an iterative approach will efficiently solve the associated field equation and optimality equation.

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OPTIMAL DESIGN FOR TRANSIENT RESPONSE

Rationale/Background

An exceptionally elegant method for structural optimization with constraints on the static response has been presented by Shield and Prager. Their derivation of the optimality condition was facilitated by a reformulation of the structural elasticity equations in terms of what was then a new variational principle - the principle of stationary mutual potential energy [12]. Their optimality condition relates the design variable to an appropriately defined "mutual strain energy". An alternative, but related approach, based upon the principle of stationary mutual complementary energy, was presented by N.C. Huang [36].

The simplicity of these principles lies in the facts that the energy functionals are stationary at the solution to the field equations and that their stationary value is proportional to the quantity to be optimized.

Functionals, which are the transient counterparts to those of Shield and Prager [12] and Huang [36], have been recently developed by Reiss [37]. His approach is quite general and leads to an explicit expression for small changes of the response in terms of an infinitesimal variation in the design of the structure.

Other investigators have developed optimality criteria for forced steady-state vibrations [16], forced harmonic loads [38] and forced periodic loads [10, 39].

Apart from computationally based approaches, the problem of transient response has received little attention in the literature. Brach [40, 41] optimizes the response of impulsively loaded beams. His method involves an expansion of the response in terms of the eigenmodes. Optimization is then carried out using a gradient projection method. Plaut [42] determines an upper bound to the transient response and then seeks to minimize that bound. Although an approximate method, he develops an explicit optimality condition, which then must be solved in conjunction with the relevant equations of motion.

Objectives

The primary objective of this portion of the research is to develop suitable measures of the dynamic stiffness for structures, and then to maximize this stiffness for specified total mass. The dual problem is to minimize the structural weight for a specified dynamic stiffness.

At least two different measures of the dynamic stiffness will be examined. These are:

- (a) the maximum (in space and time) deflection in the structure; and
- (b) a weighted quadratic functional of the displacement of the form

$$\int_0^{\infty} \int_{\Omega} f(t) \| u(x,t) \|^2 dx dt.$$

Here, u is the displacement, and f is a weight function tending toward zero as $t \rightarrow \infty$. The inclusion of $f(t)$ is necessary in order

to insure that the stiffness integral is non-singular. Physically, f may simulate structural damping when the driving function is non-zero for a finite period of time.

Procedure

Explicit optimality criteria can be developed using either the variational or Green's functional approach alluded to earlier [37]. These optimality conditions are highly non-linear integro-differential equations for which closed form solutions are extremely unlikely.

When optimality conditions can be explicitly obtained, iterative techniques render approximate solutions for even the most complex problems. The studies in [6-7, 43] are representative of the iterative techniques, which have been developed primarily for finite-element or finite-difference formulations of the field equations. More to the point, the form of the optimality condition [37] for the continuous structure suggests that the iterative technique applied for beams and plates [34, 35] for static problems may also be applicable in the transient case. Essentially this approach entails (i) an initially assumed set of design variables; (ii) solution of the field equations for the stresses and displacements; and (iii) subsequent updating of the design from the optimality criterion using the just calculated state variables. The updated design becomes the new initial design and the procedure is continued until satisfactory convergence has been obtained.

OPTIMAL DESIGN OF TRUSS BEAMS WITH ATTACHED VIBRATION ABSORBERS

Rationale/Background

The design of passive damping for space-structure applications has been the subject of several recent investigations. Den Hartog [44] has treated, in detail, the dynamics of a two-degree of freedom unconstrained system. The problem of optimally designing the same absorber has been solved by Hamad [45] using direct search techniques. Kwak, et al. [46] applied the method of steepest descent to optimally design an absorber which would be employed over a range of driving frequencies applied to the main mass. The foregoing methodologies are particularly useful for vibrating continua or multi-degree of freedom systems whenever the driving frequency is sufficiently close to a resonant frequency, so that the structure may be modelled as a lumped mass-spring system. Juang [47] has recently presented an iterative method for optimally designing a vibration absorber for a multi-degree of freedom system.

A related question which has not received much attention but is nevertheless worthy of consideration concerns the redesign of the basic structure in order to maximize the efficiency of one or more specified vibration absorbers. However, similar optimization problems without attached absorbers have been discussed in the open literature. For example, Prager and Taylor [11] considered the optimal design of a structure in order to maximize its fundamental frequency, and Icerman [16] minimized the maximum

steady state tip deflection of a rod subject to harmonic excitation. Although the necessary condition for optimality is the same for each of the aforementioned problems, it is also sufficient for the former, but is only sufficient in the latter case when the fundamental frequency exceeds the excitation frequency.

Objectives

The objectives of this phase of the research is to optimally design a cantilevered space-truss beam with specified structural mass and a specified tip vibration absorber. The truss beam will be modelled as a continuum whose dynamic bending stiffness is a specified function of its specific mass. The determination of this function properly belongs to the "megamechanics" work elsewhere in this proposal. However, as a first approximation, a linear reaction between specific mass and stiffness will be assumed.

Several different cost functionals will be considered.

These include

- (a) maximization of fundamental undamped frequency of the coupled beam-vibration absorber system; and
- (b) minimizing the maximum steady state deflection of the beam subject to a specified excitation frequency.

Procedure

Optimality criteria are most easily obtained when the governing field equations are represented in a variational formulation, provided the functional is identical to the cost functional at the solution of the field equations. Since the fundamental undamped frequency occurs at the minimum to the Rayleigh quotient, problem (a) above entails

$$\max_{S(x)} \min_{\{Z, Y(x)\}} \frac{k Z^2 + \int_0^L S(x) Y'^2(x) dx}{\int_0^L \rho(S) Y^2 dx + m[Z + Y(L)]^2 + M Y^2(L)}$$

where k is the spring constant of the absorber, m is the mass of the absorber, M is the concentrated tip mass attached to the beam, Z is the amplitude of the relative displacement between m and M in the fundamental mode, $Y(x)$ is the amplitude of vibration in the fundamental mode, $S(x)$ is the bending stiffness and ρ is the mass of truss beam per unit length.

Minimizing the maximum steady state deflection is somewhat less straight. In order to follow Icerman's [16] specific approach, consistent with the general methodology outlined by Prager and Taylor [11], it is first necessary to develop an appropriate variational representation to the steady state forced response of the coupled beam - vibration absorber system. Methods of determining such variational principles have been discussed recently by Reiss and Haug [48] and Reiss [49]. An alternative approach that does not require a variational representation of the field equation is based upon the design derivative of

Green's functional [50]. Either or both of the above suggested procedures may be expected to readily yield optimality criterion.

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BUDGET

Dr. Robert Reiss, Principal Investigator

Optimization of Space Structures

Year 1984 - 1985

1. Salaries
Principal Investigator
(2 months)
Bo Qian

Fringe Benefits @26%

TOTAL SALARIES
 2. Wages
Fringe Benefits @ 26%
TOTAL WAGES
 3. Travel
 4. Supplies
 5. SUBTOTAL
 6. INDIRECT COST (90%)
 7. Student Stipends
Mr. Ramachandran (includes tuition)
Master student
Undergraduate Students
TOTAL
-

15

LN84 24481

DYNAMICS AND CONTROL OF FLEXIBLE ORBITING SYSTEMS

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*Support is included in the administrative portion of the budget for the LSSI (see Part V).



Proposed Studies to be Performed During the Period

July, 1984 - July, 1985

by

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Inertially Fixed Attitude Stabilization of Large Flexible Spacecraft

With the successful operation of the space shuttle, the dream of building large structures in space, such as solar energy collectors, microwave reflectors, solar sails, telescopes, etc., is likely to become a practical reality in the near future¹. These structures would be extremely flexible due to their large size, low rigidity and the low natural damping available in lightweight construction materials. The attitude control tasks for large flexible spacecraft may be classified into two categories: (a) maintenance of the spacecraft in a desired attitude with no vibration (configuration or shape control) and (b) achieving attitude reorientations with simultaneous vibration suppression.

Flexible spacecraft represent continuous dynamic systems possessing an infinite number of degrees of freedom. In practice, discrete models of finite but very large dimension are required to describe their dynamics accurately. On the other hand, flight computers available for control implementation are of limited capacity when compared to the size of the spacecraft model. Hence, the problem of large space structure control becomes

that of controlling a large dimensional plant with a substantially reduced controller. Unfortunately, the standard modern control theory does not provide a readymade solution to the problem². The interaction of the reduced order controller and the full-order system results in performance deterioration and may even cause instability due to control and observation spillover^{3,4}. Development of reduced order controllers capable of maintaining the shape of flexible spacecraft represents the major thrust of recent research in this field³⁻¹¹.

The problem of attitude reorientation of flexible spacecraft has received some attention. Markley¹² and Turner and Junkins¹³ studied single-axis attitude maneuvers of spacecraft consisting of a rigid central hub and flexible appendages. Employing a torquer mounted on the rigid hub, these studies develop open-loop control strategies to achieve single-axis rotational maneuvers along with the minimization of the associated in-plane structural excitation of the appendages. Extensions of the approach to the more complex three-axis maneuvers are reported to be in progress¹³. Breakwell¹⁴ proposed a feedback control law for the single-axis attitude maneuver and demonstrated its effectiveness experimentally.

The studies on vibration suppression and attitude maneuvers assume a torque-free space environment and ignore orbital motion effects. The interaction of gravity-gradient torques with the elastic deformation of highly flexible space structures in orbit was highlighted by Ashley¹⁵ and Kumar and Bainum¹⁶. The possibility of achieving passive gravity-gradient stabilization of

very flexible beam, plate and shell type structures along local vertical and local horizontal orientations was demonstrated by Bainum, et al.¹⁶⁻¹⁸. In a recent paper¹⁹, the authors developed a hybrid control approach involving a passive gravity anchor and active point actuators.

The foregoing indicates that studies on the control of flexible space structures either ignore the environmental torques or are restricted to achieving an earth-oriented attitude in the gravity gradient field. Development of control systems capable of maintaining space-orientation of large flexible structures in the presence of gravitational torques has remained unexplored. On the other hand, attitude stabilization of flexible spacecraft along inertially-fixed orientations would find applications in astronomical observations, scientific missions to study solar activity, solar energy collection, space based structural construction activity, etc.

This project aims at evolving control systems capable of stabilizing the attitude of large space structures along any specified inertially-fixed orientation. In the initial phase of the work, it is proposed to consider the inertially-fixed attitude stabilization of a very flexible beam in a circular orbit. A distributed controller, consisting of a number of torquers and point actuators distributed throughout the structure, is envisaged to simultaneously counter the disturbing gravity gradient torques and suppress the structural vibration. The linearization of the governing equations in the neighborhood of the desired

inertial orientation is likely to result in a system with time-varying coefficients. Some results due to Juang²⁰ may find an application during the control synthesis. The feasibility of employing an adaptive constant gain control strategy will be examined. Efforts will be directed at accomplishing a robust controller design capable of satisfactory performance in presence of structural parameter uncertainties. The approach will then be extended to the more complex problem of maintaining an inertially-fixed attitude of a large flexible space platform. Finally, modifications of the control law will be considered to accomplish attitude reorientations of the flexible structure from one inertially-fixed attitude to another.

The proposed research, aimed at space-orientation of large flexible spacecraft, would compliment the previous work of Bainum, et al.¹⁶⁻¹⁹ on earth-orientation of such bodies. The investigation would represent an extension of the author's previous work on inertial attitude stabilization of rigid spacecraft by solar pressure control²¹⁻²³.

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Proposed Studies to be Performed During the Period

July, 1984 - July, 1985

by

Mr. R. Krishna, Senior Graduate Research Assistant

(1) Further Analysis of Environmental Effects

The shape and orientation control of orbiting flexible beams and plates have been studied previously using different techniques, neglecting the environmental effects.^{1,2} To test the effectiveness of these control systems it is necessary to obtain mathematical models of the environmental disturbances. The nature and magnitudes of the disturbances should be understood in order to predict the actual flight performance of these control systems and to determine whether steady state RMS pointing requirements can be met.

Recently the effect of solar radiation pressure torques have been included into the previously developed dynamics of simple structures such as free-free beams and plates.³ It was found, in general, that for extremely large flexible systems, it will sometimes be necessary to redesign the previously derived control laws for actuators which could simultaneously provide for both orientation and shape control. In certain cases it may even be advisable to reconsider the placement and/or number of actuators rather than simply redesigning the control law gain coefficients. In addition the effect of moments induced due to thermal gradients was also added to the beam and plate models.³ It was found that, for representative materials, the moments attributed

to the interaction of solar pressure with the thermally deflected structure could be more significant than those due to the interaction of solar pressure with the freely vibrating structures under small amplitudes.

A previous controllability analysis and the control law synthesis of the proposed Hoop/Column Antenna System (Fig. 1) did not include the environmental disturbances.⁴ It is now proposed to study the combined solar radiation pressure and heating effects on a very simplified model of the Hoop/Column System. For this application the mast will be considered to be a flexible beam having a circular cross section. The mode shapes of the mast will be used to obtain the solar radiation disturbance expression for the vibrating mast. The mode shapes and frequencies of the lower solar panels will be obtained using a finite element program and these results will be used to simulate the effects of solar radiation pressure acting on the vibrating solar panels. Nominal thermal deflections of the column and the solar panels will be assumed and the resulting moment expressions due to interaction of solar radiation pressure will be developed. The disturbance effects contributed by the rest of the structure are assumed to be negligible. The solar radiation disturbance model thus obtained will be included in the dynamic model of the Hoop/Column antenna. The effect of this disturbance on the transient responses of the Hoop/Column with the previously designed control laws will also be studied. Where necessary, modifications to the previous control laws will be incorporated.

(2) Modelling of Thermal Shock Effects

The thermal gradients induced in space structures due to solar radiation heating can cause severe thermal deformations. When these structures emerge from the Earth's shadow (or a simulated shadow in a laboratory experiment) very large thermal gradients may be induced due to light-incident heating for short intervals of time. Large amplitude oscillations may result depending on the magnitude of the thermal gradients. To analyze the effects of such thermal shocks on the dynamic behavior of the structures, the thermal stresses induced in the structure as a function of time will have to be evaluated. For simple structures such as beams and plates, the temperature distribution can be obtained by solving a one-dimensional nonhomogeneous boundary value problem of heat conduction in an infinite region.⁵ The thermal stresses and the strains generated in the structure can then be evaluated either analytically⁶ or through numerical methods.⁷ It is proposed to consider a thin square plate exposed to solar radiation heating as an application. A control system to maintain the shape and orientation of the plate during the thermal shock will be developed. Peak control forces and the total control effort required during this phase will also be evaluated and recommendations made as to the necessity of substantial modifications in the previously developed control laws.

(3) Modelling of Solar Radiation Pressure and Solar Heating Effects due to Local Shadowing.

The force and moment expressions due to solar radiation pressure⁸ will be evaluated over the part of the illuminated structure as a function of the percentage illumination. Due to the complexity of the problem it is anticipated that only numerical integration will be used to evaluate the forces and moments. Expressions for thermal deformations of the structures due to the shadowing will be developed. The moments due to solar radiation pressure, as a result of the thermally deflected structure, will also be evaluated. For selected shadowing conditions, the force and moment expressions will be used to evaluate the performance of the previously developed control laws. Where necessary appropriate modifications in the control gains and/or form of the control laws will be considered.

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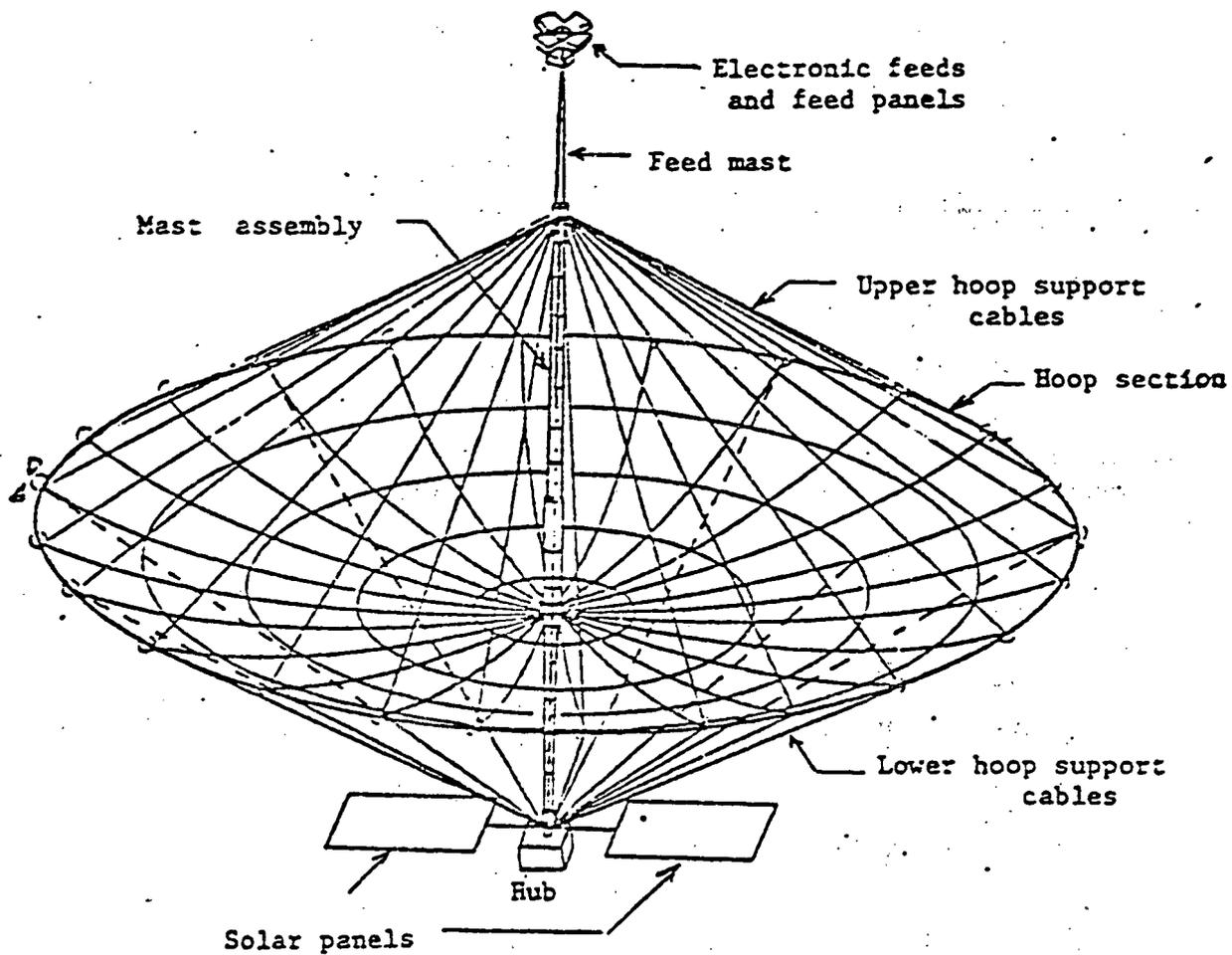


Fig. 1 The Hoop/Column Antenna System

Proposed Studies to Be Performed During the Period

July 1984 - July 1985

by

Mr. A.S. Sivaramachandran, Ph.D. Student, Mechanical Engineering

Preliminary Analysis of a Hybrid Control System for Space Mast Structures

I. Introduction

During the next grant period it is proposed to commence an analysis of a hybrid control system for space mast structures. It is anticipated that this first phase would require both analytical and numerical techniques. A proposed candidate space experiment¹ possibly suitable for the Space Technology Experiments Platform (STEP) would involve a long flexible antenna mast which is attached to the Shuttle orbiter and which could be dynamically excited by the accelerations induced on the orbiter. In Ref. 1 a simple method for selecting a vibration absorber for a large flexible mast was described, based on Den Hartog's vibration absorber theory² for a two-degree-of-freedom system. The results indicated that for large flexible masts (lengths of 100m.), the mass of the vibration absorber required for tip deflection tolerances of the order of centimeters may be at least an order of magnitude larger than the antenna feed mass at the tip of the mast.¹ Recently Juang³ extended the work of Ref. 1, by developing an optimization scheme, using a quadratic cost function, which resulted in the optimum sizing of the tip vibration absorber. It was concluded that non-colocated active control and/or distributed passive control may be necessary when the

initial conditions are such that a prohibitively large mass ratio result for the sizing of the absorber, or when multiple system modes are likely to be excited by external disturbances. With this in mind, it is proposed to consider a hybrid control system consisting of one (or more) active point actuators acting simultaneously with the passive (damper) absorber.

The motivation for considering such a hybrid control system may be found in Refs. 4 and 5 where the dynamics and control of free-free earth pointing beams and platforms were considered. These structures, in equilibrium, would assume an orientation along the local horizontal. It was assumed that gravitational stabilization could be provided by attaching a rigid light weight dumb-bell at the center of mass by a spring loaded hinge, which could also provide passive viscous damping. In addition, orientation and shape control was also assumed to be provided by active point thrusters. This control system, when operated in a hybrid manner, was seen to generally result in improved transient characteristics while requiring less over-all force impulse than that required for the active system operating alone. It is the objective of the present study to find, by appropriate design, a suitable trade-off between absorber mass required in the former case and the combined resulting mass of the proposed hybrid control system. A clear advantage of the hybrid control system is the obvious built-in redundancy offered by both passive and active components.

2. Definition of the Problem

Large mast-like structures have been proposed for a variety of space applications such as in the key supporting structure of multi-beam orbiting antenna systems, and may form the major elements in the construction of modular type space stations. A particular example of the space mast in the proposed 55 meter diameter offset wrap-rib space antenna system is described in Ref. 1 (Fig. 1). In some of these applications, where the mast is attached to the orbiter, the mast can be modelled as a long, flexible cantilevered beam with a concentrated tip load. The problem is to control the deflections at pre-selected points on the mast, once the disturbing forces/torques at the root (connected to the Shuttle orbiter) are known. To realize this control a combination of any one of the following control concepts may be considered:

- (1) a passive vibration absorber at a pre-selected points on the mast;
- (2) one or more active point actuators at pre-selected points; or
- (3) a varying moment scheme, in which the position of a fixed mass is continuously varied along the longitudinal direction of the mast.

3. Review of Different Formulations

3a. Den Hartog's Model²

Den Hartog, in his book on "Mechanical Vibrations" (Ref. 2) has shown that the amplitude of vibrations of a single-degree-of-

freedom-system (Fig. 2a) can be controlled by attaching a secondary mass-spring system, thereby converting it into a two-degree-of-freedom-system (Fig. 2b). The analysis of this system is presented in Ref. 2, giving also a plot of amplitude as a function of frequency. The existence of two fixed points, P and Q (Fig. 3), in this plot has been well-emphasized. Through these points pass all the curves, irrespective of the value of damping. This fact has been exploited to develop the theory of the vibration-absorber that minimizes the amplitude of vibration of the main system. An absorber can be tuned also in such a way that its frequency is made equal to the frequency of the main system.

3.b Card's Analysis¹

In his paper, cited as Ref. 1, Card has presented an analysis of the vibration-absorber theory applied to space-mast structures. Using Den Hartog's theory as the basis, equations have been developed for the two cases separately, namely, the case where the vibration amplitude of the main system is minimized, (referred to as the "best-tuned absorber") and the case where both the frequencies are matched ("frequency-matched absorber"). The space mast structure has been approximated as a long cantilever beam with an equivalent static load at the free end. One third the mass of the beam has been assumed to be concentrated at the free end, acting along with the feed mass. The mass of the absorber, normalized with respect to the combined mass of the antenna-system and connected structures, has been plotted against the length of the cantilever beam in both the best tuned case and the frequency matched case. The graphs indicate that the mass of

the absorber, in the best tuned case, becomes prohibitively large as the mast length approaches 62 m. In the frequency matched case there is no real solution beyond a beam length of 40.5 m. For arriving at these values the author has assumed orbiter disturbances of the order 0.001 radians/sec², and the requirement for the tip deflections to be controlled within + 10 cm displacement from the nominal equilibrium position. An equivalent mass of 360 kg has been assumed to be acting at the free end of the beam having a stiffness of 2×10^7 N.-m².

Evidently the conclusion is that a passive damper alone may not be the choice for large space structures. The results of the analysis suggest that, as an alternative, an active mode of control, or a hybrid system which combines features of both active and passive systems, should be considered.

3.c The Present Proposal

According to the present proposal, one or two point actuators are proposed to be used in combination with the passive absorber (Fig. 4a). A drive motor mounted on the beam can translate, on command, the entire block which could accommodate the absorber as well as the point actuator. Any standard mechanism such as the rack and pinion arrangement or helical screw mechanism is to be thought of for converting the rotary motion of the drive motor into linear motion. In addition to supplying a varying moment for control, this sort of arrangement will ensure also that the point loads are not applied at any of the nodal points of the key modes of vibration. One possible disadvantage

of this arrangement would be that the mass of the drive motor and point actuators could be a "burden" on the flexible beam, without effectively contributing to the absorber mass. This drawback can be partially eliminated by using an arrangement as shown in Fig. 4b. In this case the drive motor itself forms part of the absorber mass, serving a dual function. The drive shaft is not rigidly connected to the beam, although it can be engaged with the rack attached to the beam. An ideal design should take care of the following:

- (1) nodal points of key modes to be controlled are avoided in actuator placement;
- (2) the operation of the drive motor does not further complicate the dynamics of the system; i.e. - care must be taken to avoid undesired interaction torques or resonances due to misalignments, asymmetries, etc.
- (3) energy loss due to friction is minimized for the optimum design of the drive motor.

The analysis may be carried out for the best tuned and frequency matched absorber in this case also, of course, taking into consideration the additional effect of the point actuators as well.

4. Methodology

The research activity can be streamlined in the following steps:

- Step 1: Use Den Hartog's model of a two-degree-of-freedom-system for designing a fixed vibration absorber. Study the effects of varying the absorber mass, spring constant and damping factor, leading to an optimum design.^{3,6}

- Step 2: Add the varying-moment technique and study the effects of moving the absorber mass along the length of the mast using a drive motor.
- Step 3: Incorporate now the effect of a point thruster at a fixed point on the beam and synthesize the control law gains, using standard existing software algorithms⁷ as applied to modern control theory.
- Step 4: Combine Steps 1 and 3 for the hybrid control system, evaluating the trade-off points.
- Step 5: Combine Steps 2 and 3 to include the varying moment technique.
- Step 6: Expand the beam model now to a multi-degree-of-freedom system for obtaining more realistic results.
- Step 7: Design a suitable scaled laboratory model for validating the performance of the hybrid control system. Prepare a master plan for simulating the disturbing forces/torques and measuring the responses.
- Step 8: Develop the dynamic model, test-it and correlate the theoretical and experimental results

5. Proposed Schedule

The task could be accomplished in 3 phases:

Phase 1 (First year): steps 1 to 5 (inclusive)

Analysis based on a two-degree-of-freedom approximation could be accomplished during the first year. This will give an insight into the more complicated multi-degree-of-freedom model. Included in the analysis will be the simulation of the effect of the drive motor for the varying-moment technique and the use of the ORACLS⁷ software package.

Phase II (Second year): steps 6 and 7

Extension of the analysis for multi-degree-of-freedom systems, possibly to include elastic displacements due to transverse bending as well as other flexible modes, could be completed during this phase. This involves a reformulation of the more complex mathematical model. Design of the scale model and preparation of the drawings could be carried out. Specifications of the required instrumentation would be decided after conducting a thorough survey in this area.

Phase III (Third year): step 8

Fabrication of the scale model, procurement of sensors, assembly and testing are planned for this phase. Finally, correlations between experimental and numerically simulated results would be completed and conclusions made concerning the adequacy of both the scale laboratory model and the simulated mathematical model in predicting the actual results expected during an in-orbit test situation. Special consideration of appropriate scaling must be taken into account to insure accurate laboratory modelling of expected disturbance effects.

References

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WRAP-RIB LMSS CONFIGURATION AND MASS PROPERTIES

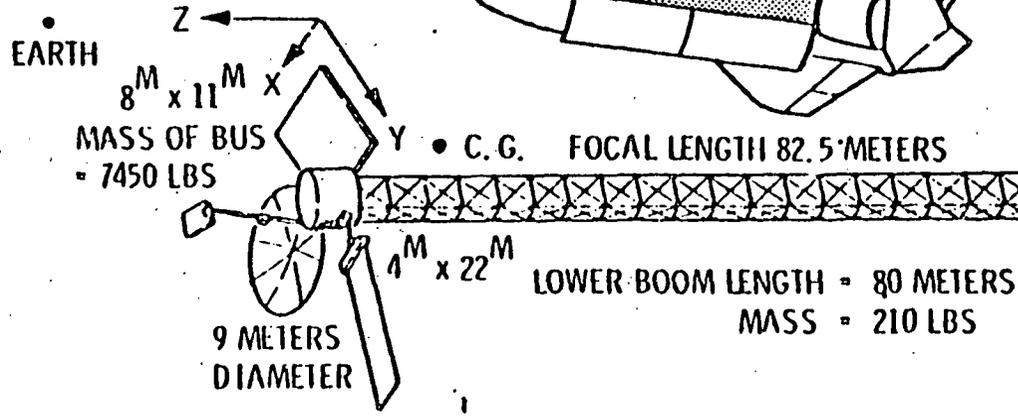
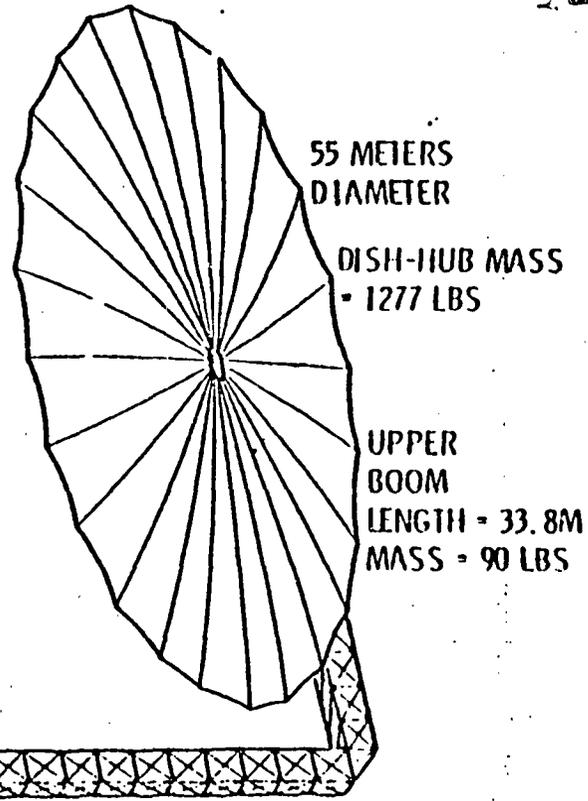
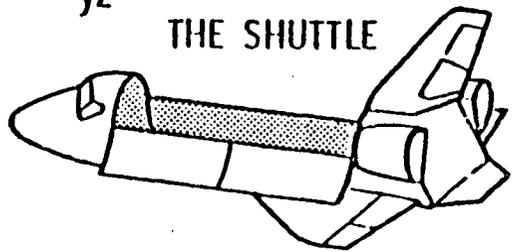
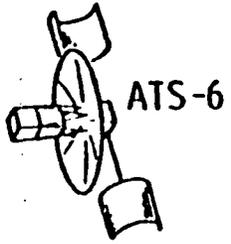
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TOTAL MASS 9695 LBS

MOMENTS OF INERTIA

$$\begin{cases} I_x = 2.91 \times 10^6 \text{ SLUG-FT}^2 \\ I_y = 2.64 \times 10^6 \\ I_z = 0.37 \times 10^6 \end{cases}$$

PRODUCTS OF INERTIA

$$\begin{cases} I_{xy} = -3.56 \times 10^3 \\ I_{xz} = -4.22 \times 10^3 \\ I_{yz} = 0.72 \times 10^6 \end{cases}$$


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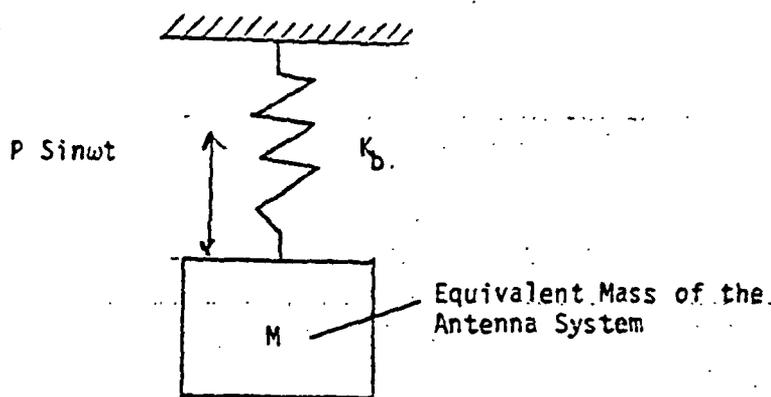


Figure 2.a. SINGLE-DEGREE-OF-FREEDOM APPROXIMATION

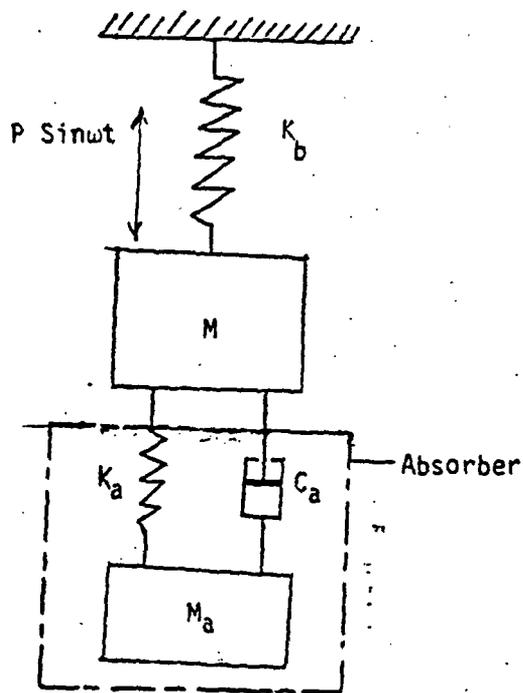


Figure 2.b. ABSORBER MASS ADDED TO THE MAIN SYSTEM, CONVERTING IT INTO A TWO-DEGREE-OF-FREEDOM SYSTEM.

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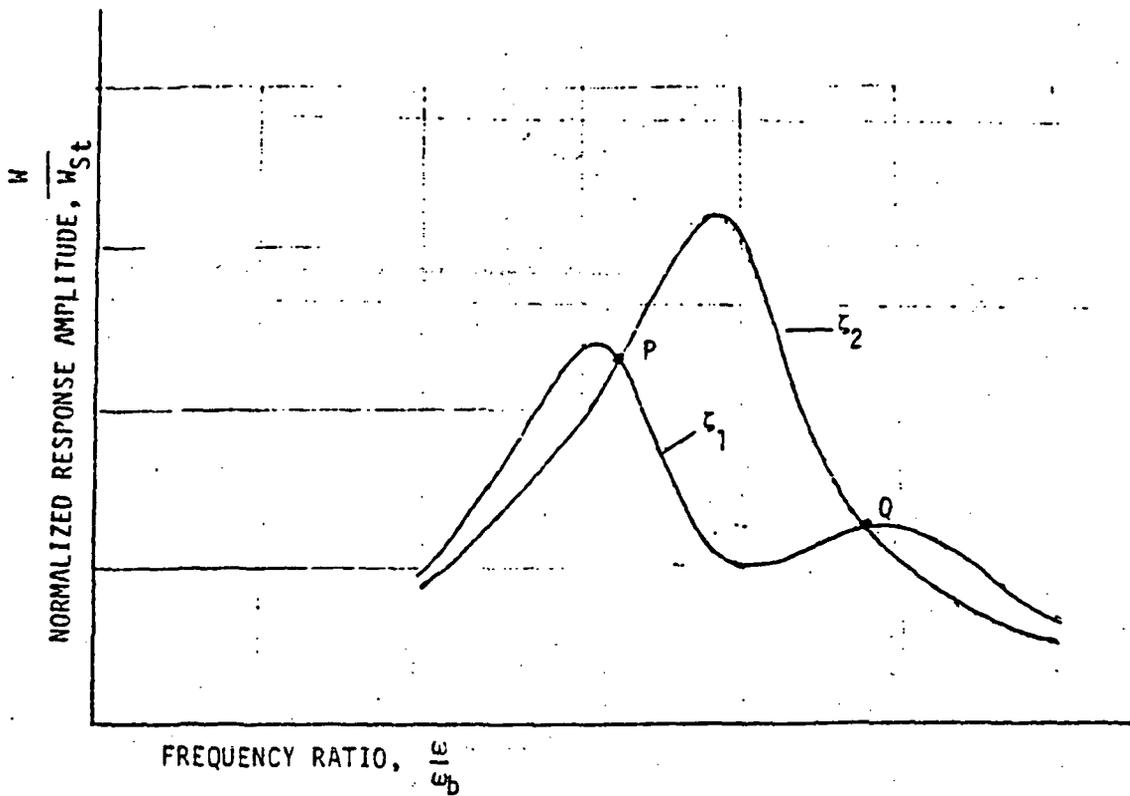


Figure 3. NORMALIZED RESPONSE AMPLITUDE PLOTTED AGAINST
FREQUENCY RATIO, WITH DAMPING AS A PARAMETER

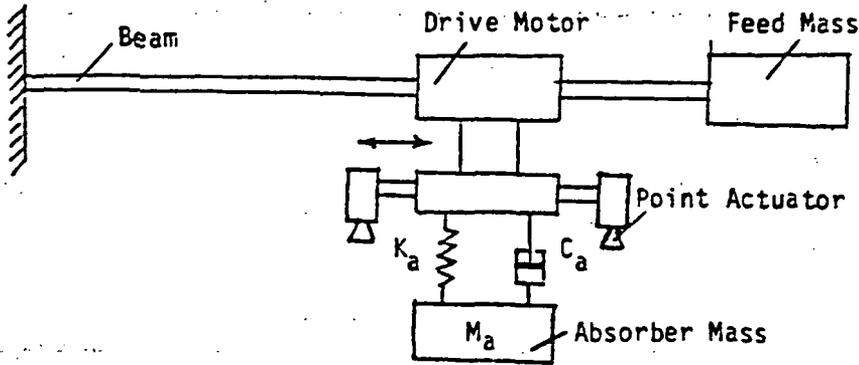


Figure 4.a. SCHEMATIC OF THE HYBRID SYSTEM IN WHICH THE AXIAL POSITIONS OF THE ABSORBER MASS AND POINT ACTUATOR CAN BE VARIED USING A DRIVE MOTOR.

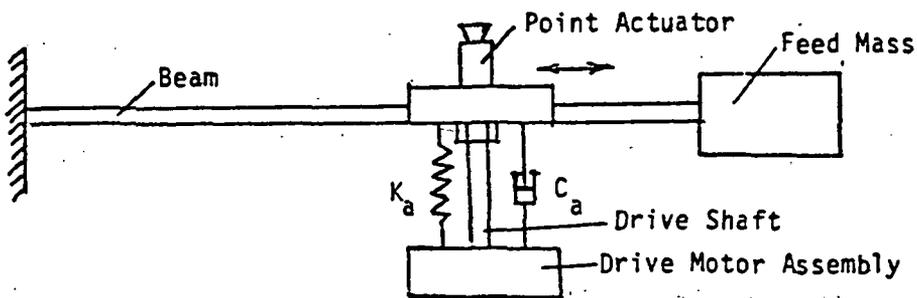


Figure 4.b. SCHEMATIC ARRANGEMENT OF THE HYBRID SYSTEM IN WHICH THE DRIVE MOTOR ASSEMBLY FORMS PART OF THE ABSORBER MASS.

Proposed Studies to Be Performed During the Period

July 1984 - July 1985

by

Mr. S. Ananthakrishnan, Graduate Research Assistant

Mechanical Engineering

STOCHASTIC OPTIMAL CONTROL OF A FLEXIBLE SPACE ANTENNA SYSTEM

Earlier analyses of the Hoop/Column System considered either a deterministic linear system with noise free plant and sensors,² or a stochastic linear system (with plant and sensor noise) but with the restriction that sensors are collocated and that only torque actuators on the feed mast are considered in controlling the antenna shape and attitude.³ In the proposed controls analysis here both plant and measurement noise will be taken under consideration; in addition, the controls analysis will be carried out with one of the actuators assumed to be placed on the hoop. (In Ref.2 the controls analysis has been carried out with a single actuator on the hoop). A similar analysis has been done for a spacecraft with dynamically significant elastic appendages attached to a rigid central part.⁴

It will be assumed that the complete state, $X(t)$, of the plant cannot be accurately measured at all times and will consequently not be available for feedback. This assumption is true in practical control systems since noise is present in both the plant as well as the sensors. Therefore, in the proposed control law design of this investigation both sensor and plant noise will be included. It will be assumed that the continuous linear system

under consideration is driven by a white Gaussian process with known statistical properties.

When the noise processes, $w(t)$ and $v(t)$, are present, the optimal control problem must be posed differently than for the deterministic case, since the exact value of the state vector is unknown due to the noisy measurement data. A statistical measure of the performance is needed and this can be achieved by taking the expected value of the performance index.⁵

$$J = E \left(\lim_{t_f \rightarrow \infty} \frac{1}{2t_f} \int_{t_0}^{t_f} (X(t)Q(t)X(t) + U(t)R(t)U(t)) dt \right) \quad (1)$$

where

J - cost function

E - expectation value operator

t - initial time

t - terminal time

$X(t)$ - state vector

$U(t)$ - control vector

$Q(t), R(t)$ - positive semi-definite and positive definite (respectively) state and control weighting matrices.

The optimal stochastic control problem is to choose $U(t)$ so that J is minimized subject to the equation of motion

$$\dot{X}(t) = A(t)X(t) + B(t)U(t) + G(t)w(t) \quad (2)$$

where

$A(t), B(t), G(t)$ are matrices of compatible dimension and $w(t)$ is the plant noise. If a feedback control is sought, $U(t)$ depends on the measurement data, $Y(t)$, which can be related to the state

according to:

$$Y(t) = H(t)X(t) + v(t) \quad (3)$$

where

$Y(t)$ - measurement vector

$H(t)$ - observation matrix

$v(t)$ - sensor noise

The optimal control law consists of two separate cascaded functions. First, a conventional Kalman filter is employed to obtain an optimal estimate of the state vector. Then, the control command, $U(t)$, is generated according to the relation,

$$U(t) = -C(t)\hat{X}(t) \quad (4)$$

Where $C(t)$ is the set of control gains derived in the deterministic case.

$\hat{X}(t)$ - estimate of the state vector, $X(t)$

The following figure, Fig.1, shows the functional diagram of the control law.⁵

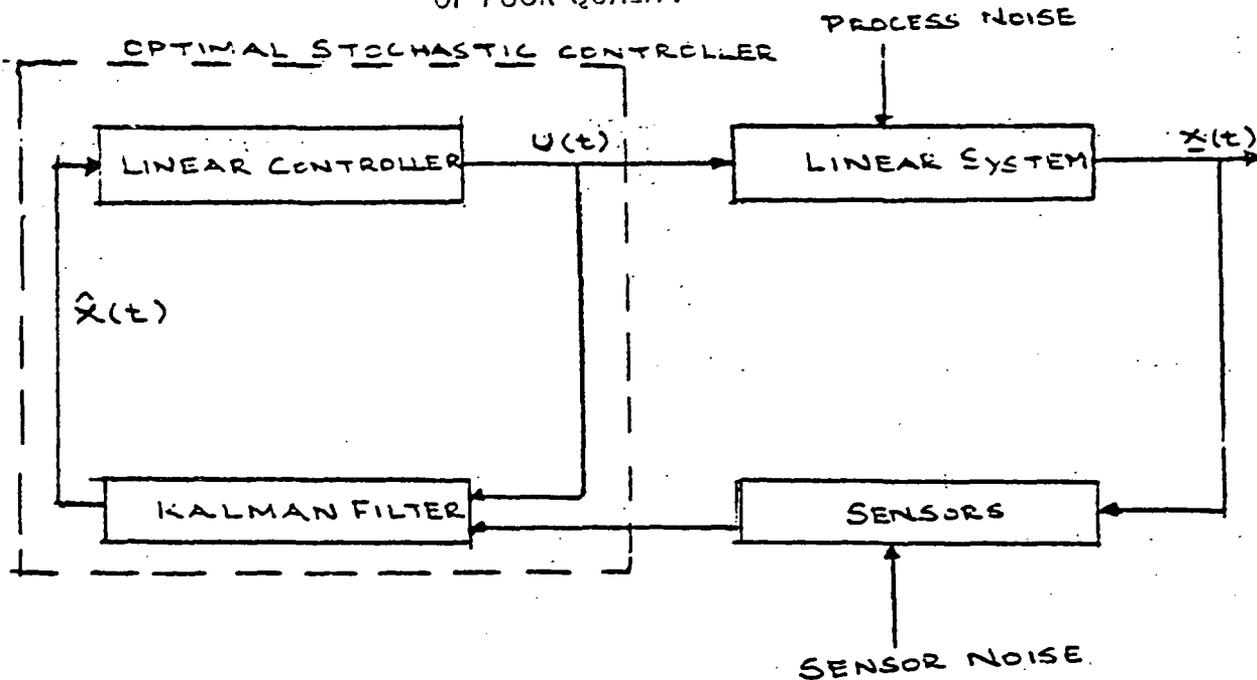


FIG. 1

DESCRIPTION OF THE MODEL UNDER CONSIDERATION:

The Hoop/Column antenna system is one of the configurations under consideration for use in the future multi-beam Land Mobile Satellite System⁶, designed to provide point to point communications for 250,000 subscribers across the U.S in the mid 1990s. The system is based on a large geosynchronous relay antenna and a number of mobile, Earth based receivers. In order to achieve the required RF performance a pointing accuracy of (0.03-0.10) degree RMS and a surface (antenna) accuracy of 12mm RMS will be required. The Hoop/Column antenna system², depicted in Fig. 2 in the deployed configuration, contains the deployable (telescoping) mast system connected to the hoop by support cables under tension. The hoop contains 48 rigid sections, to be deployed by motor drive units. The desired shape of the RF reflective mesh is produced by a secondary drawing surface using surface control cables. The reflective mesh is connected to the hoop by quartz or

graphite stringers. At one end of the mast the electronic feed assemblies are positioned, whereas at the other end are the principal solar arrays connected to the main bus based control.

MATHEMATICAL FORMULATION OF THE PROBLEM:

The dynamic model of the Hoop/Column structural system in the absence of damping can be represented as

$$M\ddot{X} + KX = B_c U \quad (5)$$

where X is the state vector containing the generalized coordinates of each node and will be of the order (nx6) for n number of nodes and all 6 degrees of freedom. M is the modal matrix of order (6nx6n) and K is the stiffness matrix of order (6nx6n). The control matrix, B, is of the order of (6nxp) for p number of actuators to be arranged on the structure. The data supplied by NASA¹ has eigenvectors for 112 nodes and, therefore, n=112 for the present model. To decrease the dimensionality of the problem a modal transformation is carried out, by defining

$$X = \phi q \quad (6)$$

where, ϕ is the matrix containing the eigen vectors of equation (5) and is of the order (6nxm), for m number of modes and q is the vector of order (mx1). Through diagonalization of equation (5) the following matrix equation is obtained.

$$(\phi^T M \phi) \ddot{q} + (\phi^T K \phi) q = \phi^T B_c U \quad (7)$$

or

$$(-m_i) \ddot{q} + (-k_i) q = \phi^T B_c U \quad (8)$$

and

$$[m_i] = \begin{bmatrix} m_1 & & \\ & m_2 & \\ & & \ddots \\ & & & m_m \end{bmatrix} \quad (9)$$

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where

m_i - modal masses, and

$$[k_i] = \begin{bmatrix} k_1 & & & \\ & k_2 & & \\ & & \dots & \\ & & & k_n \end{bmatrix} \quad (10)$$

where

k_i - modal stiffnesses

Equation(7) can be written in the state vector form as

$$\begin{bmatrix} \dot{q} \\ \ddot{q} \end{bmatrix} = \begin{bmatrix} 0 & I \\ -\frac{1}{m_i} k_i & 0 \end{bmatrix} \begin{bmatrix} q \\ \dot{q} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{m_i} \phi^T U \end{bmatrix} \quad (11)$$

where k_i , m_i , ϕ are available with the finite element model.

Equation(11) is of the form

$$\dot{X}(t) = AX(t) + BU(t) \quad (12)$$

Now considering the stochastic problem the plant noise is included in equation(12) to yield a stochastic linear dynamic system of the form,

$$\dot{X}(t) = AX + BU + Gw \quad (13)$$

The measurement equation can be written as

$$Y(t) = HX + v \quad (14)$$

The plant noise and the measurement noise are assumed to be white Gaussian processes with zero mean. After minimizing the cost function, the optimal control vector U becomes

$$U = -C\hat{X} \quad (15)$$

where

\hat{X} - estimate of X

C - control gain given by

$$C = \bar{R}^{-1} E^T K \quad (16)$$

where K is the steady state solution of the matrix Riccati differential equation

$$-\dot{K} = KA + A^T K - KBR^{-1}B^T K + Q \quad (17)$$

where R and Q are the control and state weighting matrices, respectively.

The estimate, \hat{X} , is obtained from

$$\dot{\hat{X}} = A\hat{X} + BU + F(Y - H\hat{X}) \quad (18)$$

with the filter gain, F, expressed as

$$F = P H^T V^{-1} \quad (19)$$

where P is the solution of the filter matrix Riccati differential equation

$$-\frac{dP}{dt} = \dot{P} = AP + PA^T - PH^T V^{-1} HP + GWG^T \quad (20)$$

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where

$$\begin{aligned} V &= E(vv^T) \text{ and} \\ W &= E(ww^T) \end{aligned} \quad (21)$$

The linear model of the plant and the estimator can be written as

$$\dot{\hat{X}} = A\hat{X} - BC\hat{X} + Gw \quad (22)$$

$$\dot{\hat{X}} = (A - FH - BC)\hat{X} + FHx + Fv \quad (23)$$

The general scheme of the stochastic optimal control configuration represented by equations (22) and (23) is shown in Figure.3. This configuration is taken as the basis for studying the system behavior.

An attempt will be made to obtain numerical results for the Hoop/Column System filter gains and the control forces required in the actuators, using ORACLS - a system for linear quadratic Gaussian control law design. Interactive computer graphics techniques will be used to interpret the transient performance characteristics. Comparison of the numerical results with those of Ref(2) and Ref(3) is expected to provide an idea about the degradation of the system performance due to the noise characteristics. If the control and filter gains in the presence of noise deviates much from the case where noise is absent the optimal control law will be redesigned.

References

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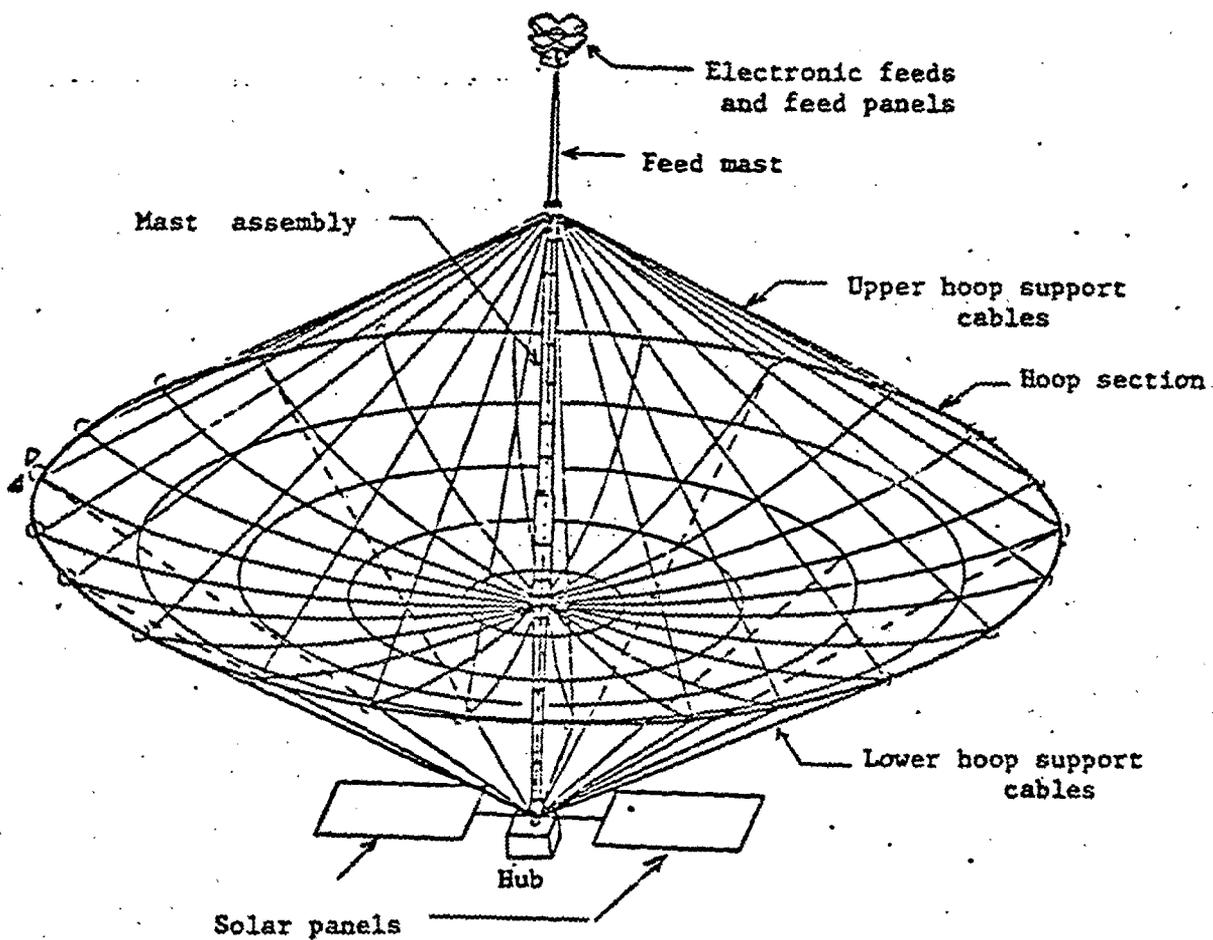


Fig. 2 The Hoop/Column Antenna System

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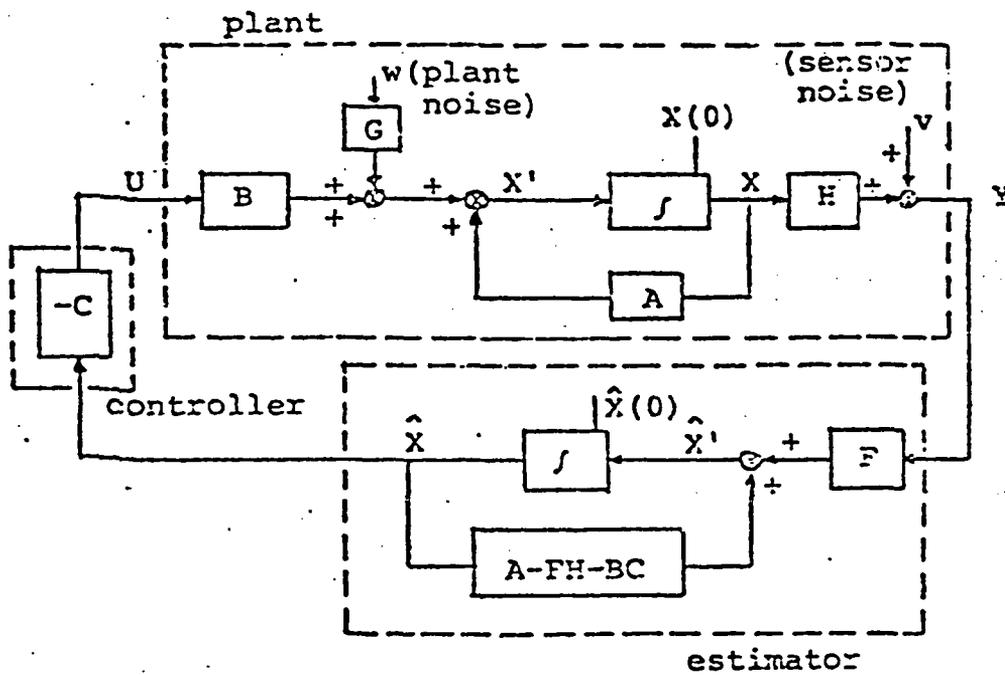


Fig. 3 Stochastic optimal control configuration

PLAN 1 - Budget

Dr. Peter M. Bainum, Principal Investigator

Year 1984-1985

Principal Investigator
(3 man-month)

Wages - Preparation of Reports
Presentation Materials

Total Salaries and Wages

Fringe Benefits (28% salaries & wages)

Supplies

Journal Page Charges, preprints

Travel

Computer Time - University IBM System

SUB-TOTAL

INDIRECT COSTS (90% of Sub-Total)

Graduate Students
3 Ph.D. level
Stipends Summer

Stipends Winter

Equipment (Computer Terminals, etc.)

TOTAL

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135 183

Deployment Dynamics

by

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DEPLOYMENT DYNAMICS

Actions have been taken to initiate research in the area of deployment dynamics as a complement to the projects already under way in the Institute. It is planned that Dr. Irving W. Jones, Professor of Civil Engineering and Dr. K.C. Park of the Applied Mechanics Laboratory, Lockheed Missiles and Space Company (LMSC) will be co-principal investigators for this work. To date, Dr. Jones and Dr. Park have met at NASA Langley Research Center with Dr. J. Housner, Technical Monitor, to discuss possible administrative formats for the collaborative effort, some results of work done at NASA Langley Research Center in the area of deployment dynamics and possible directions for efforts to advance the status of technology in this field. These matters will continue to be pursued and will result in the preparation of a proposal to NASA Langley Research Center for a FY 1985 grant to fund Howard and LMSC, with some supplemental funding to be provided by the Institute.

BUDGET

1. Salaries		
I. Jones	5,000.00	
Fringe Benefits		
@ 28%	1,400.00	
TOTAL SALARIES		6,400.00
2. SUB-CONTRACTOR		
Lockheed (K.C. Park)		<u>5,000.00</u>
TOTAL		\$11,400.00

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MICROPROCESSOR BASED IMPLEMENTATION OF ATTITUDE AND
SHAPE CONTROL OF LARGE SPACE STRUCTURES

by

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Howard University
Washington, DC 20059

Abstract**Microprocessor Based Implementation of Attitude and Shape Control of Large Space Structures**

The conceptual studies of future space missions in terms of large space structures are gaining wide attention in academic as well as industrial communities. One of the main areas of interest is the attitude and shape control of such large space structures. Many of the studies assume that this control is achieved using modern control laws and state variable feedback. Such control laws have to be implemented by on board microprocessors to generate signals which in turn operate the actuators. The purpose of the proposal is to study the feasibility of off the shelf 8 bit and 16 bit microprocessors to implement linear state variable feedback control laws and assessing the real time response to spacecraft dynamics, writing the needed software and implementing it on a microprocessor to relate the complexity of the dynamic model (order of system matrix) and the computational speed of the microprocessor. The outcome of this research is a laboratory consisting of an experimental setup of a beam, microprocessor system for implementing the control laws and the needed generalized software to implement any state variable feedback control system.

Microprocessor Based Implementation of Attitude and Shape Control of Large Space Structures

The linearised equations of motion of large space structures can be described by a set of coupled second order differential equations as:⁵

$$\ddot{X} + K\dot{X} + DX = BU \quad (1)$$

where

X is an $n \times 1$ position vector including attitude and vibrational coordinates.

K is an $n \times n$ position matrix.

D is an $n \times n$ damping matrix.

B is an $n \times m$ control influence matrix.

U is an $m \times 1$ control vector.

The most commonly used control law is of the form⁶

$$U = -F_p X - F_r \dot{X} \quad (2)$$

with

F_r = $m \times n$ rate feedback gain matrix

F_p = $m \times n$ position feedback gain matrix. In reality, all the states (X and \dot{X}) are not directly available for sensor measurements. The output available may be of the form

$$Y = H\dot{X} + v \quad (3)$$

where

$$\underline{X} = [\underline{X}; \underline{X}]^T$$

\underline{Y} is the sensor output.

H is the sensor influence matrix, $(p \times 2n)$.

and \underline{v} is the noise, $(2n \times 1)$.

One has to estimate \underline{X} (say \underline{X}) from the outputs \underline{Y} , available using state estimator of the form:

$$\underline{X} = A\underline{X} + BU + G(\underline{Y} - H\underline{X}) \quad (4)$$

where

\underline{X} = estimate value of \underline{X}

$$A = \begin{bmatrix} 0 & I \\ -D & -K \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ B \end{bmatrix}$$

G is the kalman gain matrix.

Implementing a control law of form (2) with X and \underline{X} substituted by their corresponding estimated values (\underline{X}) directly translates to evaluating U and solving differential equation (4) on a microprocessor.

Selection of a Microprocessor

A large variety of microprocessors that are available off the shelf will be compared for the word size, cycle time, and instruction repertoire. The 8 bit and 16 bit microprocessors will be considered for the range of control variables of interest. The effect of the microprocessors output at discrete intervals of time on the continuous dynamic model will be used as a criterion

to decide the optimum cycle time of the microprocessors to be selected. For a wide variety of microprocessors, the maximum dimension of the dynamic model it can handle to supply control signals in real time without impairing the continuous control system design characteristics.

The main characteristics of the commercial microprocessors that will be compared for selection are the following:

- (1) general register size(8 bit/ 16 bit/ 32 bit)
- (2) cycle time
- (3) instruction repertoire(execution times)
- (4) memory addressability

No special attention may be paid for the adoptability of these commercial microprocessors to space environments in this phase of study.

Control algorithms will be implemented using software written in assembler language and then loaded in memory in directly executable code.

Evaluation

The different microprocessors are evaluated in terms of the performance of the control system. The microprocessor controlled actuator has change of the magnitude at discrete intervals of time. The minimum time between two consecutive control signals depend upon the overall response of the microprocessor to input signals. The relation between state inputs and control signals can be described as

$$U_{i+1} = FX_i \quad (6)$$

where

X_i is the estimated state at time t_i

U_{i+1} is the control signal at time t_{i+1}

F is the gain matrix.

Thus the effect of digital step control signals on the performance of a continuous system will be evaluated in terms of required time response and stability. The possible compensation for the time delay due to microprocessor may be incorporated in terms of discrete state predictors instead of state estimators.

Practical Example

A free-free beam or a free-free square plate in a low earth orbit will be taken as an example to test the microprocessor based control system. The model may be of the order of 10 modes (rigid as well as flexible) thus giving a 20th order plant. The dynamics of the continuous model will be simulated on an analog computer and the microprocessor based control system will be interfaced with analog computer to have simulation of closed loop control system and dynamic plant behavior.

Equipments

The following equipments are needed for completing the investigation proposed here.

1. Microprocessor development system.
2. A/D and D/A Converter cards and required interfaces.
3. Strain gauges, Deflection and Velocity Sensors.
4. Supporting electronic components.

The required laboratory space for conducting the necessary

experiments is available from Mechanical Engineering
Laboratories.

References

1. "Large Space Systems Technology- 1980" , Vol I & II, NASA Conference Publication 2168, Second Annual Technical Review held at NASA Langley Research Center, Hampton, Virginia, Nov 18-20, 1980.
2. "Large Space Structures Technology- 1981", Parts 1&2, NASA Conference Publication 2215, Third Annual Technical Review held at NASA Langley Research Center, Hampton, Virginia, Nov 16-19, 1981.
3. Proceedings of the First, Second, & Third VPI & SU/AIAA Symposiums on Dynamics and Control of Large Flexible Spacecrafts, 1977, 1979, 1981.
4. Reddy, A.S.S.R., Ph.D Thesis on "Attitude and Shape Control of Large Space Structures", Dept. of Mechanical Engineering, Howard University, Nov, 1982.
5. Hughes, P.C., and Skelton, R.E., "Controllability and Observability of Linear Matrix Second Order Systems", Transactions of ASME, June, 1980, Vol 47, pp. 415-420.
6. Bainum, P.M., et al., "Dynamics and Control of Large Space Structures", Final Reports of NASA Grant: NSG-1414, Supplements I-VI, 1977-1982.
7. Gelb, Arthur., editor., "Applied Optimal Estimation", The MIT Press, Massachusetts Institute of Technology, Cambridge, Mass., 1974.
8. Proceedings of the AIAA Conference on "Computers in Aerospace IV", oct 24-26, 1983, Sheraton- Hartford, Connecticut.
9. Williams, J.P., and Montgomery, R.C., "Simulation and Testing of Digital Control on a Flexible Beam", paper no. 81-1569, Proceedings of the 1981 AIAA Guidance and Control Conference, August, 1981, pp. 403-409.
10. Farrar, F.A. and Eidens, R.S., "Microprocessor Requirements for Implementing Modern Control Logic", IEEE Transactions on Automatic Control, Vol. AC-25, No. 3, June 1980, pp. 461-468.

Proposed Budget

Personnel Salaries:

Principal Investigator

(2.5 Man Months)

Graduate Research Assistant

(Full Time May16, 1985-Aug15, 1985)

Graduate Research Assistant

(Half Time Jan1, 1985-May15, 1985

and Aug16, 1985-Dec31, 1985)

Total Salaries

wages

Total Salaries & wages

Fringe Benefits(28% of Investigators

Salaries and Wages)

Supplies(Microprocessor Development Sy-

stem, Support Components & Systems)

Travel(3 Trips to NASA(with student)

Travel to other professional conferences

MODIFIED TOTAL DIRECT COSTS

INDIRECT COSTS

TOTAL

III. HU HUMAN SUPPORT PLAN

A. RESUMES OF KEY PERSONNEL

A. Taft H. Broome, Jr., D. Sc.*
Acting Chairman
Department of Civil Engineering

ACADEMIC PREPARATION

Engineering Degrees

Institution	Date of Graduation	Degree
A. Howard University	1966	B.S.C.E.
B. George Washington University	1968	M.S.E.
C. George Washington University	1972	D.Sc.

SCHOLARLY AND CREATIVE PRODUCTIVITY (Sample)

Technical Reports (Sample)

- A. Broome, T.H. and Hyman, B.I., "A New Approach to Shallow Shell Theory", NAVSHIPS, subproject SF0130302, Task 1960, Washington, D.C., 1968.
- B. Broome, T.H. and Hyman, B.I., "An Approach to the Analysis of Spheroidal Shells with Locat Flat Sports", NAVSHIPS, subproject SF0130302, Task 1960, Washington, D.C., 1971.
- C. Hyman, B.I. and Broome, T.H., "A Survey of Computer Programs for Structural Analysis of Pressure Vessels", published by and for the private use of MPR Associates, 1140 Connecticut Avenue, N.W., Washington, D.C., October, 1972.

Publications (Sample)

- A. Broome, T.H. and Hyman, B.I., "An Analysis of Shallow Spheroidal Shells By a Semi-Inverse Contour Method", International Journal of Solids and Structures, December, 1975. (Broome's D.Sc. Dissertation, Hyman advising).
- B. Tesfaye, E. and Broome, T.H., "Effect of Weight on the Stability of Masonry Walls", J. of the Structural Division, A.S.C.E., May, 1978, (Tesfaye's M.S. Thesis, Broome advising).
- C. Broome, T.H., "Issues in Ethics for Engineering School Publications: An NSF-Funded Program", Professional Engineer, January, 1978.
- D. Citations for contributions in:

O'Neill, Gerard K., Space Resources and Space Settlements, NASA SP-428, Washington, D.C., 1979.

*An extended version of this resume is on file at NASA/Langley as part of the Megamechanics Research Consortium proposal.

T.H. Broome

_____, Science and Engineering Education for the 1980's and Beyond, NSF/Dept. of Education, Washington, D.C., 1980.

Research Projects

- A. Title: "A New Approach to the Solution of Partial Differential Equations with Biomedical Relevance".

Principal Investigator: T.H. Broome

Support: N.I.H. (February 1974 - May 1975), Mini-Grant

Magnitude: \$600.00 for one student

- B. Title: "Weight Minimization of Large Area Expandable Space Structures With Respect to a Minimum Allowable Natural Frequency".

Principal Investigator: T.H. Broome

Support: NASA (December 1974 - March 1978, July 1982 - June, 1983)

Magnitude: \$32,000 with two students (First year)
\$39,811 with two students (Second year)
\$28,370 with two students (Third year under the
new title "Continuum Modeling of Large Area Space Structures").
\$150,000: Megamechanics Research Consortium

- C. Postdoctoral Fellowship

Support: NSF/NEH (September 1980 - February 1982)

Magnitude: \$31,500 ... Stipend
3,000 ... activities support (R.P.I.)
1,500 ... activities support (Howard U.)
\$36,000 ... Total

E. Dr. Ajit K. Choudhury

Associate Professor
Department of Electrical Engineering
Howard University
Washington, D.C. 20059

Present Home Address :-

5635 67th Avenue
Riverdale
Maryland 20737
(301) 577-6514

I ACADEMIC PREPARATION

B.Sc. (Math Hons)
St. Xavier's College, Calcutta
University of Calcutta 1954

M.Sc. (Applied Mathematics)
University of Calcutta, 1958

M.S. (Control Systems Engineering)
University of California
Los Angeles 1967

Ph. D. (Systems Science Engineering)

Major field : Control Systems Engineering

Minor fields: Communications Systems Engineering

Applied Mathematics

University of California

Los Angeles . 1969

PROFESSIONAL EXPERIENCE

ORIGINAL PAGE 13
OF POOR QUALITYA INDUSTRIAL

1. Goddard Space Flight Center

National Research Council Fellow (1970-1972)

Worked on the application of concatenated convolution coding with multifrequency shift keyed signalling for low data rate communication for deep space planetary mission

2. General Electric Company
Space Systems
Beltsville
Maryland

Systems Engineer (1972-1973)

Worked on thermal design of small astronomical spacecraft(SAS-D) and the quality of imagery of Landsat satellite pictures.

3. Summer Employment

(a) Systems Engineer , IBM Manassis,virginia
June 1st to August 22nd, 1974

Worked on the problem of the optimum flow of data back and forth between one big computer and three small computers. This problem appears in the testing of computer chips and semi-conductor devices.

(b) Lewis Research Center, Cleveland
National Aeronautics and Space Administration

Summer Faculty Fellow
June 1st to August 22nd, 1976

Worked on the application Invariant pole technique of modern control systems for the control of large flexible spacecraft.

(c) Goddard Space Flight Center,Greenbelt
NASA Summer Faculty Fellow 1980

Worked on the GPS(Global position Satellite) receiver desing.

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(d) Bell Telephone Laboratories , Holmdel, NJ.

Systems Engineer (June 1st to August 22nd, 1982)

Developed an automatic technique (digital adaptive filtering) to remove the holding sinusoid tone from the received signal in telephone transmission impairments measurements especially the impulse noise, phase drop, gain drop, phase jitter etc. The method was based on adaptive least square filtering.

UNIVERSITY

1. Lecturer. University of California , Los Angeles, spring semester, 1969
Taught course on linear systems

2. Assistant Professor University of Maryland 1969-1970
Taught courses on Control Systems Engineering, Network Analysis, Electrical Machinery.
Performed unfunded research on controllability of Delay-Differential Systems.

3. Assistant Professor. Howard University, Washington, D.C. 1973-1976.
Taught graduate and undergraduate courses on Communications Systems , Control Systems Engineering and Network Analysis.
Performed research on funded NASA Grant on Kalman Filtering.
Developed new graduate courses on Estimation, Filtering , Circuits and Systems

4. Associate Professor . Howard University
Washington, D.C.
1976 to present.

(a) Taught courses on Communications Systems, Control Systems Engineering, Advanced Engineering Analysis, Random process.

(b) Conducted funded research (NASA) on Navigation of small aircraft, Receiver design of low-cost Global position Satellite Receiver design, Hoop-column antenna design for large flexible space structures.

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ADDED BIBLIOGRAPHY.

Construction of Non-regular Pointwise Degenerate Delay-differential Systems.
To appear - IEEE Transactions Automatic Control 1978. Vol. AC-23, No. 3.

Control on Degenerate Delay-difference Systems. To appear in IEEE Transaction,
Automatic Control, 1978.

Construction of Non-regular Pointwise Degenerate Delay-differential Systems.
Its Applications to Control Theory. Proceedings of the Joint Automatic
Control Conference, San Francisco, 1977 pp. 1662 - 1667.

On the Pointwise Completeness of Delay-differential Systems of the Neutral
Type. Siam Journal of Mathematics Analysis and Applications, Vol. 7. No. 6
September, 1976, pp. 913-929.

Controllability of Linear Time-invariant Systems Using Multiple One-
dimensional Linear Delay Feedbacks. Proceedings of the International
Symposium on Dynamical Systems. pp. 317-323. Academic Press, 1976.

Pointwise Degeneracy of Linear Time-invariant Delay-differential Systems.
Proceedings of International Conference on Differential Equations. Edited
by A. Antosiewicz. Academic Press, 1975.

Construction of Time-optimal Zero-output Delay-Feedback Controllers.
The Finite Case. Proceedings of the International Conference on Systems
Theory, Patras, Greece, 1976: Published by Hemisphere Publishing Co.

Ajit Kumar Choudhury

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(continued)

Maximum and Minimum Degeneracy Set of Linear Time-invariant Delay-differential System of the Neutral Type. Proceedings of the International Conference on Nonlinear Systems, Arlington, Texas. Edited by Lakshmikantham. Academic Press, 1977.

On the Existence of an Optional Solution of the Epsilon Variational Problem - Journal of Optimization Theory and Applications. Vol. 11, No. 5, pp. 494-505, 1973.

Necessary and Sufficient Conditions of Pointwise Completeness of Linear Time-invariant Delay-differential Systems. International Journal of Control.

A Contribution to the Controllability of Time-lag Systems, International Journal of Control. Vol. 17, No. 2, pp. 305-373, February 1973.

Algebraic and Transfer-function criteria of Fixed-time Controllability of Linear Time-invariant Delay-differential Systems. International Journal of Control, Vol. 16, No. 6, pp. 1073-1082, December, 1972.

D. Dr. James A. Donaldson

PERSONAL DATA:

Name: James Ashley Donaldson

Birth date: [REDACTED]

Birth place: [REDACTED]

Height: 6' 3½"

Health: Good

Present Address: [REDACTED]

Telephone: [REDACTED]

EDUCATION:

Diploma, Madison County Training School,
Madison, Florida, 1957.

A.B. (Mathematics), Lincoln University,
Lincoln University, Pennsylvania, 1961.

M.S. (Mathematics), University of Illinois,
Urbana, Illinois, 1963.

Ph.D. (Mathematics), University of Illinois,
Urbana, Illinois, 1965.

Results of my mathematical research have been read before the following scientific meetings.

1. The annual meeting of the American Mathematical Society, Chicago, Illinois, January, 1966.
2. The annual meeting of the American Mathematical Society, New Orleans, Louisiana, January, 1969.
3. The annual meeting of the National Institute of Science and Beta Kappa Chi, Philadelphia, Pennsylvania, April, 1973.
4. The annual meeting of the National Institute of Science and Beta Kappa Chi, New Orleans, Louisiana, April, 1974.
5. The Conference Board of Mathematical Sciences regional conference on "Improperly posed problems in partial differential equations", Albuquerque, New Mexico, May, 1974.
6. The International Conference on The Fractional Calculus, New Haven, Connecticut, June, 1974.
7. The International Congress of Mathematicians, Vancouver, British Columbia, Canada, August, 1974.
8. The annual meeting of the American Mathematical Society, Special Session on Singular Cauchy Problems, Washington, D.C., January, 1975.
9. The annual meeting of the American Mathematical Society, Special Session on Special Functions, San Antonio, January, 1976.
10. Mathematical Association of America, Tallahassee, Florida, 1976.
11. First Pan African Congress of Mathematicians, Rabat, Morocco, 1976.
12. The International Conference on Functional Analysis and its Applications, Kumasi, Ghana, August, 1979.
13. The meeting of the American Mathematical Society, Special Session on Differential Equations, Washington, D.C., October, 1979.

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III. PROFESSIONAL EXPERIENCE:

Visiting Lecturer in Mathematics,
Southern University, Baton Rouge, La.,
Summers of 1964, 1965, 1966.

Assistant Professor of Mathematics,
Howard University, Washington, D.C.,
8/65 to 8/66.

Assistant Professor of Mathematics,
University of Illinois (Chicago),
Chicago, Illinois, 8/66 to 8/69.

Visiting Member, Mathematics Institute,
University of Aarhus, Aarhus, Denmark,
Summer, 1969.

Assistant Professor of Mathematics (On Leave),
University of Illinois (Chicago),
Chicago, Illinois, 8/69 to 8/70.

Post Doctoral Fellow and Research Associate in
Mathematics, University of New Mexico,
Albuquerque, New Mexico, 8/69 to 8/70.

Associate Professor of Mathematics,
University of New Mexico, 8/70 to 8/71.

Professor of Mathematics,
Howard University, 1971-

Chairman of the Mathematics Department,
Howard University, 1972-

Visiting Member, Courant Institute of
Mathematical Sciences, New York University,
New York, New York 9/76 - 6/77.

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IV. OTHER PROFESSIONAL EXPERIENCE:

Consultant for The Educational Internship Program at Federal City College, Washington, D.C. (Summer, 1971).

Consultant for The Arthur Flemings Awards Commission, 1973.

Consultant for The College Science Improvement Division of the National Science Foundation, 1973 and 1974.

Member of The Exchange Commission of The International Union of Mathematicians, August, 1974 - 1978.

Member of Science and Technology Commission of the Sixth Pan American Congress, Dar Es Salaam, Tanzania, June, 1974.

Consultant for the National Science Foundation, 1975 and 1977.

Consultant for the Mathematics Department, Jackson State University, Jackson, Mississippi, 1977.

National Research Council Panel (for reviewing applications for NSF Fellowships) 1978 and 1979.

Member at Large, Council of the American Mathematical Society, 1978 - 1980.

Chairman, American Mathematical Society's Committee on Opportunities in Mathematics for members of Disadvantaged Groups, 1980 -

Member, American Mathematical Society's Committee on Service to Mathematicians in Developing Countries.

Member of CUPM, Mathematical Association of America.

D.C. Coordinator of Blacks and Mathematics Program, Mathematical Association of America.

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V. MEMBERSHIPS IN PROFESSIONAL SOCIETIES.

1. The National Association of Mathematicians
2. The American Mathematical Society
(Member of the reviewing staff of the
Mathematical Reviews)
3. The Mathematical Association of America
4. The American Association of the Advancement
of Science
5. American Association of University Professors
6. Association for Women in Mathematics
7. Beta Kappa Chi
8. National Institute of Sciences
9. The Society for Industrial and Applied Mathematicians

VI. MEMBERSHIPS IN HONORARY SCIENTIFIC SOCIETIES.

1. Sigma Xi, 1965-
2. Pi Mu Epsilon, 1974-

VII. AWARDS AND HONORS.

Post Doctoral Research Fellowship, University
of New Mexico, 1969 to 1970.

Election to Membership in Sigma Xi, 1965.

Outstanding Young Man of America, 1976.

Visiting Member, Courant Institute of Mathematical Sciences,
New York University, New York, New York, 1976-1977.

VIII. PARTICIPANT IN SCIENTIFIC MEETINGS AND SYMPOSIA.

The North British Year in Partial Differential Equations at the University of Edinburgh, Edinburgh, Scotland, May-June, 1972.

Summer Seminar on Stochastic Differential Equations, University of Alberta, Edmonton, Alberta, Canada, July 17-28, 1972.

The Conference Board on Mathematical Sciences Regional Conference on Improperly Posed Problems in Partial Differential Equations. University of New Mexico, Albuquerque, New Mexico, May, 1974.

The International Conference on the Fractional Calculus, University of New Haven, New Haven, Connecticut, June, 1974.

The International Congress of Mathematicians, Vancouver, British Columbia, Canada, August, 1974.

A Special Session on Singular Cauchy Problems at the Annual Meeting of the AMS, Washington, D.C., January, 1975.

Le Seminaire de Mathematiques Superieures a L'Universite de Montreal, Montreal, Quebec, Canada, June 16, 1975-July 11, 1975.

Colloque sur L'enseignement des Mathematiques dans les Universites Africaines., Dakar, Senegal, December 8-13, 1975.

A Special Session on Special Functions at the Annual Meeting of the AMS, San Antonio, Texas, January, 1976.

The First Pan African Congress of Mathematicians, Rabat, Morocco, July, 1976.

The AAAS annual meeting, Washington, D.C. 1978.

The International Congress of Mathematicians, Helsinki, Finland, August, 1978.

The International Conference on Functional Analysis and its Applications, Kumasi, Ghana, August, 1979.

A Special Session on Differential Equations at the meeting of AMS at Howard University, October, 1979.

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X. RESEARCH GRANTS.

Junior Investigator, National Science
Foundation Grant #GP 8734 for Research in
Applied Mathematics, University of Illinois
(Chicago), Chicago, Illinois, 1967-1969.

Principal Investigator, National Science
Foundation Grant #GY-11066 for
Research in Analysis, Howard University,
Washington, D.C. 1973-1977

X. RESEARCH PAPERS.

1. Integral Representations of the Extended Airy Integral Type of the Modified Bessel Function. *J. of Math. and Phys.*, Vol. 46, No. 1 (1967)
2. Expansions for $K_\nu(\xi)$ involving Airy's Function. *Proc. of the Cambridge Philosophical Society*, Vol. 66 (1969).
3. A Singular Abstract Cauchy Problem. *Proc. of the National Academy of Science, USA*, Vol. 66, 269 (1970)
4. A Perturbation Series for Cauchy's Problem for Higher-Order Abstract Parabolic Equations. *Proc. of the National Academy of Sciences, USA*, Vol. 67, 41 (1970), (With R. Hersh).
5. New Integral Representations for Solutions of Cauchy's Problem for Abstract Parabolic Equations. *Proc. of National Academy of Sciences, USA*, September, 1971.
6. An Operational Calculus for a Class of Abstract Operator Equations. *Journ. of Math. Analysis and Applications*. Vol. 37, No. 1. Jan. 1972.
7. On the Invariance Principle of Scattering Theory. *University of New Mexico Technical Report No. (259)*. August (1972). (With A. Gibson and R. Hersh).
8. On the Invariance Principle of Scattering Theory. *Journal of Functional Analysis*, Vol. 14 (1973), 131. (With A. Gibson and R. Hersh).
9. A Singular Cauchy Problem with a Small Parameter. *Funkcialaj Ekvacioj (Serio Internacio)*, Vol. 16, 89 (1973).
10. A Family of Integral Representations For The Solution of the Diffusion Equation. (*Proc. Internat. Conf., Univ. New Haven, West Haven, Conn., 1974*) pp. 146-150. *Lecture Notes in Math.*, Vol. 457, Springer, Berlin, 1975.
11. A Uniqueness Class For Two Improperly Posed Problems Arising in Mathematical Physics. Improperly Posed Boundary Value Problems (*Conf., Univ. New Mexico, Albuquerque, N.M., 1974*), pp. 9-16. *Research Notes in Mathematics Series, No. 1, Pitman, London, 1975.*
12. Regular and Singular Perturbation Problems for a Singular Abstract Cauchy Problem. *Duke Mathematical Journal*, Vol. 42, No. 3, 1975. (With George Butcher)

13. The Cauchy Problem for a First Order System of Abstract Operator Equations. Bulletin of the American Mathematical Society, Vol. 81, 576 (1975).
14. The Abstract Cauchy Problem and Banach Space Valued Distributions. Howard University Mathematics Report #13, 38 pages (1975).
15. Some Remarks On Uniqueness for a Class of Singular Abstract Cauchy Problems. Proc. Amer. Math. Soc., Vol. 54, 149 (1976) (With J. Goldstein).
16. The Abstract Cauchy Problem. Journal of Differential Equations, Vol. 25, 400 (1977).
17. Singular Perturbation Theory and Abstract Operator Differential Equations. Proc. of the Second International Symposium in West Africa on Functional Analysis and its Applications, Kumasi, Ghana, 1979.

XI. PAPERS, COLLOQUIUM LECTURES ON MATHEMATICAL RESEARCH

Results obtained by me in the areas of Special Function Theory, Differential Equations, Operational Calculus and Singular Perturbations were reported in the following lectures:

1. Mathematics Colloquium Lecture, Southern University, Baton Rouge, La., July, 1965.
2. Mathematics Colloquium Lecture, University of Texas, El Paso, March, 1970.
3. Mathematics Colloquium Lecture, Drexel University, Philadelphia, Pennsylvania, March, 1970.
4. Mathematics Colloquium Lecture, University of New Mexico, Albuquerque, New Mexico, April, 1970.
5. Mathematics Colloquium Lecture, Howard University, Washington, D.C., April, 1971.
6. Mathematics Colloquium Lecture, University of Maryland, College Park, Maryland, March, 1972.
7. Mathematics Colloquium Lecture, Lincoln University, Lincoln University, Pennsylvania, Spring, 1973.
8. Mathematics Colloquium Lecture, Tulane University, New Orleans, Louisiana, May, 1974.
9. Mathematics Colloquium Lecture, University of Nairobi, Nairobi, Kenya, July, 1974.
10. Mathematics Colloquium Lecture, George Mason University, Fairfax, Virginia, March, 1975.
11. Mathematics Colloquium Lecture, University of New Mexico, Albuquerque, New Mexico, April, 1975.
12. Mathematics Colloquium Lecture, Georgetown University, Washington, D.C., April, 1975.
13. Mathematics Colloquium Lecture, Federal City College, Washington, D.C., April, 1975.
14. Mathematics Colloquium Lecture, Salisbury State College, Salisbury, Maryland, October, 1975.
15. Mathematics Colloquium Lecture, Howard University, Washington, D.C., August, 1977.
16. Mathematics Colloquium Lecture, University of Victoria, Victoria, British Columbia, April, 1978.

Dr. Robert Reiss
Professor
Department of Mechanical Engineering
Howard University
Washington, D.C. 20059

I. ACADEMIC PREPARATION

<u>College</u>	<u>Year</u>	<u>Degree</u>
Brown University	1963	Sc.B. Applied Math
Ill. Inst. Technology	1967	Ph.D. Solid Mechanics

II. PROFESSIONAL EXPERIENCE

A. Industrial/Government

1. Assistant Project Engineer. Pratt and Whitney Aircraft, East Hartford, Connecticut (1967-70).
 - Mechanical analysis of composite materials
 - Design analysis of hollow rotating fan blades
 - Design analysis of containment rings for fan and turbid blades
2. Senior Engineer. Hughes Aircraft, Canoga Park, California (Summer, 1978).
 - Participant in Summer Faculty Program
 - Studied mechanical response of solid rocket propellants
3. Summer Fellow. NASA-Langley, Hampton, Virginia (Summer, 1978).
 - Participant in NASA/Hampton Institute summer Fellowship Program
 - Modelled the mechanical response of composite compression specimens
4. Summer Faculty Program, Bell Laboratories, Whippany, New Jersey (summer, 1982).
 - Modelled thermoelastic response of multi-layered, printed circuit boards.
5. Research Fellow. U.S. Army, AMMRC, Watertown, Massachusetts (4 weeks, Summer 1983).

Surveyed state of art knowledge of the effect of the stacking sequence upon mechanical properties of

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B. University

1. Teaching Assistant. Illinois Institute of Technology, Chicago, Illinois (1963-1964)
 - . Taught sections of Statics and Dynamics
 - . Was awarded NDEA Title IV fellowship 1964-1967
2. Assistant Professor of Engineering Mechanics University of Missouri, Rolla, Missouri (1970-1973)
 - . Taught undergraduate courses in Engineering Mechanics and a graduate course in Continuum Mechanics. Taught an average of 10-12 hours/semester.
 - .. Conducted research in the area of minimal weight design for plates and shells.
3. Assistant Professor of Materials Engineering, University of Iowa, Iowa City, Iowa (1973-77)
 - . Participating faculty member of Biomedical Engineering, Mechanical Engineering, and Mechanics and Hydraulics academic programs
 - . Participating member of the Biomechanics and Optimization Research Groups
 - . Directed one Ph.D. thesis and six (6) M.S. students
 - . Participated in funded research in biomechanics
 - . Chairman of Deformable Bodies Course Committee (1974-77)
4. Graduate Professor of Mechanical Engineering, Howard University, Washington, D.C. 20059 (1982-)
 - . Associate Professor (1977-82)
 - . Associate Chairman of Mechanical Engineering (1981-)
 - . Responsible for initiating and developing a curriculum and research program in solid mechanics. As of Jan. 1, 1983, the program had graduated two MS students.
 - . Teaching M.E. undergraduate and graduate courses
 - . Directing graduate theses.

III. TEACHING COMPETENCE

ORIGINAL PAGE 19
OF POOR QUALITYA. Student Evaluation

- The student section of ASME at Howard University selected Dr. Reiss as Outstanding Faculty Member for 1978-79 and 1981-1982.
- The student section of ASME at Howard University selected Dr. Reiss as Most Popular Faculty Member for 1980-1981
- Student ratings of Dr. Reiss have consistently been above average

B. Ph.D. Theses Supervised

- S. Ting, "The Statical Method of Designing Axisymmetric Sandwich Plates Subject to Alternative Loads," October 1975, University of Iowa

C. M.S. Theses Supervised

- Tse-Min Yao, "Effect of Load Introduction on Graphite/Epoxy Compression Specimens", Dec. 1980, Howard University.
- T.S. Ravigururajan, "Optimal Structural Design For Minimum Mean Square Deflection", Dec. 1981, Howard University

D. Courses Taught

INSTITUTION	UNDERGRADUATE	GRADUATE
Univ. of Missouri	Statics Dynamics Mechanics of Materials (Lecture and Lab)	Continuum Mechani
University of Iowa	Deformable Bodies Statics Dynamics Independent Study	Elasticity I Elasticity II Mechanical Vibra- tions Energy Methods
Howard University	Materials Science Engineering Methods Introduction to Solid Mechanics Senior Project Special Topics (Bioengineering)	Graduate Seminar (Coordinator) Variational Meth- ods Applied Elasticit

E. Course Development (Howard University)

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- Developed new course, Variational Methods, offered for first time, Fall 1979
- Developed new course, Applied Elasticity, offered each Spring since 1980

Other (Howard University)

- Initiated new graduate programs in solid mechanics at M.S. and Ph.D. levels
- Developed concept and proposal to NOAA for a joint minority program with MIT in Ocean Engineering

IV. SCHOLARLY AND CREATIVE PRODUCTIVITY

A. Grants

- Co-investigator: "Study of the Biomechanics of Hip Disease", (1973-75), funded at \$80,000/year by NIH. Principal Investigator: R.C. Johnson
- Co-investigator: "Deformation Pattern and Stress Analysis of the Left Ventricle", (1974-76), funded at \$17,000/year. Principal Investigator: K. Rim.
- Principal Investigator: The Deformation Pattern of the Normal Left Ventricle During Systole (1973-4), Seed grant funded at \$3,900 by the University of Iowa.
- Principal Investigator: "Application of Variational Principles to Problems of Optimal Structural Design," (1979-80). Howard University seed grant funded at \$2,200.
- Principal Investigator: "Effect of Load Introduction on Graphite Epoxy Compression Specimens," Jan. 1, 1980 - Dec. 31, 1980, \$21,144, NASA-Langley
- Principal Investigator: "A Variational Approach to Optimal Design of Structures," May 1, 1980 - Dec. 31, 1982, \$52,000, NSF.
- Travel Grant: NSF travel grant to India, Dec. 1981, \$2,506.

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- Co-investigator: "LSSI", July, 1983 - July, 1984 - \$537.5K, NASA-Langley (P.I. Optimization component @ \$60,000 annually)

B. Proposals

- Co-Principal Investigator: "Research Quality Interactive Computer Graphics". Submitted to DOD through the Office of Naval Research, November 1983. Proposed amount: \$350,000.

C. Publications in Journals or Proceedings with Rigorous Review Procedures

- Reiss, R. and Megarefs, G.J., "Minimal Design of Sandwich Axisymmetric Cylindrical Shells Obeying Mises Criterion," Acta Mechanica, July, 1969, pp. 72-98.
- Reiss, R. and Megarefs, G.J., "Minimal Design of Sandwich Axisymmetric Plates Obeying Mises Criterion," International Journal of Solids and Structures, June, 1971, pp. 603-623.
- Reiss, R., "Minimal Design of Sandwich Plates Obeying Mises' Criterion," Developments in Mechanics, Proceedings of the 13th Midwestern Mechanics Conference, August, 1973, pp. 997-1010.
- Reiss, R., "Minimal Weight Design for Conical Shells," Journal of Applied Mechanics, September, 1974, pp. 599-603. Also: Presented at 7th U.S. Congress of Applied Mechanics, June 1974, Boulder, Colorado.
- Reiss, R., "Minimal Plate Design for Singular Regions," International Journal for Non-Linear Mechanics, October, 1974, pp. 383-396.
- Reiss, R. and Ting, S., "Design of Sandwich Plates for Maximum Stiffness," Developments in Mechanics, Proceedings of the 14th Midwestern Mechanics Conference, March, 1975, pp. 331-340.
- Soderberg, G.L., Reiss, R., Johnston, R.C. and Gabel, R., "Kinematic and Kinetic Change During Gait as a Result of Hip Disease", Proceedings of the 5th International Congress of Biomechanics, Jyvaskyla, Finland 1975.
- Reiss, R., "The Method of Stress Variation Applied to Minimal Design for Multiple Loading," International Journal of Solids and Structures, 1976, pp. 135-146.
- Reiss, R., "Optimal Compliance Criterion for Axisymmetric Solid Plates," International Journal of Solids and Structures, 1976, pp. 319-329.
- Ting, S. and Reiss, R., "Design of Axisymmetric Sandwich Plates of Alternative Loads," Journal of Optimization Theory and Applications, March 1977, pp. 387-421.
- Reiss, R., "Minimum Principles for Linear Elastodynamics," Journal of Elasticity, Jan. 1973, pp. 35-45. Also, Proc. 13th Midw. Mecn. Conf., March 1977, Chicago, pp. 159-160, (Abstract)

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- Wu, H.C. and Reiss, R., "Finite Elastic Deformation of Layered Soft Biological Tissues, Journal of Biomechanical Engineering (ASME), May 1977, pp. 98-105.
- Reiss, R. and Haug, E.J., "Extremum Principles for Linear Initial-Value Problems of Mathematical Physics," International Journal of Engineering Science, April 1978, pp. 251-251.
- Reiss, R., "Dual Extremum Principles for Coupled Thermoelasticity," Proceedings, SECTAM X, Developments in Theoretical and Applied Mechanics, April 1980, pp. 623-633.
- Reiss, R., "A Note on Optimal Conical Shells," Journal of Applied Mechanics, September 1980, pp. 669-671.
- Reiss, R. and Ravigururajan, T.S., "On Minimizing the Mean Square Deflection of Thin Elastic Beams", Proceedings, SECTAM XI, Developments in Theoretical and Applied Mechanics, April 1982, pp. 125-135.
- Reiss, R., Yao, T-M. and Clark, R.K., "Effect of Load Introduction in Compression Testing of Composite Laminates," Compression Testing of Homogeneous and Composite Materials, ASTM STP 808, Richard Chait and Ralph Papirno, Eds., American Society for Testing and Materials, 1983, pp. 200-220.
- Reiss, R., "A Unified Approach to Green's Functions for Initial-Value Problems" Quarterly Journal of Mechanics and Applied Mathematics (To appear).

Papers Presented in Major Professional Meetings

- Reiss, R., Rim, K., Falsetti, H.L. and Carroll, R.J., "Activation and Deformation Modeling of the Left Ventricle. "Abstract", AAMI Journal, 1975. Presented at AAMI Meeting, Boston, March, 1975
- Reiss, R., "Optimal Design for Vibrating Beams," (Abstract) Proceedings of the 1975 SIAM National Meeting, Presentation was withdrawn due to a death in my family.
- Gehl, J., Reiss, R. and Andrews, J.G., "A Dynamic Analysis of Gait, Advances in Bioengineering, ASME, Ed. A.C. Bell and R.M. Nerem, November 1975, pp. 105-100. Presented at the ASME Winter Annual Meeting, Houston, 1975.
- Ting, S. and Reiss, R., "On the Optimum Plastic Design of Sandwich Plates for Two Loads," Proceedings of the 15th Midwestern Mechanics Conference, March 1977, Chicago, pp. 102-103.
- Reiss, R., "Optimum Design for Minimum-Maximum Deflection," Proceedings of the 17th Midwestern Mechanics Conference, May 1981, Ann Arbor.

- Reiss, R., "On the Applicability of Variational Principles in Optimum Structural Design," Indian Society of Theoretical and Applied Mechanics (26th ISTAM Congress) December 1981, Coimbatore, India (Invited Paper)
- Reiss, R., "On the Design Derivative of Green's Functional", Proceedings of the 18th Midwestern Mechanics Conference, May, 1983, Iowa City, Iowa.
- Reiss, R., "Structural Optimization with Constraints on Transient Response," NASA Symposium on Recent Experiences in Multidisciplinary Analysis and Design, April, 1984.

E. Reports

- "Torsional Analysis of Hollow Fan Blades in a Centrifugal Field," Pratt and Whitney Aircraft, 1967
- "Effect of Blade Buckling on Containment," Pratt and Whitney Aircraft, 1969. (With D. Lacoss)
- "Mechanical Response of Solid Rocket Propellants," Hughes Aircraft, Aug. 1978, 58 pages.
- "Materials Evaluation for Coal Oil Mixture Slurry Pumps," Final Report to Pailen-Johnson Associates, Dec. 1980, 33 pages.
- "Effect of Load Introduction on Graphite Epoxy Compression Specimens," Final Report on NASA Grant NAG1-23. With (Tse-Min Yao), Jan. 1981, 96 pages.
- "Thermal Strains in Laminates - I: Classical Theory," Bell Laboratories, TM-82-52411-6, August 1982, 40 pages.

F. Invited Lectures/Conference Participation

- "...Extremum Principles for Linear Initial-Value Problems," University of Pittsburgh, February 22, 1977
- "Minimum Principles for Initial Value Problems," Clarkson College of Technology, May 10, 1977
- Invited participant to Optimization Forum, 17th Midw. Mech. Conf., Ann Arbor, May 8, 1981
- Session Chairman, 26th ISTAM Congress, Coimbatore, India, Dec., 1981
- "Variational Principles and Optimal Structural Design," Space Science and Technology Colloquia, Indian Institute of Science, Bangalore, India, Jan. 1982
- Session Co-Chairman, 19th Annual Meeting of the Society of Engineering Science, Rolla, Missouri, October, 1982.

- Session Chairman, 18th Midwestern Mechanics Conference, Iowa City, Iowa, May, 1983
- "Green's Functional: Application to Optimal Design", Army Materials and Mechanics Research Center, June 14, 1983

PROFESSIONAL STANDING AND PERFORMANCE

A. Memberships in Technical, Professional and Honorary Societies

1. Full member of Sigma Xi (1967-)
2. Associate member ASME (1971-)
3. Member of Academy of Mechanics (1980-)
4. Senior member of Society of Women Engineers (1980-)

B. Consulting Activities:

1. Mechanical Engineering consultant to HUD, Office of the Assistant Secretary for Policy Development and Research. (1977-79)
2. Consultant to Sterling Systems, Washington, D.C. (1979)
3. Consultant to Pailen-Johnson Associates, McLean, Va. (1980-)
4. Consultant to Nuclear Safety Associates, Bethesda, Md. (1981)

C. Reviewing Activities

- American Mathematical Reviews (1979-)
- Journal of Applied Mechanics (1974)
- Journal of Engineering Mechanics ASCE (1974)
- National Science Foundation (1976)
- National Council of Engineering Examiners (1976-77)
- International Journal of Engineering Sciences (1978)
- Journal of Structural Mechanics (1980-)
- Applied Mechanics Reviews (1973-1976)

D. Awards/Honors

- Sloan Foundation Scholarship, Brown University, 1959-1963
- 2nd Hartshorn Prize in mathematics, Brown University, 1960
- NDEA Title IV Fellowship, I.I.T. 1964-7
- Summer Faculty Fellow at HAC, 1978
- Summer Faculty Fellow at NASA/NI 1979
- Outstanding Faculty Award from H.U. Chapter ASME (1978-9 and 1981)
- Most Popular Faculty Award from H.U. Chapter ASME (1980-81)
- External Ph.D. Examiner of Ph.D. candidate Ramnath Kanango, Indian Institute of Technology, Kharagpur, India, 1983

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E. Service to University

1. Departmental

- . Associate Chairman of Mechanical Engineering (1981-)
- . Member of Graduate Program Committee (1977-)
- . Member of Curriculum Committee (1977-)
- . Coordinated and Prepared M.E. Department's request for ECPD Visit (1979-80)
- . Prepared a review with recommendations on uniform guideline for M.S. and Ph.D. Comprehensive Exams
- . Responsible for preparing proposal to develop an Ocean Engineering Program

2. School-Wide

- . Faculty advisor to Society of Women Engineers
- . Member of Educational Services Committee (1977-79), Chairman of Building Maintenance subcommittee (1977-79)
- . Member of Educational Policy Committee (1979-)

3. University-Wide

- . Member of Task Force which prepared the unsuccessful proposal to create a Minority Center for Science Education at H.U. (1977-78)
- . Member of Academic Affairs Committee (1978-9)
- . Member of Graduate School Executive Committee (1982-)

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S. Kamachandran

3719, 12th Street, NE, #201B

Washington, D.C. - 20017.

(202)-525-3031(H)

(202)-636-7124(O)

Academic Record:

1. Degree Obtained: B.Sc

University of Study: Madurai University, Madurai, India.

Courses of Study: Physics as the major subject and Mathematics and Chemistry as ancillaries.

Classification: Placed in the First Class.

Year of Study: 1974-1977 (completed in May, 1977.)

2. Degree Obtained: B.Tech.

University of Study: Anna University, Madras, India.

Institute Attended: Madras Institute of Technology, Madras, India.

Major: Aeronautical Engineering

Classification: Placed in the Second Class.

Year of Study: 1977-1980 (completed in May, 1980.)

3. Degree Obtained: M.E.

University of Study: Anna University, Madras, India.

Institute Attended: Madras Institute of Technology, Madras, India.

Major: Aeronautical Engineering with emphasis on Structural Mechanics.

Thesis Dissertation in M.E.:

"Optimization of Circular and Elliptical Rings in a Shell Partially Filled with Fluid".

Classification: Placed in the first Class.

Year of Study: 1980-1982.(completed in September,82.)

Awards and Scholarships:

I secured the Teaching fellowship of the Anna University and served as a Teaching fellow in Madras Institute of Technology, Madras since November, 1982 till May, 1983.

Subsequently I had been the recipient of Indian Institute of Technology, New Delhi, India, scholarship as a Research Scholar.

References and further information upon request.

RESUME

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1. Name: Qian Bo
(Surname) (First name)

2. Personal

Marital Status: Married

Nationality: China

Date of Birth: [REDACTED]

Place of Birth: [REDACTED]

3. Present professional title: Lecturer

Institution: The Dept. of Mech., Zhejiang Univ.

4. Education

Name of University: Tsinghua Univ. (The Dept. of Engrg. Mech.)

Location: Beijing

Dates Attended: Sept. 1965 -- Aug. 1970

Degree Received: *

Year: 1970

*There wasn't any degree in China before 1981.

Name of University: The graduate college of Zhejiang Univ.

Location: Hangzhou

Dates Attended: Sept. 1979 -- Nov. 1981

Degree Received: Master of Science

Year: 1981

5. Professional experience including research and teaching (place and date concerned)

institute	title	duties	dates
Sontao Machine-building Factory	Assistant engineer	designing & research	Sept. 1970- Oct. 1977
Hangzhou Camera Institution	Assistant engineer	Research	Nov. 1977- Aug. 1979
Zhejiang Univ. (The Dept. of Mech.)	Lecturer	Teaching & research	Nov. 1981-

6. Courses taught:

(1) Theory of Plates and Shells

(2) Numerical Analysis

7. Administrative

No

8. Main scientific papers or publications

(1) The Analytical Method for Bending Problems on Ring Sector Cantilever Plates, Jan., 1981

(2) The Series Solution for Triangular Plates, May, 1981

(3) Bending of Trapezoidal Plates, June, 1981

- (4) The Analytical Solution for the Circular Cylindrical Panel with Clamped Edges, July, 1981
 - (5) A New Method for the Conical Shell with Constant Thickness, July, 1981
 - (6) A New Method of Collocation, Jan., 1982
 - (7) Biomechanical Principle of a New Screw Pin Internal Fixation in Fractures of the Femoral Neck, Sept. 1982
 - (8) Boundary Fourier Transformation Method for Plate Bending Problems, July, 1983
 - (9) A New Numerical Method for Structural Analysis — Boundary Fourier Transformation Method, Sept., 1983
9. Results of English tests and Summary of English instruction to date:
- I have been trained in an English class taught by an American teacher for one year. There are 30 students in the class. My mark of English test is 91.5. (hundred-mark system) It is the second highest score in our class. In addition, my mark of English proficiency test in graduate school was 90. (hundred-mark system)
10. Detailed description of research area desired
- (1) Numerical methods for structural analysis, such as F.E.M. & B.I.E.M. etc.
 - (2) Analytical methods for engineering problems on bending, vibration and buckling of plates and shells.
 - (3) Mechanics of composite material.
 - (4) Other fields of solid mechanics.
11. Length of time expected to remain in U.S.: 2 years

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Qian Bo

RESUME

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Dr. Peter M. Bainum, P.E.
Graduate Professor of Aerospace Engineering
and Director, Graduate Studies
Dept. of Mechanical Engineering
Howard University
Washington, D.C. 20059

Areas of Specialization: Spacecraft Attitude Dynamics, Orbital Mechanics,
Stability Theory

1. ACADEMIC PREPARATION

<u>College</u>	<u>Year</u>	<u>Degree</u>
Purdue University	1955-56	
Texas A&M University	1956-59	B.S. Aero. E.
M.I.T.	1959-60	M.S. Astronautics
Catholic University	1962-67	Ph.D. Aero. E.

2. PROFESSIONAL EXPERIENCE

Dr. Bainum has a combined teaching and practical experience totaling approximately 24 years since receiving his bachelor's degree in 1959. He is a registered professional engineer in the District of Columbia.

Teaching Experience:

Howard University	1976-	Graduate Professor
Howard University	1974-	Director, Graduate Studies
Howard University	1973-	Professor
Howard University	1969-73	Associate Professor
Howard University	1967-69	Adjunct Asst. Prof.
Martin Company	1961-62	Evening Program Instructor

Professional Practice:

<u>Place</u>	<u>Year</u>	<u>Position</u>
Douglas Aircraft Co.	Summers 1958, 59	Mathematician & Associate Engineer
M.I.T. Naval Supersonic Laboratory	1959-60	Asst. Engineer
Martin Company	1960-62	Senior Engineer
IEM Federal Systems Div., Space Systems Center	1962-65	Staff Engineer
Applied Physics Lab., Johns Hopkins Univ.	1969-72	Senior Staff, Aerospace Engineer; Consultant

Place

NASA-Goddard
WEP & Associates, Inc.

Summers 1970-71
1977-

NASA/ASEE Faculty Fellow
Vice President-Research
and Consultant, Tethered
Magsat Project for NASA
Ball Brothers; Upper At-
mospheric Research Satellite
Dynamics and Control for
NASA GSFC.

3. TEACHING EFFICIENCY

Dr. Bainum has been responsible for the design, development, and offering of courses at both the undergraduate and graduate level.

Undergraduate: Engineering Methods I&II
Graduate: Advanced Dynamics I&II; Astronautics;
Space Flight Dynamics and Attitude Control

He has been advisor to sixteen graduate students including the School of Engineering's first two Ph.D. graduates. Twelve of these have received their degrees and thirteen students have successfully presented their thesis problems at major professional meetings and published in refereed journals.

Dr. Bainum was cited by the 1971-72 Student Council for superior teaching.

4. SCHOLARLY AND CREATIVE PRODUCTIVITY

Principal Investigator of the following Research Grants:

1. NASA-NGR-09-011-039, "The Motion and Stability of a Dual-Spin Satellite During the Momentum Wheel Spin-Up Maneuver," 12/1/71 - 2/28/73 - \$13,389.
2. NASA-NGR-09-011-053, "The Three Dimensional Motion and Stability of a Rotating Space Station - Cable Counterweight Configuration," 6/16/73 - 6/15/74 - \$14,961.
3. NASA-NGR-09-011-053 (Supplement No. 1) "The Dynamics of Spin Stabilized Spacecraft with Movable Appendages," 5/16/74 - 5/15/75 - \$22,853.
4. NASA-NSG 1181, "The Dynamics of Spin Stabilized Spacecraft with Movable Appendages - Part II," 5/16/75 - 5/15/76 - \$27,516.
5. NASA-NSG 1181, Suppl. No. 1, "The Dynamics and Optimal Control of Spinning Spacecraft with Movable Telescoping Appendages," 5/16/76 - 5/15/77 - \$34,630.
6. NASA-NSG 1414, "The Dynamics and Control of Large Flexible Space Structures," 5/16/77 - 5/15/78 - \$34,974.
7. Ball Brothers Research Corp. RFP3603, "Tethered Satellite System Control Law Analysis," 2/1/78 - 12/31/78 - \$8,613.

8. NASA-NSG 1414, Suppl. No. 1, "The Dynamics and Control of Large Flexible Space Structures II," 5/16/78 - 5/15/79 - \$50,458.
9. NASA-NSG 1414, Suppl. No. 2, "The Dynamics and Control of Large Flexible Space Structures III," 5/16/79 - 5/16/80 - \$57,244.
10. International Telecommunications Satellite Organization, Contract INTEL-108, "Agreement for Computer and Other Support of Analysis and Simulation of Attitude Control Systems for Flexible Spacecraft," 3/80 - 9/80, \$10,080.
11. NASA-NSG 1414, Suppl. No. 3, "The Dynamics and Control of Large Flexible Space Structures IV," 5/16/80 - 5/15/81 - \$68,278.
12. NASA-NSG 1414, Suppl. No. 4, "The Dynamics and Control of Large Flexible Space Structures V," 5/16/81 - 5/15/82 - \$74,702.
13. NASA-NSG 1414, Suppl. No. 5, "The Dynamics and Control of Large Flexible Space Structures VI," 5/16/82 - 5/15/83 - \$80,164.
14. Nippon Telegraph and Telephone Public Corporation, "Study on Optimal Control Law of Flexible Antenna Pointing on Large Spacecraft," 8/16/82 - 3/15/83, \$26,113.
15. Nippon Telegraph and Telephone Public Corporation, "Study on Optimal Control Law of Flexible Antenna Pointing on Large Spacecraft II," 4/16/83 - 3/15/84, \$41,000.
16. NASA NSG-1414, Suppl. No. 6, "The Dynamics and Control of Large Flexible Space Structures VII," (with Dr. A.S.S.R. Reddy, Co-Investigator), 5/16/83 - 2/15/84, \$81,902.
17. NASA Large Space Structures Institute (Dr. Bairum one of five co-investigators), 7/11/83 - 7/10/84, \$537,500.

Refereed Publications: (Journal articles, symposium proceedings and presentations)

1. "Perturbations and Lyapunov Stability of a Multiple-Connected Gravity-Gradient Satellite at Synchronous Altitude," by Peter M. Bainum, D.K. Anand and D.L. Mackison, Fifth U.S. National Congress of Applied Mechanics, University of Minnesota, Minneapolis, June 14-17, 1966.
2. "Comments on Use of Malkin's Theorem for Satellite Stability in the Presence of Light Pressure," Proceedings of the IEEE, Vol. 5², Sept. 1967, pp. 1658.
3. "Gravity-Gradient Stabilization of Synchronous Orbiting Satellites," by Peter M. Bainum and D.L. Mackison, Journal of the British Interplanetary Society, Vol. 21, No. 4, Dec. 1968, pp. 341-359; also published in Stabilization of Artificial Spacecraft (in Russian), Ed. V.A. Sarychev, Moscow, 1974, pp. 126-151.
4. "Magnetic Sample-and-Hold Damping of a Gravity-Gradient Stabilized Satellite," by Donald L. Mackison and Peter M. Bainum, National Symposium on Gravity-Gradient Attitude Stabilization, El Segundo, Calif., Dec. 3-5, 1968, sponsored by A.F. Systems Command and Aerospace Corporation, published in official Proceedings of Symposium, Aerospace Corp. TR-0066 (5134-1), Sept. 1969, pp. 5-13 - 5-26.
5. "Motion and Stability of a Dual-Spin Satellite with Nutation Damping by Peter M. Bainum, P.G. Fueschsel, and D.L. Mackison, Journal of Spacecraft and Rockets, Vol. 7, No. 6, June 1970, pp. 690-696; also published in Mechanica, (in Russian) Vol. 1, Moscow, 1975, pp. 59-78.
6. "Motion and Stability of a Rotating Space Station-Cable-Counterweight Configuration," by P. Stabekis and Peter M. Bainum, Journal of Spacecraft and Rockets, Vol. 7, No. 8, August 1970, pp. 912-918.
7. "The Attitude Motion of a Nutationally Damped Dual-Spin Spacecraft in the Presence of Near-Earth Environment," by P.G. Fuechsel, Peter M. Bainum, and P.J. Grunberger, AIAA 9th Aerospace Sciences Meeting, New York, N.Y., January 25-27, 1971, AIAA Paper No. 71-90; synoptic published in Journal of Spacecraft and Rockets, Vol. 8, No. 9, Sept. 1971, pp. 913-914.
8. "Attitude Stability and Damping of a Tethered Orbiting Interferometer Satellite System," by Peter M. Bainum, Richard E. Harkness and Willem Stuiver, The Journal of the Astronautical Sciences, Vol. XIX, No. 5, March-April 1972, pp. 364-389.

9. "Stability of a Dual-Spin Spacecraft with a Flexible Momentum Wheel," by Peter M. Bainum, P.G. Fuechsel and J.V. Fedor, Journal of Spacecraft and Rockets, Vol. 9, No. 9, September 1972, pp. 640-646.
10. "A Study of Planar Deployment Control and Libration Damping of a Tethered Orbiting Interferometer Satellite," by Willem Stuiver and Peter M. Bainum, The Journal of the Astronautical Sciences, Vol. XX, No. 6, May-June 1973, pp. 321-346.
11. "Planar Librational Motion of a Gravity-Gradient Satellite During Deployment," by V. Puri and Peter M. Bainum, XXIInd International Astronautical Congress, Sept. 20-25, 1971, Brussels, Belgium; also in Astronautical Research 1971, D. Reidel Publishing Co., Dordrecht, Holland, 1973, pp. 63-80.
12. "Nutational Stability of a Dual-Spin Satellite Under the Influence of Applied Reaction Torques," by Peter M. Bainum and Joseph V. Fedor, Journal of Spacecraft and Rockets, Vol. 10, No. 5, May 1973, pp. 295-300.
13. "Gravity-Gradient Stabilization of Synchronous Orbiting Satellites - Additional Considerations of Attitude Stability," Journal of the British Interplanetary Society, Vol. 26, No. 6, June 1973, pp. 343-347.
14. "Motion of a Dual-Spin Satellite During Momentum Wheel Spin-Up," by S. Sen and Peter M. Bainum, Journal of Spacecraft and Rockets, Vol. 10, No. 12, Dec. 1973, pp. 760-766.
15. "Development of Lyapunov Functions for Freely Spinning Dual-Spin Spacecraft," by Peter M. Bainum and Chung-jin Woan, XXIVth International Astronautical Congress, Baku, U.S.S.R., Oct. 7-13, 1973; also in Acta Astronautica, Vol. 2, May - June 1975, pp. 463-479.
16. "Three Dimensional Motion and Stability of Two Rotating Cable-Connected Bodies," by Peter M. Bainum and K.S. Evans, Journal of Spacecraft and Rockets, Vol. 12, No. 4, April 1975, pp. 242-250.
17. "Gravity-Gradient Effects on the Motion of Two Rotating Cable-Connected Bodies," by Peter M. Bainum and K.S. Evans, AIAA Journal, Vol. 14, No. 1, Jan. 1976, pp. 26-32.
18. "Spacecraft Detumbling Using Movable Telescoping Appendages," by Peter M. Bainum and R. Sellappan, XXVith International Astronautical Congress, Lisbon, Portugal, Sept. 21-27, 1975, Paper No. 75-113; also in Acta Astronautica, Vol. 3, 1976, pp. 953-969.

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19. "Dynamics of Spin Stabilized Spacecraft During Deployment of Telescoping Appendages," by R. Sellappan and Peter M. Bainum, Journal of Spacecraft and Rockets, Vol. 13, No. 10, Oct. 1976, pp. 605-610.
20. "Optimal Control of Spin-Stabilized Spacecraft with Telescoping Appendages," by P.M. Bainum and R. Sellappan, The Journal of the Astronautical Sciences, Vol. XXIV, No. 4, Oct. - Dec. 1976, pp. 329-346.
21. "The Motion and Stability of Spin Stabilized Spacecraft with Hinged Appendages," by R. Sellappan and P.M. Bainum, AIAA/AAS Astrodynamics Conference, August 16-20, 1976, San Diego, Calif., Paper No. 76-784; also in AIAA Journal, Vol. 15, No. 6, June 1977, pp. 866-869.
22. "Effect of Gravity-Gradient Torques on the Dynamics of a Spinning Spacecraft with Telescoping Appendages," by M. Rajan and Peter M. Bainum, Proceedings of Symposium on Dynamics and Control of Large Flexible Spacecraft, Blacksburg, Va., June 13-15, 1977, VPI & SU Press, Ed. L. Meirovitch, pp. 189-201; also in Cosmic Research, (in Russian) Vol. 16, No. 4, August 1978, pp. 497-504.
23. "Stochastic Optimal Attitude Control of Spacecraft with Movable Appendages," by R. Sellappan and Peter M. Bainum, 1977 AAS/AIAA Astrodynamics Conference, Jackson, Wyoming, Sept. 7-9, 1977; also in The Journal of the Astronautical Sciences, Vol. XXV, No. 4, October-December 1977, pp. 323-347.
24. "The Use of a Movable Telescoping End Mass System for the Time-Optimal Control of Spinning Spacecraft," by Peter M. Bainum and R. Sellappan, XXVIIIth International Astronautical Congress, Prague, Czechoslovakia, Sept. 26 - Oct. 1, 1977, Paper No. 77-227; also in Acta Astronautica, Vol. 5, No. 10, October 1978, pp. 781-795.
25. "Stability of Spacecraft During Asymmetrical Deployment of Appendages," by R. Sellappan and Peter M. Bainum, Journal of Guidance and Control, Vol. 1, No. 6, Nov. - Dec. 1978, pp. 446-447.
26. "Dynamics of Spinning Spacecraft During the Deployment of Flexible Booms," by P.K. James and Peter M. Bainum, AIAA/ASME 19th Structures, Structural Dynamics and Materials Conference, Bethesda, Md., April 3-5, 1978, Paper No. 78-489.
27. "Dynamics of a Flexible Body in Orbit," by V.K. Kumar and Peter M. Bainum, 1978 AIAA/AAS Astrodynamics Conference, Palo Alto, Calif., Aug. 7-9, 1978, Paper No. 78-1418; also in J. of Guidance and Control, Vol. 3, No. 1, Jan. - Feb. 1980, pp. 90-92.

28. "Modal Control of the Planar Motion of a Long Flexible Beam in Orbit," by R. Sellappan and Peter M. Bainum, XXIXth International Astronautical Congress, Dubrovnik, Yugoslavia, Oct. 1 - Oct. 8, 1978, Paper No. 78-102; also, Acta Astronautica, Vol. 7, Jan. - Feb. 1980, pp. 19-36.
29. "On the Controllability of a Long Flexible Beam in Orbit," by Peter M. Bainum and A.S.S.R. Reddy, Proceedings of Second AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, Blacksburg, Va., June 21-23, 1979, VPI & SU Press (Ed. L. Meirovitch), pp. 145-159.
30. "Decoupling Control of a Long Flexible Beam in Orbit," by A.S.S.R. Reddy, Peter M. Bainum, and H.A. Hamer, AAS/AIAA Astrodynamics Specialist Conference, Provincetown, Mass., June 26-27, 1979, Paper No. 70-158; also in Advances in the Astronautical Sciences, Vol. II, (AAS Publication), pp. 649-673.
31. "Optimal Control of the Shuttle-Tethered-Subsatellite System," by P.M. Bainum and V.K. Kumar, XXXth International Astronautical Congress, Munich, Germany, Sept. 16, 1979, Paper No. 79-190; also, Acta Astronautica, Vol. 7, Nov.-Dec. 1980, pp. 1333-1348.
32. "Control of a Large Flexible Platform in Orbit," by A.S.S.R. Reddy, Peter M. Bainum, H.A. Hamer, and R. Krishna, AIAA/AAS Astrodynamics Conference, Danvers, Mass., Aug. 11-13, 1980, Paper No. 80-1668; also Journal of Guidance and Control, Vol. 4, No. 6, Nov.-Dec. 1981, pp. 642-649.
33. "On the Dynamics of Large Orbiting Flexible Beams and Platforms Oriented along the Local Horizontal," by Peter M. Bainum and V.K. Kumar, XXXIst International Astronautical Congress, Tokyo, Japan, Sept. 21-28, 1980, Paper No. 80-E230; also, Acta Astronautica, Vol. 9, No. 3, 1982, pp. 119-127.
34. "On the Motion of a Flexible Shallow Spherical Shell in Orbit," by V.K. Kumar and Peter M. Bainum, AIAA Aerospace Sciences Meeting, St. Louis, Mo., Jan. 12-15, 1981, Paper No. 81-0170; also, AIAA Journal, Vol. 20, No. 8, August 1982, pp. 1113-1119.
35. "31st Congress of the International Astronautical Federation," Spaceflight, Vol. 23, No. 4, April 1981, pp. 102-104, (invited paper).
36. "Graph Theory Approach to the Eigenvalue Problem of Large Space Structures," by A.S.S.R. Reddy and Peter M. Bainum, Proceedings of Third VPI & SU/AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, Blacksburg, Va., June 15-17, 1981, VPI & SU Press (Ed. L. Meirovitch), pp. 175-189.

37. "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; also, The Journal of the Astronautical Sciences, Vol. XXX, No. 3, July-September, 1982, pp. 251-267.
38. "Analysis and Design of a Spacecraft Attitude Stabilization System using a Double Gimbaled Reaction Wheel," by Adi S. Salarnum and Peter M. Bainum, XXXIInd International Astronautical Congress, Rome, Italy, Sept. 6-12, 1981, Paper No. IAF 81-349; also, Acta Astronautica, Vol. 10, No. 2, 1983, pp. 55-66.
39. "Astrodynamics Highlights for 1981," Astronautics and Aeronautics, Vol. 19, No. 12, December 1981, pp. 42-43 (invited paper).
40. "The Dynamics and Control of Large Flexible Space Structures," (invited State-of-the Art Paper), 26th Congress of the Indian Society of Theoretical and Applied Mechanics, Coimbatore, India, Dec. 28-31, 1981.
41. "On the Shape and Orientation Control of an Orbiting Shallow Spherical Shell Structure," by Peter M. Bainum and A.S.S.R. Reddy, Joint IFAC/ESA Symposium on Automatic Control in Space, Noordwijkerhout, The Netherlands, July 5-9, 1982; also, in Automatic Control in Space 1982, (Ed. P. van Woerkom), Pergamon Press, March 1983.
42. "On the Modelling and Simulation of the Dynamics and Control of Large Flexible Orbiting Systems," by Peter M. Bainum, V.K. Kumar, A.S.S.R. Reddy, and R. Krishna, 10th IMACS World Congress on System Simulation and Scientific Computation, Montreal, Canada August 8-13, 1982, (invited paper); also, IMACS publication, Modeling and Simulation in Engineering, Vol. 3, North Holland Publishing Co., 1983.
43. "Controllability of Inherently Damped Large Flexible Space Structures," by A.S.S.R. Reddy, and Peter M. Bainum, XXXIIInd International Astronautical Congress, Paris, France, Sept. 26 - Oct. 2, 1982, Paper No. IAF 82-319; also, Acta Astronautica, Vol 10, May-June 1983, pp. 357-363.
44. "Effect of Solar Radiation Disturbance on a Flexible Beam in Orbit," by R. Krishna and P.M. Bainum, AIAA 21st Aerospace Sciences Meeting, Reno, Nevada, Jan. 10-13, 1983, Paper No. 83-0431; to appear, AIAA Journal.

45. "The Effect of a Flexible Massive Tether on the Stability of the Shuttle-Third-Subsatellite System during Station Keeping," by Peter M. Bainum, C.M. Diarra, and V.K. Kumar, Fourth VPI&SU/AIAA Symposium on Dynamics and Control of Large Structures, Blacksburg, Va., June 6-8, 1983.
46. "Orientation and Shape Control of an Orbiting Flexible Beam Under the Influence of Solar Radiation Pressure," by R. Krishna and P.M. Bainum, AAS/AIAA Astrodynamics Specialist Conference, Lake Placid, N.Y., August 22-25, 1983, Paper No. 83-325.
47. "On the Controllability and Control Law Design for an Orbiting Large Flexible Antenna System," by Peter M. Bainum, A.S.S.R. Reddy, and R. Krishna, XXXIVth International Astronautical Congress, Budapest, Hungary, October 10-15, 1983, Paper No. IAF 83-340.

Books Edited

1. International Space Technical Applications, (1981 Goddard Symposium), Vol. 52, Science and Technology, American Astronautical Society, Editors, A. Adelman and P.M. Bainum, 1981.
2. 17th European Space Symposium, 1980, Vol. 53, Science and Technology, American Astronautical Society, Editor, P.M. Bainum, 1981.
3. Spacelab, Space Platforms and the Future- AAS/DGLR Goddard 1982 Symposium, Volume 49, Advances in the Astronautical Sciences, American Astronautical Society, Editors, P.M. Bainum and D. Koelle, 1982.
4. Astrodyamics 1983, Vol. 54, Parts I and II, Adv. in the Astronautical Sciences, American Astronautical Society, Edited by P. Cefola, P.M. Bainum, G.T. Tseng, and D. Levinson, Jan. 1984.
5. 18th European Space Symposium, 1983, Science and Technology Series, Editor, P.M. Bainum, 1984.

Reports

1. "Three Body Guidance in Earth-Moon Space," by John W. Whitehurst and Peter M. Bainum, The Martin Co., (Orlando Div.), Final Report OR 1591-11-2, August 1961.
2. "Preliminary Planar Analysis of the Kinematics of a Space Station-Cable-Counterweight Configuration," by J.W. Whitehurst and P.M. Bainum, IBM Federal Systems Div., Space Systems Center, Aug. 1963.
3. "A Simulation Study of Attitude Stabilization by Gravity-Gradient Techniques," by P.M. Bainum, F.K. Evans, W.H. Land, Jr., and W.D. Stockwell, IBM Federal Systems Div., Space Systems Center, for NASA-GSFC, Final Report NAS-53155, Sept. 1963.
4. "Tiros 'K' Attitude Studies," by L.B. Schlegel and P.M. Bainum, IBM Federal Systems Div. for NASA-GSFC, March 1965.
5. "Lyapunov Stability and Solar Perturbations of a Passively Damped Gravity-Gradient Satellite," by P.M. Bainum, D.K. Anand and D.L. Mackison, APL/JHU Report TG-854, Sept. 1966.
6. "Analysis of the Motion of a Dual-Spin Satellite with Orthogonal Nutation Dampers," by P.M. Bainum and P.G. Fuechsel, APL/Johns Hopkins University Report, TG-1118, July 1970.
7. "Stability of SAS-A Dual Spin Spacecraft with Energy Dissipation on the Momentum Wheel," NASA-GSFC Report X-732-70-344, Sept. 1970.
8. "Nutational Stability of a Dual-Spin Satellite Under the Influence of Applied Reaction Torques," NASA-GSFC Report X-732-71-335, Sept. 1971.
9. "The Motion and Stability of a Dual-Spin Satellite During the Momentum Wheel Spin-Up Maneuver," by Peter M. Bainum and Subhash Sen, Final Report, NASA-Grant: NGR 09-011-039, Dept. of Mechanical Engineering, Howard University, Nov. 1972.
10. "The Three Dimensional Motion and Stability of a Rotating Space Station-Cable-Counterweight Configuration," by P.M. Bainum and Keith S. Evans, Final Report, NASA-Grant: NGR-09-011-053, Dept. of Mechanical Engineering, Howard University, May 1974.
11. "The Dynamics of Spin Stabilized Spacecraft with Movable Appendages-Part I," by P.M. Bainum and R. Sellappan, Final Report, NASA Grant: NGR-09-011-053 (Supplement No. 1), Dept. of Mechanical Engineering, Howard Univ., May 1975.
12. "The Dynamics of Spin Stabilized Spacecraft with Movable Appendages-Part II," by P.M. Bainum and R. Sellappan, Final Report, NASA Grant: NSG-1181, Dept. of Mechanical Engineering, Howard University, May 1976.

13. "The Dynamics and Optimal Control of Spinning Spacecraft with Movable Telescoping Appendages," by P.M. Bainum, R. Sellappan, M. Rajan, and P.K. James, Final Report, NASA Grant NSG-1181, Suppl. 1, Dept. of Mechanical Engineering, Howard University, May 1977.
14. "A Review of Tethered Subsatellite Dynamics and Control," by P.M. Bainum and Dah-Nien Fan, Final Report P.O. No. S-34516-B, WHF & Associates, Inc., to NASA Goddard Space Flight Center, June 1977.
15. "The Dynamics and Control of Large Flexible Space Structures," Parts A and B by P.M. Bainum, R. Sellappan, V.K. Kumar, and P.K. James, Final Report NASA Grant NSG-1414, NASA CR-156975 and CR-156976, Dept. of Mechanical Engineering, Howard University, May 1978.
16. "Tethered Satellite System Control Law Analysis," by P.M. Bainum and V.K. Kumar, Final Report P.O. No. 01964 (WHF & Associates, Inc.) and P.O. No. 01965 (Howard University) to Ball Aerospace Systems Division, Dec. 21, 1978.
17. "UARS Structural Dynamics and Control," by Peter M. Bainum and Dah-Nien (Dan) Fan, Final Report, P.O. No. S-45010B, WHF & Associates, Inc., to NASA Goddard Space Flight Center, January 1979.
18. "The Dynamics and Control of Large Flexible Space Structures-II," Parts A and B, by P.M. Bainum, A.S.S.R. Reddy, P.K. James, V.K. Kumar, and R. Krishna, Final Report NASA Grant NSG-1414, Suppl. 1, Dept. of Mechanical Engineering, Howard University, June 1979.
19. "The Dynamics and Control of Large Flexible Space Structures-III," Parts A and B, by P.M. Bainum, A.S.S.R. Reddy, P.K. James, V.K. Kumar, and R. Krishna, Final Report NASA Grant NSG-1414, Suppl. 2, Dept. of Mechanical Engineering, Howard University, June-Sept. 1980.
20. "Attitude Control of Flexible Spacecraft," Final Report (INTEL No. 107), WHF & Associates, Inc., and "Computer and Other Support of Analysis and Simulation of Attitude Control Systems for Flexible Spacecraft," Final Report (INTEL No. 108), Howard University, to International Telecommunications Satellite Organization, Nov. 1980.
21. "The Dynamics and Control of Large Flexible Space Structures-IV," by Peter M. Bainum, V.K. Kumar, R. Krishna, A.S.S.R. Reddy, Final Report NASA Grant NSG-1414, Suppl. 3, Dept. of Mechanical Engineering, Howard University, August 1981, NASA-CR 165815.

22. "The Dynamics and Control of Large Flexible Space Structures V," by Peter M. Bainum, A.S.S.R. Reddy, R. Krishna, C.M. Diarra, and V.K. Kumar, Final Report NASA Grant NSG-1414, Suppl. 4, Dept. of Mechanical Engineering, Howard University, August 1982.
23. "Study on Optimal Control Law of Flexible Antenna Pointing on Large Spacecraft-I," by P.M. Bainum, M.G. Manoharan, A.S.S.R. Reddy, and R. Krishna, Final Report to Electrical Communication Laboratories, Nippon Telegraph and Telephone Public Corp., Japan, Dept. of Mechanical Engineering, Howard University, March 1983.
24. "The Dynamics and Control of Large Flexible Space Structures-VI," by Peter M. Bainum, A.S.S.R. Reddy, R. Krishna, and C.M. Diarra, Final Report NASA-Grant NSG-1414, Suppl. 5, Dept. of Mechanical Engineering, Howard University, September 1983.
25. "A Study of an Upper Atmospheric Density Model as Inferred from Satellite Observations," (M.S. Thesis) M.I.T. Naval Supersonic Laboratory TR-448, 1960.
26. "On the Motion and Stability of a Multiple Connected Gravity-Gradient Satellite with Passive Damping," (Ph.D. Thesis) The Catholic Univ. of American, 1966; published as APL/JHU TG-872, Jan. 1967.

5. INVITED LECTURES, PANELIST, SESSION CHAIRMAN/ORGANIZER

1. "Design of Satellite Attitude Control Systems by Lyapunov Techniques," The Johns Hopkins University, Dept. of Electrical Engineering, Control Systems Seminar, Baltimore, Md., March 16, 1967.
2. "Stability Theory in Spacecraft Attitude Dynamics and Control," The Johns Hopkins University Evening College, Silver Spring, Md., March 18, 1971; March 25, 1971.
3. "Satellite Stabilization Techniques," Air Force ROTC Class, Howard University, April 1971.
4. "Selected Problems in Satellite Attitude Dynamics" The University of British Columbia, Dept. of Mechanical Engineering, Vancouver, Canada, July 25-26, 1974.
5. Invited participant, American Astronautical Society Symposium on the Dynamics and Control of Nonrigid Spacecraft, Stability Theory-Application of Methods Session, UCLA, Los Angeles, Aug. 1-2, 1974.
6. "The Optimal Control of Spin Stabilized Spacecraft with Telescoping Appendages," Lehrstuhl und Institut B für Mechanik, Technische Hochschule München, Munich, Germany, May 28, 1976.
7. "The Dynamics of Spacecraft with Movable Appendages," Delft University of Technology, Dept. of Aerospace Engineering, Delft, Holland, June 1, 1976.
8. "The Use of Modern Control Theory in the Design of Multi-Degree-of-Freedom Systems," University of Hawaii, Dept. of Mechanical Engineering, Honolulu, Hawaii, Jan. 28, 1977.
9. "The Optimal Control of Spin Stabilized Spacecraft with Movable Appendages," Virginia Polytechnic Institute and State Univ., Dept. of Engineering Science and Mechanics, Blacksburg, Va., March 16, 1977.
10. Invited participant, AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, Panel II - Control, VPI & SU, Blacksburg, Va., June 13-15, 1977.
11. Session Chairman, IUTAM Symposium on Dynamics of Multibody Systems, Munich, Germany, Aug. 29 - Sept. 3, 1977.
12. "Optimal and Time Optimal Control of Spinning Spacecraft with Movable Telescoping Appendages" and "Dynamics and Control of Tethered Satellite Systems," European Space Agency, European Space Operation Center, Darmstadt, Germany, Sept. 5, 1977.

13. Session Chairman, AAS/AIAA Astrodynamics Conference, Jackson, Wyo., Sept. 7-9, 1977.
14. Member Technical Program Committee and Session Chairman, AIAA-16th Aerospace Sciences Meeting, Huntsville, Ala., Jan. 16-18, 1978.
15. "The Dynamics and Control of Large Space Structures," Institutes for Propulsion and Dynamics, University of Stuttgart, Germany, Sept. 28, 1978.
16. Session Chairman, AIAA-17th Aerospace Sciences Meeting, New Orleans, La., Jan. 15-17, 1979.
17. Invited participant, AIAA National Capital Section Fourth Annual Mini-symposium, "Aerospace and You," Panel-Aerospace Education Session, University of Maryland, College Park, Md., Feb. 24, 1979.
18. Session Chairman, Second AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, VPI&SU, Blacksburg, Va., June 21-23, 1979.
19. "On the Stabilization of Large Space Structures" DFVLR (German Space Agency), Stuttgart, Germany, Sept. 24, 1979.
20. "Stabilization of Large Space Structures" and Control of Shuttle-Tethered Subsatellite Systems," European Space Agency, European Space Operations Center, Darmstadt, Germany, Sept. 25, 1979.
21. "Stabilization and Control of Large Orbiting Structures," Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada, Nov. 2, 1979.
22. Session Chairman, AIAA-17th Aerospace Sciences Meeting, Pasadena, Calif., Jan. 14-16, 1980.
23. Session Chairman and AAS Organizer, 17th European Space Symposium, London, England, June 4-6, 1980.
24. "Dynamics and Control of Large Orbiting Space Structures" and "Control of a Shuttle-Tethered Subsatellite System," Delft University of Technology, Dept. of Aerospace Engineering, Delft, Holland, June 9, 1980.
25. "The Large Space Structures Technology Program," National Aerospace Laboratory, Amsterdam, Holland, June 10, 1980.

26. "The Dynamics and Control of Large Flexible Space Structures" and "The Dynamics and Control of the Shuttle-Tethered-Subsatellite System," Indonesian National Institute of Aeronautics and Space (LAPAN), Jakarta, Indonesia, Sept. 30 - Oct. 1, 1980.
27. "Shuttle-Tethered-Subsatellite System Dynamics and Control," Indian Space Research Organization, Bangalore, India, October 3, 1980.
28. "Dynamics and Control of Large Flexible Spacecraft," Indian Institute of Science, Dept. of Aeronautical Engrg., Bangalore, India, October 3, 1980.
29. "Dynamics and Control of Large Space Structures," European Space Agency, European Space Operations Center, Darmstadt, Germany, October 6, 1980.
30. Member of Program Committee, AAS Annual Meeting, Boston, Mass., Oct. 20-23, 1980.
31. Technical Program Chairman, American Astronautical Society, 19th Goddard Memorial Symposium, Pentagon City, Va., March 26-27, 1981.
32. Session Chairman and invited panelist, Third VPI&SU/AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, Blacksburg, Va., June 15-17, 1981.
33. "The Dynamics and Control of Large Flexible Earth Pointing Orbiting Systems," Catholic University of Louvain, Applied Mechanics Unit, Louvain, Belgium, Sept. 14, 1981.
34. "Dynamics and Control of Large Flexible Space Systems," Departments of Mechanical and Civil Engineering, Rice University, Houston, Texas, Oct. 30, 1981.
35. "Analysis of a Spacecraft Attitude Stabilization System Using a Double Gimballed Reaction Wheel," Indian Institute of Science - Indian Space Research Organization Space Science & Technology Colloquia, Bangalore, India, January 4, 1982.
36. "The Dynamics of Large Flexible Earth Pointing Structures with a Hybrid Control System," Indian Space Research Organization, Bangalore, India, January 5, 1982.
37. Technical Program Chairman, AAS/DGLR 20th Goddard Memorial Symposium, NASA Goddard Space Flight Center, March 18-19, 1982.

38. "The Dynamics and Control of Large Flexible Systems in Orbit," Institut fur Mechanik and Institut fur Regelungstechnik, University of Hannover, Hannover, Germany, July 2, 1982.
39. Session Chairman, AIAA/AAS Astrodynamics Conference, San Diego, Calif., August 9-11, 1982.
40. "The Dynamics and Control of Large Flexible Systems in Orbit," Seminars in Mechanics, McGill University, Dept. of Mechanical Engineering, Montreal, Canada, Oct. 12, 1982.
41. "Dynamique et Commande des Systemes larges et flexibles en Orbite," Seminaire sur Espace et Telecommunications, 12th Annual International Workshop of the African Regional Group II- INTELSAT, Bamako, Mali, March 28 - April 1, 1983.
42. Session Chairman, Fourth VPI&SU Symposium on Dynamics and Control of Large Structures, June 6-8, 1983.
43. AAS Organizer and Session Chairman, 18th European Space Symposium, London, England, June 8-9, 1983.
44. "La Dynamique et la Commande des Systemes larges et flexibles en Orbite," University of Paris VI, Dept. Mecanique Theorique, Paris, France, June 13, 1983.
45. General Conference Co-Chairman and Session Chairman, AAS/AIAA Astrodynamics Conference, Lake Placid, New York, August 22-24, 1983.
46. Rapporteur, Session-Astrodynamics-Motion About the Center of Mass, XXXIVth International Astronautical Congress, Budapest, Hungary, October 10-15, 1983.
47. "Introduction to Spacecraft Dynamics," AIAA National Capital Section Professional Study Seminar Series: Spacecraft Attitude Control Systems, NASA Goddard Space Flight Center, Oct. 17, 1983.

6. PROFESSIONAL STANDING AND PERFORMANCE

Dr. Bainum is active in numerous professional and honor societies and has been cited in several biographies.

1. Membership and Participation in Professional Societies:

American Institute of Aeronautics and Astronautics, Associate Fellow; member Astrodynamics Technical Committee, Jan. 1976 - Dec. 1978; Jan. 1981 -.

American Astronautical Society; Executive Vice President, 1982 - First Vice President, 1980-1982; Vice President, Technical, 1978-80; Vice President, Publications, 1976-78.
Fellow, AAS, 1979 -.
Student Affairs Committee, 1975-76

British Interplanetary Society, Fellow

American Academy of Mechanics

American Association for the Advancement of Science, representative of AAS to Section on Engineering.

International Astronautical Federation, Vice Chairman, Astrodynamics Technical Committee, 1984 -.

2. Membership, Honorary Societies:

Phi Eta Sigma
Tau Beta Pi
Sigma Gamma Tau
Phi Kappa Phi

3. Awards, Listings

Scholarship Purdue, 1955

Fellowship M.I.T., 1959-1960

Student Award Winner, Institute of Aeronautical Sciences, 1959

Society of Automotive Engineers, Ralph R. Teetor Award for Engineering Educators, Jan. 1971

NASA/ASEE - Summer Faculty Fellowship, 1970, 1971

Listed in Dictionary of International Biography, Vol. 9, 1973;

Vol. 12, 1975; Vol. 13, 1976-1977; Vol. 14, 1977-1978; Vol. 15,

1978-1979; Vol. 16, 1979-1980; Vol. 17, 1980-1981, Vol. 18, 1983.

Listed in Who's Who in Aviation, 1973.

Member, Intercontinental Biographical Assn., 1973 -.

Listed in International Who's Who in Community Service, 1975; 1978.

Listed in Men of Achievement, Vol. II, 1975; Vol. III, 1976; Vol. V, 1978; Vol. VI, 1979; Vol. VIII, 1981; Vol. IX, 1982; Vol. X, 1983.

Listed in Personalities of the South, 1975-76; 1976-77.

Listed in Who's Who in Engineering, 1977; 1980; 1982.

- Listed in Community Leaders and Noteworthy Americans, 1976-1977; 1979-1980.
- Listed in Notable Americans, 1976-1977; 1978-1979.
- Listed in America's Names and Faces, 1977
- Listed in Personalities of America, 1979; 1982; 1984
- Listed in The American Registry, Fall 1980.
- Listed in Notable Personalities of America, 1981.
- Listed in Two Thousand Notable Americans, 1983.
- Listed in Community Leaders of the World, 1984.
- Listed in 5000 Personalities of the World, 1984.
- Listed in International Who's Who in Contemporary Achievement, 1984.
- Listed in The Directory of Distinguished Americans, 1981, 1982-83
- Listed in American Men and Women of Science, 1982
- Listed in International Who's Who in Engineering, 1983
- Listed in Who's Who in Washington, 1982-83
- Listed in International Book of Honor, 1984
- Listed in Jane's Who's Who in Aviation and Aerospace: U.S. Edition, 1982
- Listed in Marquis Who's Who in the East, 1979-1980; 1981-82
- Listed in Men and Women of Distinction, 1979; 1980-81
- Listed in The Anglo American Who's Who, 1981
- Listed in Who's Who in Technology Today, 1980; 1982-3
- Listed in Directory of World Researchers' 1980's Subjects, 1981
- Listed in Jane's Directory of Aviation and Aerospace Professionals: U.S. Edition, 1982
- Listed in Who's Who in America, 1980-81; 1982-83
- Listed in Who's Who in the World, 5th Edition, 1980-81
- Howard University, Graduate School of Arts and Sciences, Citation for Exemplary Research, December 1976
- Sigma Xi-Scientific Research Society, 1978-
- Howard University Graduate School, Outstanding Faculty Award, 1979-80
- Howard University Award for Outstanding Research, 1980-81

HOWARD UNIVERSITY
 DEPARTMENT OF AERONAUTICS

4. Professional Activities

Currently Referee or has served as a Referee for the Journal of Spacecraft and Rockets, AIAA Journal, Celestial Mechanics Journal, The Journal of the Canadian Aeronautics and Space Institute, The Journal of the British Interplanetary Society, Acta Astronautica, and the Journal of Guidance and Control, and Applied Mechanics Reviews.

Proposal reviewer for the National Science Foundation

7. PROFESSIONAL COOPERATION

Dr. Bainum has served on important committees over the tenure of his appointment at Howard. He is currently serving on the following committees:

Graduate School: Representative to the University Faculty
 Grievance Committee

Department: Director of Graduate Studies - administrative
 head of Graduate Program (37 graduate students)
 Graduate Program Committee, Chairman
 Graduate Student Advisor
 Executive Committee

Dr. Bainum also has served as the coordinator of the Graduate Seminar and currently serves as director of the aerospace component of the graduate program. He is a member of the Aerospace Dept. Chairman's Association.

8. TEACHER-STUDENT RELATIONSHIP

Dr. Bainum invests considerable time in educational enrichment of students in his area of specialization.

Dr. Bainum helped organize and is currently serving as Co-Faculty Advisor to the AIAA Student Chapter at Howard. Chapter cited by AIAA as one of the outstanding student branches for 1976-77 and 1978-79. For the first time the Howard Student Chapter hosted the annual Mid-Atlantic Regional Student Conference, April 1982.

He has accompanied Howard graduate students to the following AIAA Local Meetings:

AIAA Communications Satellite Conference, Washington, D.C. - April 1972
 AIAA 11th Aerospace Sciences Meeting, Wash. D.C. - Jan. 1973
 AIAA Joint Student Section Meeting, at Univ. of Md. - March 1973
 AIAA 12th Aerospace Sciences Meeting, Wash. D.C. - Jan. 1974
 AIAA Annual Meeting and Display, Wash. D.C. - Feb. 1975
 AIAA 14th Aerospace Sciences Meeting, Wash. D.C. - Jan. 1976

AIAA Annual Meeting and Display, Wash., D.C. - Feb. 1978
AIAA National Capital Section, Fourth Annual Minisymposium,
Univ. of Md., Feb. 1979
AIAA International Meeting and Display, Baltimore, Md., May 1980
AIAA Annual Meeting and Display, Baltimore, Md., May 1982
AAS/AIAA - Twenty First Goddard Memorial Symposium, Greenbelt, Md.,
March 1983

9. CIVIC ACTIVITIES

- Community Activities:
1. Judge at D.C. Science Fair, Woodrow Wilson H.S., April 1973
 2. Member AIAA National Capital Section Community Action Committee, 1975-76

RESUME

ORIGINAL PAGE IS
OF POOR QUALITY

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ACADEMIC PREPARATION

<u>Year</u>	<u>University</u>	<u>Degree (Discipline)</u>
1978-84	Howard University, Washington, D.C.	Ph.D (Aerospace Engr.) (to graduate in Spring 84)
1974-76	Indian Institute of Science, Bangalore, India	M.Sc. (Aeronautical Engr.)
1969-73	University of Mysore, India	B.E. (Mech. Engr.)
1966-69	Bangalore University,	B.Sc. (Physics and Maths.)

PROFESSIONAL EXPERIENCE

<u>Year</u>	<u>Position</u>	<u>Organization</u>
1976-78	Engineer	Indian Space Research Organization, Bangalore, India

PUBLICATIONS/ PRESENTATIONS

1. Krishna, R., Shrivastava, S.K. and Prasad, U.R. "Tri-axial Control of an earth observation Satellite Using Two Reaction Wheels and Electromagnets," Zeitschrift fur Flugwissenschaften Und Weltraumforschung, Vol. 2, No. 4, July-Aug., 1978, pp. 280-290.
2. Reddy, A.S.S.R., Bainum, P.M., Krishna, R. and Hamer, H.A., "Control of a Large Flexible Platform in Orbit," Journal of Guidance and Control, Vol. 4, No. 6, Nov-Dec, 1981, pp. 642-649.
3. Bainum, P.M., Krishna, R. and Kumar, V.K. "The Dynamics of Large Flexible Earth Orbiting Structures with a Hybrid Control System," The Journal of the Astronautical Sciences, Vol. XXX, No. 3, July- Sept., 1982, pp. 251-267.
4. Bainum, P.M., Kumar, V.K., Reddy, A.S.S.R. and Krishna, R. "On the Modelling and Simulation of the Dynamics and Control of Large Flexible Orbiting Systems," the 10th IMACS World Congress on System Simulation and Scientific Computation, Montreal, Canada, Aug. 8-13, 1982.
5. Krishna, R. and Bainum, P.M. "Effect of Solar Radiation Disturbance on a Flexible Beam in Orbit," AIAA 21st Aerospace Sciences Meeting, Reno, Nevada, Jan 10-13, 1983, Paper No. AIAA-83-0219, Also in AIAA Journal April/May 1984 (to be published)
6. Krishna, R. and Bainum, P.M. "Orientation and Shape Control of an Orbiting Flexible Beam Under the Influence of Solar Radiation Pressure," Advances in the Astronautical Sciences, Astrodynamics 1983, Vol. 54, pp
7. Bainum, P.M., Reddy, A.S.S.R. and Krishna, R. "On the Controllability and the Control Law Design for an Orbiting Large Flexible Antenna System," 34th International Astronautical Congress, Budapest, Hungary, Oct. 10-15, 1983

8. Bainum, P.M. and Krishna, R. "Dynamics and Control of an Orbiting Flexible Platform in the Presence of Solar Radiation," Fourteenth International Symposium on Space Technology and Sciences, Tokyo, May 28- June 2, 1984 (accepted).
9. Krishna, R. and Bainum, P.M. "Dynamics and Control of Orbiting Flexible Beams and Platforms Under the Influence of Solar Radiation and Thermal Effects," AIAA/AAS Astrodynamics Conference, Washington, Seattle, Aug 20-22, 1984 (offered)
10. Krishna, R. and Bainum, P.M. "The Environmental Effects on the Dynamics and Control of an Orbiting Large Flexible Antenna System," 35th International Astronautical Congress, Lausanne, Switzerland, Oct. 7-13, 1984 (offered).

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REPORTS

1. Krishna, R. and Shrivastava, S.K. "Satellite Attitude Control: A Bibliography (1962-73)," Contract Report for ISRO, No.74-FDC-1, May 1974.
2. Krishna, R. and Shrivastava, S.K. "Attitude Control System for Space Missions," Contract Report No. VSSC-75-01-5001, IISc. Report 75-FDC-1, Jan. 1975
3. Shrivastava, S.K. and Krishna, R. "Attitude Control System for an Earth Resources Survey Satellite - A Preliminary Selection and Design," Technical Memorandum for ISRO No. VSSC-75-07-4001/IISc.-75-FDC-04-06, IISc., Bangalore, July 1975.
4. Shrivastava, S.K., Prasad, U.R., Krishna, R., Kumar, V.K., and Ramakrishna, Y. "Attitude Control of an Earth Observation Satellite," Contract Report for ISRO, No. VSSC. 75-05-5000: IISc.-76-FDC-01-08, May 1976.
5. Krishna, R. "An Attitude Control System for Earth Observation Satellite," M.Sc. Thesis, June 1977, Indian Institute of Science, Bangalore, India.
6. Bainum, P.M., Reddy, A.S.S.R., James, P.K., Kumar, V.K. and Krishna, R. "The Dynamics and Control of Large Flexible Space Structures - II," Final Report, NASA Grant NSG-1414, Suppl.1, Dept. of Mechanical Engineering, Howard University, June-Sept., 1980
7. Bainum, P.M., Reddy, A.S.S.R., James, P.K., Kumar, V.K., and Krishna, R. "The Dynamics and Control of Large Flexible Space Structures- III," Final Report, NASA Grant NSG-1414, Suppl.2, Dept. of Mechanical Engineering, Howard University, June-Sept., 1980.
8. Bainum, P.M., Chieh, H.T., Choudhuary, A.K., Fan, D. and Krishna, R. "Computer and Other Support of Analysis and

Simulation of Attitude Control Systems for Flexible Spacecraft," Final Report, INTEL No. 108, Howard University to International Telecommunications Satellite Organization, Nov. 1980.

9. 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, Dept. of Mechanical Engineering, Howard University, August 1981, NASA-CR 165815.
10. Bainum, P.M., Reddy, A.S.S.R., Krishna, R., Diarra, C.M., and Kumar, V.K., "The Dynamics and Control of Large Flexible Space Structures V," Final Report, NSG-1414, Suppl. 4, Dept. of Mechanical Engineering, Howard University, August 1982.
11. Bainum, P.M., Manoharan, M.G., Reddy, A.S.S.R., and Krishna, R. "Study on Optimal Control Law of Flexible Antenna Pointing on Large Spacecraft-I," Final Report to Nippon Telegraph and Telephone Public Corp., Japan, March 1983.
12. Bainum, P.M., Reddy, A.S.S.R., Krishna, R., and Diarra, C.M. "The Dynamics and Control of Large Flexible Space Structures VI," Final Report NSG-1414, Suppl. 5, Dept. of Mechanical Engineering, Howard University, August, 1983.

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AWARDS

- 1. Outstanding Research Scholar (First Place), Fifth Annual Graduate Student Symposium, Howard University, 1983.
- 2. AIAA Outstanding Student Achievement Award, Howard University, 1981-82, 1982-83.
- 3. AAS Outstanding Student Award, 1981.
- 4. Recipient, Graduate Teaching Assistantship, 1978-79 and 1982-83.
- 5. Research Scholarship (Government of India), Indian Institute of Science, 1975-76.
- 6. Indian Institute of Science Research Fellowship, 1974-75.
- 7. Merit Scholarship, University of Mysore, 1970-72.

MEMBERSHIP

- 1. AIAA Student Member (1979-)
- 2. AAS Student Member (1981-)
- 3. Sigma xi, Scientific Research Society, 1981.

PROFESSIONAL ACTIVITIES

- 1. Chairperson, AIAA Howard University Student Branch, 1982-83.
- 2. Chairperson, Graduate Student Session, Also member, Program Committee, AIAA Mid-Atlantic Regional Student Conference, Howard University, 1982.
- 3. Reviewed papers for Applied Mechanics Reviews (2) and the Journal of Guidance and Control (1).
- 4. Participated in research grants sponsored by Intelsat and Nippon Telephone and Telegraphs (Japan).

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RESEARCH EXPERIENCE

1978 Aug - : Howard University, Washington, D.C.

Position: Graduate Research Assistant

- Projects:
- (i) 'Dynamics and Control of Large Flexible Space Structures' (Research supported by NASA Grant NSG-1414)
 - (ii) 'Attitude Control and Simulation of Flexible Spacecraft' (Research supported by INTEL SAT Grant INTEL-108)
 - (iii) 'Dynamics of Large Flexible Space Structures' (Research supported by Nippon Telephone and Telegraph, Japan)

1976 - 1978 : Indian Space Research Organization, India

Position: Engineer

- Projects:
- (i) Performance Evaluation of spin axis stabilized, jet controlled earth resources satellite through digital and analog simulation.
 - (ii) Parametric optimization of 3 axis stabilized communications satellite using hybrid computer simulation.
 - (iii) Orbit-Attitude interaction during orbit transfer of the Indian communications satellite (pre-launch analysis).

1974 - 1976: Indian Institute of Science, Bangalore, India

Position: Graduate Research Assistant

- Projects:
- ISRO supported research on satellite attitude dynamics and control.

RESUME

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Name : Sivaramachandran, A.S.

Nationality : [REDACTED]

Date of birth : [REDACTED]

Educational Qualifications:

- A good Bachelor Degree in Mechanical Engineering from the University of Kerala, 1967.
- An excellent Masters Degree in Applied Maths. (Faculty of Engg.) from Coimbatore Institute of Technology, 1970.

Professional Experience:

- About 3 years' teaching experience after Masters Degree in the Mech. Engineering Dept. at Coimbatore Institute of Technology (India), 1970-73.
- About 10 years' experience in research and product-development at Indian Space Research Organisation. During this period I was promoted twice in recognition of my contribution to the Organisation. I have been associated with the following activities there:
 - Have lead a team of engineers for establishing the Static Test and Evaluation Complex, where the flight-worthiness of the rockets is ascertained. The task consisted of developing single and six-component test-stands for static firing of rockets and environmental test facilities like vibration, shock, and thermal test facilities.
 - Have developed, right from conceptual level, a System Initiation Valve for solving a shock-problem in the Thrust Vector Control System of the first Satellite Launch Vehicle of India. This component is presently part of the first stage Control System of the Vehicle. A technical paper titled, "A System Initiation Valve for Launch Vehicle Control Power Plant Pressurisation System" was presented at the 26th Congress of the Indian Society of Theoretical and Applied Mechanics, held in December, 1981.

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- Have lead a project team which has developed an experimental set up for rock-drilling using rockets.

- Last 5-6 years I was engaged in the development of Launch Vehicle Control System and Electro-mechanical Components of aerospace quality. They include a variety of high pressure fluid power components like fill and vent valves, solenoid valves, check valves, relief valves and pneumatically actuated valves. I have produced a number of reports on the development of these components. I have also proposed a few original concepts like liquid-enclosing rotary seal, partial balancing of relief valves, multiple pressure release system, automatic bottling unit etc., some of which are yet to be evaluated experimentally.

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RESUME

S. Ananthakrishnan
3719 12th Street, NE, #201B
Washington, D.C. 20017.
H:(202)-526-3031
W:(202)-636-7124

OBJECTIVE:

To achieve strong foundation in the various aspects of the work while at the same time emphasizing depth. I am interested in an active research oriented program.

EDUCATION:

.candidate-Master of Engineering program, Department of Mechanical Engineering, Howard University, Washington, D.C. 20059.(GPA- 3.79/4.0).

.B.E(Honors) in Mechanical Engineering from University of Madras, Tamilnadu, India.(May,1981).(Top 5% in a class of 89 students.)

ACCOMPLISHMENTS:

.passed the Bachelor of engineering degree with Honors- the highest accomplishment one can achieve in the Bachelors degree.(May,1981)

.recipient of the 'Graduate Apprenticeship Training' (under the Government of India Board of Apprenticeship scheme) in M/S Ashok Leyland Ltd., a leading automobile industry in India.(1981-1982).

.recipient of 'Graduate Assistantship' from the Department of Mechanical Engineering, Howard University, Washington, D.C. 20059(academic year 1982-1983).

.recipient of 'Graduate Research Assistantship' from the NASA grant (NSG1414) on 'Dynamics and Control of Large Space structures' (summer, 1983).

.recipient of 'Graduate Assistantship' from the Department of Mechanical Engineering, Howard University, Washington, D.C. 20059(academic year 1983-1984).

.recommended for 'Tau Beta Pi'(Honor Society) membership by the Department of Mechanical Engineering, Howard University, Washington,D.C.-20059.

COMPUTER RELATED EXPERIENCE:

.Working knowledge on IBM-3033 and HP-3000 computer systems. I am learning computer graphics and intend using interactive computer graphics in my Masters Thesis.

AREAS OF COURSEWORK:

.Advanced engineering mathematics, Statistics and Probability, Numerical analysis, Linear control theory, Applied mathematics with special emphasis on perturbation techniques, fourier transforms, asymptotic expansions; Operations research, Advanced dynamics, Computational methods, Digital computation, Digital Control, Aerodynamic theory.

Further I have done extensive coursework in the field of Mechanical engineering and limited coursework in the field of Aerospace engineering.

CURRENT RESEARCH INTEREST:

.stochastic optimal control and estimation as applied to hoop-column antenna systems-research supported by NASA.

.application of interactive computer graphics in the interpretation of the results of the above system.

MEMBERSHIP:

.student member AIAA

.student member 'Institution of Engineers India' (1979-1981).

.student member ASME

Reference and further information will be furnished upon request.

RESUME

IRVING W. JONES

PERSONAL

Addresses and Phone Numbers:

383 N Street, S.W.
Washington, D.C. 20024
(202) 646-0315

Civil Engineering Department
Howard University
Washington, D.C. 20059
(202) 636-6147

Security Clearance: SECRET

EDUCATION

Degrees

Ph.D. in Applied Mechanics, Polytechnic Institute of Brooklyn, 1967
Title of Dissertation: "Non Periodic Vibrations of Layered
Viscoelastic Plates."

Major: Structural Dynamics
Minor: Structural Mechanics (General)

M.S. in Applied Mechanics, Columbia University, Institute of Flight
Structures, 1957.
Title of Thesis: "Modal Analysis of Ring-Stiffened Cantilevered
Cylinders."

Major: Aerospace Structures
Minor: Numerical Structural Methods

B.S. in Civil Engineering (magna cum laude), Howard University, 1953.

Special Courses

Dynamics of Shell Structures, UCLA
Computer-Aided Structural Analysis, Stanford University
Optimized Design of Structures, University of Missouri, Rolla
Finite Element Analysis of Ship Structures, U. of Arizona
Modern Photoelastic Stress Analysis, Vishay Instruments Corp.

PROFESSIONAL EXPERIENCE

1983 - Professor, Department of Civil Engineering
Howard University, Washington, D.C.

Responsibilities: Teach and develop courses in structures and mechanics at graduate and undergraduate levels, supervise and perform research, serve on University committees, perform special tasks for the Department and School administrators.

1981 - 1983* Structural Engineering Specialist,
The Aerospace Corporation,
El Segundo, California

Responsibilities: In support of the U.S. Air Force space program, perform critical review of structural aspects of the design, testing and manufacture of Air Force space vehicles and their components, and related ground support equipment and facilities, produced by government contractors; more specifically, review stress and failure analyses, performing independent analyses where necessary, review and approve test programs and fracture control plans, and certify the flight-worthiness of space hardware. Also, develop advanced structural analysis in-house capabilities (included development of formulation for a thermo-viscoelastic structural analysis computer program suitable for solid rocket propellant grains and other polymeric materials).

1972 - 1983* Professor and Chairman, Department of
Civil Engineering, Howard University,
Washington, D.C.

Responsibilities: Administer the civil engineering programs at undergraduate and graduate levels; recruit and supervise faculty and supporting staff; assume responsibility for policy implementation, planning, budgeting, curricular and other matters; teach courses in structures and mechanics; supervise and perform research in structures; coordinate research and training projects in other areas; serve on University committees, perform community services.

Summer 1972 Consultant to the Port Authority of
New York and New Jersey

Responsibilities: Assist and advise on projects to expand the use of the computer in the structural analysis and design groups.

1969 - 1971 Associate Professor, Department of
Civil Engineering, Howard University
Washington, D.C.

Responsibilities: Teach and develop courses in structures and mechanics at graduate and undergraduate levels, supervise and perform research, organize the new graduate program in civil engineering.

*on leave from Howard University, 1981-1983

PROFESSIONAL EXPERIENCE (continued)

214

1954-1956 First Lieutenant, U.S. Air Force (Regular)
Technical Instructor, Donaldson Air Force
Base, South Carolina

Responsibilities: Teach courses in mathematics and mechanics

PUBLICATIONS (and typical technical reports)

Jones, I.W.: Evaluation of Foldable Elastic Tubes for Large Space Structure Applications, Final Report-Phase I, January 1980 (with C. Boateng), Final Report-Phase II, January, 1981 (with C.D. Williams), and Final Report-Phase III, October, 1981 (with S.O. Mitchell), NASA Grant NSG 1320.

*Jones, I.W.: "Graduate and Continuing Education: An Important Focus for the Minority Engineer," presented at the Annual Conference of the National Technical Association, Pittsburg, August 1979 and later published in the NTA Journal.

Jones, I.W., (with H. Hopkins et al), Potential Agricultural Applications for Lightweight Ground Effect Machines, NASA Research Review, August 1979.

*Jones, I.W.: "Damping of Plate Vibrations by Means of Attached Viscoelastic Material," U.S. Naval Research Laboratory Shock and Vibration Bulletin #39, pt. 4, April, 1969, pp. 63-72; presented at the NRL Symposium on Shock and Vibration, Monterey, California, 1969.

Jones, I.W. and Goben, K.: "Laboratory Evaluation of the Fragility of Shock-sensitive Shipboard Mounted Equipment", Naval Ship Research and Development Center Report, June 1979.

Jones, I.W. and Salerno, V.L.: "Guide for Users of the Dynamic Design-Analysis for Shock Resistance Evaluation of Shipboard Equipment," ATA Report No. 1124, January 1969. Prepared for NSRDC Code 745 Under Contract No. N00600-68-C0311.

Jones, I.W.: "Non-Periodic Vibrations of Layered Viscoelastic Plates," Ph.D. Dissertation, New York Institute of Technology, June 1967.

*Jones, I.W. and Savacchio, A.: "An Analytical and Experimental Evaluation of the Damping Capacity of Sandwich Beams with Viscoelastic Cores," Journal of Engineering for Industry, Trans. ASME, Volume 89, Series B, August, 1967.

Jones, I.W.: "Shock Response Analysis of a Shipboard Item (with illustrative problem and theory)," ATA Report No. 114, December 1966. Prepared for DIMB Code 070 Under Contract No. N00167-67-C0023.

*presented at national conferences by I.W. Jones.

PUBLICATIONS (continued)

*Jones, I.W. and Salerno, V.L.: "The Effect of Structural Damping on the Forced Vibrations of Cylindrical Sandwich Shells," Journal of Engineering for Industry, Trans. ASME, Volume 88, Series B, August 1966.

*Jones, I.W. and Salerno, V.L.: "The Vibration of an Internally Damped Sandwich Plate Radiating into a Fluid Medium," Journal of Engineering for Industry, Trans. ASME, Volume 87, Series B, August, 1965.

Jones, I.W.: "The Vibration of a Homogeneous Plate with Linear Damping, Radiating into a Fluid Medium," Bosco Institute for Research Report #101. Performed under ONR Contract Nonr-4199(00), November, 1963.

*Lansing, W., Jones, I.W. and Ratner, P.: "Non-Linear Analysis of Heated Cambered Wings by the Matrix Force Method," AIAA Journal, Volume 1, pp. 1619-1926, 1963.

Lansing, W. and Jones, I.W.: "Non-Linear Shallow Shell Analysis by the Matrix Force Method," NASA TN D 1510, 1962.

*Lansing, W., Jones, I.W., and Ratner, P.: "A Matrix Method for Analyzing Heated Structures, Including Large Deflections," ONR-ACT 62, Symposium Proceedings, Structural Dynamics of High Speed Flight, April 1961.

Also numerous other technical reports and memoranda at Grumman Aerospace Corporation, Applied Technology Associates, Inc., Fairchild-Hiller Corporation and The Aerospace Corporation.

*presented at national conferences by I.W. Jones.

Member of the following professional societies:

American Institute of Aeronautics and Astronautics
American Society of Civil Engineers
Committee on Minority Programs, National Capital Section,
American Society of Civil Engineers
American Society for Engineering Education
International Association for Computational Mechanics
American Association for the Advancement of Science
ICES (Integrated Civil Engineering Systems) Users Group
National Technical Association, Committee on Education

served on Design and Analysis Committee of Pressure Vessel
and Piping Committee, ASME, 1963-1969
served on Pressure Vessel Research Committee of the Welding
Research Council, Engineering Foundation, 1963-1969

Elected to the following honorary societies:

Tau Beta Pi (Engineering)
Pi Mu Epsilon (Mathematics)
Sigma Xi (Science)
Sigma Gamma Tau (Aerospace Engineering)

Listed in the following publications:

Leaders in Education
American Men and Women of Science
Who's Who in Engineering (Engineers Joint Council publication)

Received the following awards:

Guggenheim Foundation Fellowship in Flight Structures 1956-1957
ASCE Outstanding Instructor Award 1970
Meritorious Service Award, Graduate School, Howard University, 1975

Included in "Outstanding Black Scientists", a permanent exhibit at the
Philadelphia Museum of Black History and Culture, 1977.

RESUME

Dr. A.S.S.R. Reddy

Dr. A.S.S.R. Reddy
Assistant Professor
Department of Mechanical Engineering
Howard University
Washington, D.C. 20059
Tel. No. (O) 202-636-6622
(R) 301-587-4998

Areas of Interest:

Teaching: Courses in Dynamics and Control, Instrumentation,
Computer Graphics, Computer Aided Design.

Research: Control of Large Space Structures, Computer Aided
Design, Robotics, Microprocessor Oriented Control
Systems.

Professional
Memberships:

Member, Sigma XI

Member, American Institute of Aeronautics and Astronautics

Member, American Astronautical Society

ACADEMIC PREPARATION:

<u>YEAR</u>	<u>INSTITUTION</u>	<u>ACADEMIC ACHIEVEMENT</u>	<u>REMARKS</u>
1977-1982	Howard University, Washington, D.C.	Ph.D (Doctor of Philosophy)	3.85/4.0 GPA in course work. Specialization: Dynamical and Control.
1977-1981	Howard University, Washington, D.C.	Master of Computer Science (M.C.S.)	4.0/4.0 G.P.A.
1972-1974	Indian Institute of Science Bangalore, India	Master of Engineering (M.E.) in Electrical	First Class with Distinction
1968-1971	Government Engineering College Kakinada, A.P., (India)	B.E. (Electronics and Communications) Third, Fourth and Final years	First Class with Distinction
1966-1968	Andhra University Engineering College, Waltair, A.P., (India)	Bachelor of Engineering (B.E.), First two years in Electronics and Communications	
1965-1966	Andhra Loyola College, Vijaywada, A.P., (India)	Pre-University Course (P.U.C.)	First Class
1959-1965	S.K.V.H. School, Kuchipudy, A.P., (India)	Secondary School Leaving Certificate (S.S.L.C.)	First in School

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WORK EXPERIENCE:

<u>YEAR</u>	<u>INSTITUTION</u>	<u>POSITION</u>	<u>NATURE OF WORK</u>
1977 September - 1982 Nov.	Howard University Washington, D.C.	Graduate Assistant	Working on the project "Attitude and Shape Control of Large Space Structures" (using ORACLS software control laws).
1975 May - 1975 November	Societe Engins Matra, Velizy France	Trainee	Understanding of 3-Axis stabilization of communication Satellite OTS.
1974 June - 1977 September	Indian Space Research Organization (ISRO) Bangalore, India	Engineer	Worked in Control and Guidance group. Design and simulation of altitude control system of scientific (spin stabilized) and communication (3.Axis stabilized) Experience on IBM 360/44, Applied Dynamics AD/Five and EAI's PACER 600 computer.
1972 April - 1972 August	Indian Space Research Organization (ISRO) Trivandrum, India	Technical Assistant	Designing a wide Bandwidth amplifier using discrete components.
1971 November - 1972 April	National Institute of Engineering (N.I.E.) Mysore, India	Lecturer	Teaching undergraduate students Electro Acoustics.

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PUBLICATIONS/PRESENTATIONSORIGINAL PAGE IS
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1. Reddy, A.S.S.R., "A Method for Frequency Domain Simplification of Transfer Functions," Int. J. Control, 1976, Vol. 23, No. 3, pp. 603-608.
2. Reddy, A.S.S.R., "Generation of Harmonics without Tuned Circuits," Applied Ideas, Electronic Engineering, Vol. 50, No. 613, mid-October, 1978.
3. Bainum, P.M. and Reddy, A.S.S.R., "On the Controllability of a Long Flexible Beam in Orbit," presented at Second AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, June 21-23, 1979, Blacksburg, Virginia, also in Proceeding of VPI&SU/AIAA Symposium, pp. 145-59.
4. Reddy, A.S.S.R. and Bainum, P.M., "Decoupling Control of Long Flexible Beam in "Orbit", presented at AAS/AIAA Astrodynamics Specialists Conference, Provincetown, Massachusetts, June 25-27, 1979, also in Advances in Astronautical Sciences, Vol. 40, pp. 649-673.
5. Reddy, A.S.S.R., Bainum, P.M., Hamer, H.A., and Krishna, R., "Control of a Large Flexible Platform in Orbit," presented at AIAA/AAS Astrodynamics Conference, August 11-13, 1980, Danvers, Massachusetts, also in Journal of Guidance and Control, Vol. 4, No. 6, November - December 1981, pp. 642-649.
6. Reddy, A.S.S.R., and Bainum, P.M., "Graph Theory Approach to the Eigenvalue Problem of Large Space Structures," accepted for presentation at Third VPI&SU/AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, June 15-17, 1981, Blacksburg, Virginia, U.S.A., also in the Proceedings of Third VPI&SU/AIAA Symposium, pp. 175-89.
7. Bainum, P.M. and Reddy, A.S.S.R., "On the Shape and Orientation Control of an Orbiting Shallow Spherical Shell Structure," presented at Joint IFAC/ESA Symposium on Automatic Control in Space, Noordwijkerhout, The Netherlands, July 5-9, 1982.
8. Bainum, P.M., Kumar, V.K., Reddy, A.S.S.R., and Krishna, R., "On the Modelling and Simulation of the Dynamics and Control of Large Flexible Orbiting Systems," presented at the 10th IMACS World Congress on System Simulation and Scientific Computation, Montreal, Canada, August 8-13, 1982.

9. Reddy, A.S.R. and Bainum, P.M., "Controllability of Inherently Damped Large Flexible Space Systems," presented at the 33rd International Astronautical Congress, Paris, France, Sept. 27-Oct. 2, 1982, also to appear in Acta Astronautica.
10. Bainum, P.M., Reddy, A.S.S.R., and Krishna, R., "On the Controllability and Control Law Design for an Orbiting Large Flexible Antenna System" presented at the 34th International Astronautical Congress, Budapest, Hungary, Oct. 10-15, 1983.
11. Reddy, A.S.S.R., "Solution of Kepler's Equation as a Differential Equation," presented at AIAA 22nd Aerospace Sciences Meeting, Reno, Nevada, Jan. 9-12, 1984.

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B. RESUMES OF POST DOCTORAL CANDIDATES

CURRICULUM VITAE

Dr. Harijono Djojodihardjo
Senior Chief Lecturer/Associate Professor of Aerospace Engineering
and Head, Aero & Hydrodynamics Laboratory
Department of Mechanical Engineering
Institute of Technology Bandung, Indonesia
and
Director, Aerospace Technology Center
National Institute of Aeronautics and Space (LAPAN)
Jakarta, Indonesia
and
Chief, Dynamics and Loads
Directorate of Technology, Nurtanio Aircraft Industry
Bandung, Indonesia

Areas of Specialization : Aerodynamics and Gas Dynamics, Aeroelasticity, Stability
and Control, Orbital Mechanics, Wind Energy, Computational
Methods

1. PERSONAL DATA

Place and Date of Birth:



Marital Status:

married, to Dr. Bulantrisna Djojodihardjo, a medical doctor
three children : Krishna (a boy, 11), Bismo (a boy, 7) and
Asmara (a girl, 6)

2. ACADEMIC QUALIFICATION

<u>College</u>	<u>Year</u>	<u>Degree</u>
Institut Teknologi Bandung	1958-62	Sarjana Teknik Mesin (Ir)
University of Kentucky	1963-64	M.S. in Mechanical Engineering
Massachusetts Institute of Technology	1964-68	Mech.E. (1965), S.M. in Naval Architecture and Marine Engineering (1966) Sc.D. in Aerodynamics and Gas- Dynamics (1968)

Training and Postdoctoral Courses Attended

<u>Organization</u>	<u>Time</u>	<u>Subject</u>	<u>Fellowship</u>
National Physical Laboratory (Teddington, England)	Jan-Apr 72	Windtunnel Design & Techniques	British Council
International Centre for Theoretical Physics	Sep-Nov 74	Control Theory & Functional Analysis	ICTP

<u>Organization</u>	<u>Time</u>	<u>Subject</u>	<u>Fellowship</u>
International Centre for Theoretical Physics	Sep-Nov 76	Application of Functional Analysis to Mechanics	ICTP

2. PROFESSIONAL EXPERIENCE

Dr. Harijono Djojodihardjo has a combined teaching and practical experience totaling approximately 21 years since receiving his Sarjana Teknik (Ir) degree in 1962.

University Teaching and Research

Institut Teknologi Bandung	1983-	Senior Chief Lecturer/Associate Professor (IV/c) ^e
	1979-83	Chief Lecturer (IV/b)
	1975-79	Lecturer (IV/a)
	1973-75	Senior Associate Lecturer (III/d)
	1971-73	Associate Lecturer (III/c)
	1969-71	Senior Assistant Lecturer (III/b)
Massachusetts Institute of Technology	1962-63	Assistant Lecturer (III/a)
	1964-65	Part-time Research Assistant, Gas Turbine Laboratory
	1966-68	Research Assistant, Aerodynamics and Structures Research Laboratory
	68-Feb 69	Research Staff Member, Measurement Systems Laboratory

Courses Taught:

Institute of Technology Bandung:

Machine Elements (1962-63), Fluid Mechanics (1969-81), Heat Transfer (1969-70), Thermodynamics (1969-72), Aerodynamics (1969-74), Airplane Performance/Flight Mechanics (1974-1983), Airplane Stability and Control (1974-83), Applied Mechanics (1972-76), Numerical Analysis (1972-present), Aerodynamics Laboratory (1976-present), Mathematical Physics (1972-present)

Graduate courses:

Aerodynamics (1976-present), Aeroelasticity (1982-present), Applied Mathematics (1979-82), Rocket Flight Mechanics (1976), Spacecraft Dynamics and Control (1983)

Other Universities:

Military Technical Academy, Bandung, 1962-63 : Applied Mechanics, Thermodynamics
 State Administration Institute, Bandung, 1972-74: Introduction to Computers
 Graduate School of the Institute for Teaching and Education, Bandung, 1976-81:
 Introduction to Computer and Computation
 University of Indonesia, Jakarta, 1969-71: Fluid Mechanics, Dynamics
 Naval Institute of Science, Jakarta, 1969-71 : Energy Conversion

^e University Teaching Position in Indonesian State Universities falls into Civil Servant classification. For University graduates, the rank starts at III/a (for Master's Level) or III/b (for Doctorate's level). The highest is IV/e, for Senior Professor, and is equivalent to Major General/Air Vice Marshall.

Academic and Professional Positions:

Institute of Technology Bandung, Department of Mechanical Engineering

- 1969- present Head, Aero & Hydrodynamics Laboratory
- 1969- 1972 Head, Aeronautical Engineering Sub-Department
- 1972 Executive Secretary

Institute of Technology Bandung, Computer Center

- 1972-1977 Director for Research, Development and Computer Science

National Institute for Aeronautics and Space (LAPAN)

- 1975- present Director, Aerospace Technology Center
- 1977-1979 Manager, Personnel Development Project
- 1979-1983 Manager, Wind Energy Research and Development Project

Nurtanio Aircraft Industry

- 1983- Chief, Dynamics and Load, Directorate for Technology

Consulting Experience:

<u>Place</u>	<u>Year</u>	<u>Activities</u>
Air Force Research Institute Directorate General for Aircraft Industry	1969-74 1969-74	Aircraft Technology Development, Hovercraft Techno-Economic Feasibility /Preinvestment Studies for Air Transportation System and Aircraft Industry
LIPNUR Aircraft Esta- blishment	1969-74	Aircraft Technology Development
P.T.Konstruktor	1969-71	Airconditioning
P.T.Widya Pertiwi Engineering	1975-76	Systems Analysis, Environmental Studies
P.T.Bumi Prasadhi	1980-82	Systems Analysis, Environmental Studies

3. TEACHING AND RESEARCH LEADERSHIP

Dr.Harijono Djojodihardjo has been responsible for the design, development and offering of the following courses:

- undergraduate: Air Transportation System (1970-71)
- Numerical Methods, Mathematical Physics
- graduate : Aeroelasticity, Spacecraft Dynamics and Control
 (special graduate program offered for LAPAN scientists)

Dr.Harijono Djojodihardjo has also been responsible for the establishment of the following laboratories:

- Aero & Hydrodynamics Laboratory at Institute of Technology Bandung
- Wind Energy Laboratory at LAPAN (under preparation)

He has also organized a non-degree graduate program for LAPAN scientists , under a cooperative framework between LAPAN and ITB (Institut Teknologi Bandung). Some twenty engineers and scientists have completed this program in order to provide additional background required for their assignments at LAPAN.

Undergraduate:

1. A Simple Method to Analyse and Calculate Rocket Trajectory, Urip Subagyo, 1970.
 2. Route and Traffic Analysis of Domestic Air Transportation System, S.W.Hidayat, 1970.
 3. A Study on Gyro-Dynamics, S.B.Pamungkas, 1970.
 4. The Design and Construction of an Optical Stress Analysis Demonstration Rig, W.Gitosayono, 1971.
 5. The Design and Construction of a Water Table, Nyoo Seng Tjwan, 1972.
 6. The Design and Construction of a Pyramidal Balance, Nugroho, 1972.
 7. The Design of a Windtunnel Balance, Djinawi, 1972.
 8. Heat Transfer Calculation of Bandung Nuclear Reactor, Antarikso, 1972.
 9. The Design and Construction of a windtunnel wire balance, Sumantri, 1973.
 10. The design of a two-stage sounding rocket, Indrawan, 1973.
 11. An Experimental Study of Hovercraft Lift System, Subari, 1973.
 12. The Calibration of ITB Low Speed Windtunnel, M.Agus, 1972.
 13. An experimental investigation of the flow characteristics around a circular cylinder at Reynolds number of 10^4 , Rudiono, 1973.
 14. An experimental investigation of Darrieus Rotor Model, H.Abdulrachim, 1974.
 15. An experimental investigation of the influence of aspect ratio on the aerodynamic drag of rectangular cylinders, Sugiarmadji, 1974.
 16. The design of a transport aircraft, Wahyono, 1974.
 17. Numerical heat transfer analysis of grain drying process, Rohmanuddin, 1975.
 18. An experimental investigation of a high rise building model, L.U.Kamil, 1976.
 19. Experimental investigation of propeller type windturbine rotor, B.Suraryo, 1976.
 20. An aerodynamic analysis of sail windmill rotor, R.R.Malik, 1976.
 21. Aerodynamic analysis of Darrieus Windturbine Rotor, Rasuldin, 1976.
 22. Construction and field tests of Savonius Rotor, W.Hidayat, 1977.
 23. Analysis of Wind Data for Energy Utilization, D.A.Salim, 1977.
 24. Construction and Field Test of Thai Bamboo Mat Windmill, Zulfian, 1977.
 25. A Study of Gyro Windmill, Asyaman, 1977.
 26. The design of a small hovercraft, Herman, 1977.
 27. An experimental investigation of the pressure distribution around a TV Tower Model, Onn Yusoff, 1978.
 28. A Matrix Method for Structural Analysis of a Non-Prismatic Beam, Sulistyono, 1978.
 29. An Experimental Investigation of an N-pentane solar pump, Radialtono and Idrus, 1978.
 30. Construction and Field Tests of a Clapper Windmill, Santosa, 1979.
 31. The Design of the Propeller for an Open Circuit Windtunnel, M.Wirata, 1980.
 32. Windtunnel Test of Some Automobile Models, Pramudji, 1981.
 33. Finite Element Analysis of Flow Through an Orifice, B.Priyatmoko, 1983.
 34. An analysis of the influence of gravitational anomaly on the geostationary orbit, Yus Kadarusman, 1983.
 35. The Design and Construction of a Bicycle Wheel Windmill Rotor. B.Hasan, 1983.
 36. Experimentation and design of a laser anemometer, Chumaeni Latief, 1975.
 37. The design and construction of a small windtunnel for environmental studies, Adi Sadewo Salatun, 1975.
 38. Preliminary design of a trainer aircraft, Manahara Parhusip, 1974.
 39. The design of a windtunnel fan rotor, Ali Syaifullah, 1978.
- Ongoing:
1. The Design of a Darrieus Wind Turbine System, D.Kasworo.
 2. Wind Data Analysis of Bandung Northern Hills, Surya Wahidin.
 3. An Analytic and Experimental Investigation of Tip-Vane Concept, T.Sarief.
 4. A Newton-Raphson Approach for the Analysis of the influence of Gravitational Anomaly on Geostationary Orbit, H.Sudjono.

Graduate Projects/Theses:

1. Structural Analysis of a Rocket Airframe, D.Sebayang, 1976.
2. Rocket Trajectory Analysis, Susetyo Mulyodrono, 1976.
3. Analysis and Design of a two-stage sounding rocket, S.Silitonga, 1976.
4. Analysis and Assessment of the ground track of low earth orbits for earth observation, D.Ginting, 1979.
5. A Vortex Lattice Method for Aerodynamic Calculation of Three Dimensional Wings, S.Ginting, 1979.
6. Conceptual Design of a Communication Satellite, E.Satrya, 1979.
7. Finite Element Analysis of a Cantilevered Non-prismatic Beam, S.Atmadi, 1979.

Ongoing:

1. Aeroelastic Analysis of Troposkien Rotor Blades, S.Lubis.
2. An experimental investigation of the vibrational characteristics of a Darrieus Rotor Blade, A.Gaspers.

Doctoral Theses Supervised

(Member of Doctoral Thesis Committees)

1. Analysis of Geoid in Indonesian Region, Joenil Kahar, 1981.
2. The Application of Optimal Regulator-Kalman Filter for the design of Automatic Control System, Arifin Wardiman, 1983.

4. SCHOLARLY AND CREATIVE PRODUCTIVITY

Principal Investigator of the following Reserach Grants and Projects:

1. Department of Defense Grant for the Development of Low Speed Windtunnel at ITB, 1969.
2. LAPAN Grant for the Construction of ITB Low Speed Windtunnel Test Section, 1970.
3. Department of Education Grant for the Calibration of ITB Low Speed Windtunnel, 1971-1972.
4. Department of Education Grant for Model Testing at ITB Low Speed Windtunnel, 1973-1974.
5. Department of Education Grant for the Study and Development of Windmills for water pumping, 1977-1978
6. Air Force Research Institute Project for the Design and Construction of a Hovercraft, 1970.
7. Air Force Research Institute Project for the Study on the Development of Aircraft in Indonesia, 1970.

8. Air Force Research Institute Project for the Modification of Gelatik Aircraft for reconnaissance mission, 1970.
9. Air Force Research Institute Project for Performance Evaluation of Hovercraft XEV-01, 1973.
10. Directorate General of Aircraft Industry Project for Preliminary Design of an Overhaul Enterprise for Light Aircraft Engines, 1972-1973.
11. Directorate General of Aircraft Industry Project for the Techno-Economic Study for the Assembling of Other Types of Aircraft at LIPNUR, 1973-1974.
12. Ford Foundation Grant to ITB for the Development of Computer Sciences at ITB, 1972-1976.
13. P.N.Timah (State Tin Enterprise) Project for the Design of Computer System for the Support of Exploration Activities at P.N.Timah, 1974-1975
14. P.N.Timah Sub-project for the design of Computer Processing System for Maintenance Inventory, 1976.
15. P.N.Aneka Tambang (State Mining Enterprise) Project for Management Personnel Familiarization with Computer System, 1975.
17. LIPNUR Aircraft Industrial Institute Project for Structural Analysis of LT-200 trainer aircraft, 1975.
18. Directorate General for Building Research Grant for windtunnel studies of High-rise Building Model, 1976.
19. PT Widya Pertiwi Engineering Project on Baseline Studies for the Development of Ciliwung-Cisadane River Basin, 1975.
20. PT Widya Pertiwi Engineering Project on Environmental Modelling of Greater Jakarta Metropolitan Area, 1978-1979.
21. PT Bumi Prasidhi Project on Project Monitoring System , 1980-1981.
22. Department of Finance Project for the Design of Computerized Procedure, 1974.

Refereed Publications : (Journal articles, symposium proceedings and presentations)

1. Development of Aerodynamic Computation Routine for Road Vehicles Using Panel Method, International Pacific Conference on Automotive Engineering, November 7-10, 1983, Tokyo, Japan.
2. Development of Indonesian Sounding Rockets, with K.Subandhi and S.Silitonga, 34th Congress of the International Astronautical Federation, October 10-15, Budapest, Hungary.
3. Assessment of Wind Energy Potential in Indonesia and Considerations of Economic Aspects, National Energy Workshop, organized by Indonesian National Committee for World Energy Conference, April 28-29, 1983, Jakarta, Indonesia.

4. Wind Energy in Indonesia: Resource Evaluation and Applications Development, International Symposium - Workshop on Renewable Energy Sources, organized by Clean Energy Research Institute, University of Miami and Pakistan Council of Scientific and Industrial Research, March 16-22 1983, Lahore, Pakistan.
5. The design of Cambered Blade Propeller Windgenerator EN-P-02XA (in Indonesian), with Sugiarmadji and S.Atmadi, Majalah LAPAN, No.25, ISSN 0126-0480, May-July 1982.
6. Analysis of the Influence of the Gravitational Anomaly on Geostationary Orbit (in Indonesian), with Y.Kadarisman, Majalah LAPAN, No.25, May-July 1982.
7. Computational Scheme for Geostationary Satellite Orbit due to Bravitational Anomaly of the Earth, with Y.Kadarisman, Proceedings ITE, ISSN 0125-9350, vol.15, No.3, 1982.
8. Progress and Projection of Indonesian Wind Energy Program, Proc. Fourth International Symposium on Wind Energy Systems, September 28-October 2, 1982, Stockholm, Sweden, organized by BHRA Fluid Engineering.
9. Aerodynamic Computation of Automotive Vehicles (in Indonesian), 4th IATO Conference, Jakarta, October 27-28, 1982.
10. Technology Development of Wind Generators, with Sugiarmadji, First Congress of the ASEAN Federation of Engineering Organizations (CAFEO I), Jakarta, August , 1982.
11. LAPAN Low Subsonic Open Circuit Windtunnel at Rumpin (in Indonesian), with J.Kromodiharjo and I.Sidarta, Scientific Meeting, Laboratory for Aerodynamics and Gas Dynamics, BPP Technology, Jakarta, April 6-7, 1982.
12. The use of earth surface observation data for development planning of Greater Jakarta Metropolitan Area (JABOTABEK), with E.Saparjan, paper presented at 29th Congress of the International Astronautical Federation, October 1-8, 1978, Dubrovnik, Jugoslavia.
13. Wind Energy Research and Development Program in Indonesia, with particular reference to electricity generation, International Conference on Using Renewable Resources in Developing Countries, Berlin (West), June 30-July4, 1980.
14. An assessment of the development of wind energy applications in Indonesia, (in Indonesian), with Sugiarmadji, Warta LAPAN, no.5, October, 1981.
15. The design of multibladed windpumper EN-SM-03 (in Indonesian), Majalah LAPAN, August-October, 1981, No.22.
16. Preliminary Assessment of Wind Data at Selected Sites in Indonesia, with D.Sebayang, LAPAN-DFVLR Workshop on Wind Energy Systems, Jakarta, March 3-5, 1981.
17. LAPAN Vertical Axis Wind Turbine Program, LAPAN-DFVLR Workshop on Wind Energy Systems, Jakarta, March 3-5, 1981.

18. The Design and Construction of LAPAN 6M Darrieus Wind Turbine, LAPAN-DFVLR Workshop on Wind Energy Systems, Jakarta, March 3-5, 1981.
19. Preliminary Design of LAPAN 6M Propeller Wind Turbine, with D.Ginting, LAPAN-DFVLR Workshop on Wind Energy Systems, Jakarta, March 3-5, 1981.
20. Progress and Status of LAPAN Windpumpers Development Program, with D.Ginting, S.Atmadi and N.Sanrosc, LAPAN-DFVLR Workshop on Wind Energy Systems, Jakarta, March 3-5, 1981.
21. Windtunnel Testing of Models of Commercial Vehicles (in Indonesian), with Pramudji, Third IATO Conference, Jakarta, June 11-12, 1981.
22. Aerodynamic Consideration for Fuel Saving in Automotive Vehicle Design (in Indonesian), Second IATO Conference, October 11-12, 1979, Jakarta.
23. The Determination of the Influence of Various Parameters on the Aerodynamic Characteristics of Vehicles by Utilizing Wind Tunnel, (in Indonesian), First IATO (Indonesian Automotive Society) Conference, January 19-20, 1979, Jakarta.
24. Heat Transfer from the Outer Surface of a Rotating Cylinder in Cross Flow, with Dr.Aryadi Suwono, Proc. National Heat and Mass Transfer Conference V, Hyderabad, India, February 13-16, 1980.
25. Performance Evaluation of a Propeller Windturbine for Micro-Electricity Generation (in Indonesian), with H.Sosrohadisewoyo, Workshop on Non-Conventional Energy Development, organized by the Directorate General of Energy, January 28-29, 1980, Jakarta.
26. Wind Energy Research and Development Program at the Indonesian National Aerospace Institute (in Indonesian), Workshop on Wind Energy Applications Development, May 27-28, 1980, Jakarta.
27. The Applications of Wind Energy for Water Pumping and Electricity Generation, (in Indonesian), Workshop on Non-Conventional Energy Development, organized by the Directorate General of Energy, January 28-29, 1980, Jakarta.
28. A Method for the Aerodynamic Computation for Vertical Axis Wind Turbine (in Indonesian), with S.Mulyodrono, Workshop on Wind Energy Applications Development, May 27-28, 1980, Jakarta.
29. The Design and Construction of 1.3KW Darrieus Wind Turbine (in Indonesian), with Sugiarmadji, Workshop on Wind Energy Applications Development, May 27-28, Jakarta.
30. Analysis of Wind Data on Some Regions in Indonesia (in Indonesian), with D.Sebayang, Workshop on Wind Energy Applications Development, May 27-28, 1980, Jakarta.
31. Optimization of the Aerodynamic Performance of Propeller Rotor for the Design of Wind Energy Conversion System (in Indonesian); with S.Ginting, Workshop on Wind Energy Applications Development, May 27-28, 1980, Jakarta.
32. The Design and Construction of a Wind Energy System Consisting of a Bamboo-Mat windmill, a pump and a grain thresher (in Indonesian), with S.Atmadi, Workshop on Wind Energy Applications Development, Jakarta, May 27-28, 1980.

33. Technological Capabilities in Wind Energy Conversion System in Indonesia (in Indonesian), with Dr. Aryadi Suwono and Dr. Mardjono Siswosuwarno, Workshop on Wind Energy Applications Development, May 27-28, 1980, Jakarta.
34. Wind Energy in Indonesia: Prospects and Challenge (in Indonesian), National Energy Workshop organized by the Indonesian National Committee for World Energy Conference, April 1979, Jakarta.
35. Orbital Dynamics of Geostationary Communication Satellites (in Indonesian), Workshop on Space Communication Systems organized by LAPAN, March 13-15, 1979, Jakarta.
36. Wind Energy Conversion System Technology and Development Prospects in Indonesia (in Indonesian), theme paper, Seminar on Atmospheric and Space Research, organized by LAPAN Space Research Center, Bandung, February 5-7, 1979.
37. Some Experimental Results of Savonius Rotors and Prospects for Water Pumping Applications, (in Indonesian), Seminar on Atmospheric and Space Research, LAPAN, Bandung, February 5-7, 1979.
38. Construction and Test Results of Solar Energy Water Pump (in Indonesian), with Raldiantono Kustur and M. Idrus, Seminar on Atmospheric and Space Research, LAPAN, Bandung, February 5-7, 1979.
39. Field Testing of Savonius Rotor Prototype (in Indonesian), with W. Hidayat, Majalah LAPAN, no. 11, Vol. iii, 1979.
40. The Influence of Aspect Ratio on High Rise Buildings of Rectangular Cross Sections in Uniform Flow (in Indonesian), with Sugiarmadji, Majalah LAPAN, no. 8, Vol. III, 1978.
41. Analysis of Wind Data at Cilaut Eureun for Energy Utilization (in Indonesian), with D. A. Salim, Majalah LAPAN, no. 5, vol. II, 1977.
42. Research and Prospects of Utilization of Wind Energy in Indonesia, (paper no. NR/ERD/EW GBW/CR.17), Proceedings of the ESCAP Expert Working Group on Solar and Wind Energy, Bangkok, 1976 (published by the United Nations)
43. Formulation and Analysis of the Aerodynamic Load on Darrieus Rotor Blades, (in Indonesian), Second National Mathematics Conference, Jogjakarta, November 1977.
44. Aerospace Technology for National Development: Indonesian Study, Inter Congress of the Pacific Science Association, Denpasar, Bali, July 1977.
45. Aerospace Technology Development in Indonesia (in Indonesian), theme paper, Seminar on Rocketry, LAPAN, Bandung, February 1976.
46. A Simple Method to Calculate Rocket Orbit (in Indonesian), with U. Subagyo. Seminar on Rocketry, LAPAN, Bandung, February 1976.
47. Contributions of Aerospace Technology in Environmental Development, (in Indonesian), Seminar for Environmental Development, Ministry for Environmental Development, May 1978, Jakarta.

48. The Selection of Aircraft in an Air Transportation System: A Case Study (in Indonesian), with S.W.Eidayat and E.Taroepratjeka, Mechanical Engineering Seminar, December 18-29, 1971, Bandung.
49. Satellite Orbital Considerations for Remote Sensing in Indonesia (with J.Salatun and Prof.Dr.Iskandar Alisyahbana), Joint UN-FAO Regional Seminar on Remote Sensing Applications, Jakarta, November 1975.
50. Computer at ITB: Progress and Problems, with Harsono and T.Mardiono, 7th Hawaiian International Conference on System Sciences, January 1974, Honolulu, Hawaii.
51. A simple potential flow model for the calculation of the oscillating lift on a circular cylinder, 10th International Symposium on Space Technology and Science, Tokyo, September 1973.
52. A Numerical Method for the Calculation of Nonlinear, Unsteady, Lifting Potential Flow Problems, with Dr.S.E.Widnall, 7th Aerospace Sciences Meeting, New York, N.Y, USA, January 1969; also appeared in AIAA Journal vol.7, no.10, October 1969.
53. Wind Loads on Tall Buildings, Conference on Tall Buildings, December 9-11, 1974, Jakarta.
54. Fully Developed Laminar Flow in a Stepped Rectangular Channel, with Dr.J.F.Thorpe, ASME Journal of Applied Mechanics, June, 1966.
55. Vinti's Surface Density as a means of representing the Earth's Disturbance Potential, Proceedings ITB, vol.7, no.4, 1974.
56. Some Notes on the Design, Construction and Performance of the Low Subsonic Windtunnel at ITB, Proceedings ITB, Vol.7, no.3, 1973.
57. Locally linearized solution of the lifting transonic flow by method of parametric differentiation, Proceedings ITB, vol.6, no.1, 1971.
58. An Observation on Research and Development of Wind Energy Conversion System in Indonesia, Technical Discussion, World Federation of Engineering Organizations, November 7-10, 1979, Jakarta.

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Books:

1. Harijono Djojodihardjo : Pengantar FORTRAN IV (Introduction to FORTRAN IV), ITB Computer Center, 1974; superceded by Harijono Djojodihardjo and Muhammadi Siswosudarmo: Pengantar Pemrograman dalam Bahasa FORTRAN IV (Introduction to FORTRAN IV Programming), published by PT Gramedia, 1978 .
2. Harijono Djojodihardjo: Mekanika Fluida (Fluid Mechanics), PT Erlangga, 1983.
3. Harijono Djojodihardjo: Metoda Numerik (Numerical Methods), PT Erlangga, 1983.
4. Harijono Djojodihardjo and Jens Peter Molly (editors): Wind Energy Systems, PT Alumi, 1983.
5. Harijono Djojodihardjo : Termodinamika Teknik (Engineering Thermodynamics), PT Gramedia (in press)
6. Harijono Djojodihardjo : Pengantar Sistem Komputer (Introduction to Computer System) (editor), PT Erlangga (in press)
7. Author of a chapter on Automotive Aerodynamics, in a Handbook of Automotive Engineering, in Indonesian, prepared by IATO (Indonesian Automotive Society).
8. Harijono Djojodihardjo and Sanusi Tanoemihardja (editors): Pengembangan Pemanfaatan Energi Angin (Development of Wind Energy Applications), proceedings, published by LAPAN.

Research and Project Reports: (in Indonesian)

1. The Design of LAPAN 1.75 x 2.35 m Low Speed Wind Tunnel (in Indonesian, as chief designer), LAPAN Interim Report, 1979.
2. Structural Analysis of the Fuselage of XT-400, H.Djojodihardjo, S.Atmadi, W.Harun and M.Wirata, January 1978, Aero & Hydrodynamics Laboratory Report, ITB.
3. The Design and Construction of Savonius Rotor Windmill, with W.Hidayat, Aero & Hydrodynamics Laboratory Report, ITB, December, 1978.
4. Windtunnel Investigation of TV Tower Model, with O.Yusoff, Aero & Hydrodynamics Laboratory Report, ITB, August 1978.
5. Analysis of Wind Data for Energy Utilization, with D.A.Salim, Aero & Hydrodynamics Laboratory Report , August 1977.
6. Windtunnel Investigation of High Rise Building Model, with L.U.Kamil, Aero & Hydrodynamics Laboratory Report, prepared for the Directorate for Building Research, June 1976.

7. An Experimental Investigation of a Vertical Windmill Model, with Sugiarmadji, Aero & Hydrodynamics Laboratory Report, July 1974, ITB.
8. An Experimental Investigation on the Influence of Aspect Ratio on Tall Buildings of Rectangular Cross-Section, Sugiarmadji and Harijono Djojodihardjo, June 1974, Aero & Hydrodynamics Laboratory Report, ITB.
9. A Computer Aided Analysis of the Grain Drying Process, Harijono Djojodihardjo and M. Rohmanuddin, April 1975, Computer Science Division, Computer Center, ITB.
10. A Study of Windmills with an experimental investigation on vertical axis panemones, Harijono Djojodihardjo & Abdurrachim, February 1974, Aero & Hydrodynamic Laboratory, ITB.
11. An Experimental Investigation of Tall Building Models, Sugiarmadji, L.U.Kamil and Harijono Djojodihardjo, Aero & Hydrodynamics Laboratory Report, ITB, August 1975.
12. The Design and Development of a Hovercraft Type XHV-01, Harijono Djojodihardjo et al, Air Force Research and Development Center, March, 1971, Bandung.
13. Fan and Performance Test of the Experimental Hovercraft XHV-01, Harijono Djojodihardjo and Sugiarmadji, Air Force Research and Development Center, Bandung, 1973.
14. Preliminary Design of an Overhaul Enterprose for Light Aircraft Piston Engines, Harijono Djojodihardjo et al, August 1973, Foundation for Research and Industrial Affiliation ITB.
15. A Techno-Economic Study for the Assembling of Other Types of Aircrafts at LIPNUR, Harijono Djojodihardjo et al, March 1974, Foundation for Research and Industrial Affiliation ITB.
16. A Study on Transportation in Nusa Tenggara, a survey commissioned by BAPPENAS, (The Indonesian National Development and Planning Agency), 1972 (member of working team).
17. A Design of Computer System for the Support of Exploration Activities at P.N.Timah, Final Report, June 1975 (Project Officer).
18. Structural Analysis and Calculation of the Fuselage of LT-200 (trainer aircraft), Report to LIPNUR (Aircraft Industrial Institute), October 1975.
19. Baseline Study of the Development of Ciliwung Cisadane River Basin Region, a study prepared for the National Development Planning Agency through P.T.Widya Pertiwi Engineering, 1975.
20. A Study on the Environmental Modelling of Greater Jakarta Metropolitan Area (JABOTABEK), with R.J.Widodo, report for the National Resources and Environment Management, BAPPENAS, prepared by P.T.Widya Pertiwi Engineering, 1979.
21. Computer at ITB: Prospects and Capabilities (with Dr. Filino Barahap), a survey paper prepared on behalf of Computerization and Data Processing Team, ITB, for the Ford Foundation, 1970.

5. INVITED LECTURES, PANELIST, SESSION CHAIRMAN, ORGANIZER

Invited Lectures:

1. Feasibility of Space Cooperation among ESCAP Member States, United Nations Regional Seminar on Space Applications Focusing on the Implementation of the Recommendations of UNISPACE 82, ESCAP Headquarters, Bangkok, Thailand, May 30-June 3, 1983.
2. Communications Satellite System: Observation and Expectation, IAF-COSPAR Forum, Vienna, August 4-6, 1982.
3. A Review on the Formulation of Development Alternatives and Requirements of Future Indonesian Satellite Communication System (with co-author E.Jamin), Goddard Memorial Symposium, American Astronautical Society, Washington, D.C., March 28-30, 1979.
4. Techno-Economic Study on a Manufacturing Plant for the Overhaul of Aircraft Engines (in Indonesian), Third Seminar on Aircraft Industry, Directorate General of Aircraft Industries, Jakarta, January 29, 1974.
5. Wind Energy Technology and Potential Assesment of Lombok Area, West Nusa Tenggara Regional Planning and Development Agency, Mataram, Lombok, July 1982.
6. Assessment of Wind Energy Application in Rural Areas, University of Diponegoro Workshop on Non-Conventional Energy, Semarang, September 1981.
7. Advances in Space Technology and its Impact on High School Education, Indonesian Institute of Sciences Lecture Series for Dissemination of Science, Pontianak, West Kalimantan, 1982.
8. Progress in Space Technology , Air Force Staff School, Jakarta, May, 1983.
9. Recent Advances in Space Science and Technology, invited lecture delivered for Naval Officers, Jakarta, November 1982.
10. System Analysis and Computer Science, Air Force Staff and Command School, Bandung, 1974, 1975.
11. Wind Energy Systems Technology: Indonesian Experience, ASEAN-US Energy Technology Seminar, organized by the Indonesian Institute of Science and US-AID, Bandung, June 7-19, 1982.
12. Instructional Methods in Curriculum for Technical High School (in Indonesian), Seminar/Workshop on Curriculum Development at Technical High Schools, Department of Education, Jakarta, 1978.

Member of Indonesian Delegation:

1. United Nations Committee for Peaceful Uses of Outer Space, Scientific and Technical Subcommittee , New York, 1977,1978.
2. Association of South East Asian Nations, Committee on Science and Technology, Sub-committee on Climatology, Jakarta, 1981.
3. ESCAP Expert Working Group on Solar and Wind Energy, Bangkok, 1976.

Panelist, Session Chairman, Organizer:

1. Member, Committee for Liaison with International Organizations and Developing Countries, International Astronautical Federation, since 1979.
2. Referee/Panelist, IAF-COSPAR UNISPACE Forum, Vienna, August 1982.
(Point-to-point Communication)
3. Session Co-Chairman, XXXIInd Congress of the International Astronautical Federation, Earth Observation from Space, Data Processing, Rome, September 1981.
4. Chairman, session for the drafting of conclusions and recommendations, United Nations Regional Seminar on Space Applications Focusing on the Implementation of the Recommendations of UNISPACE 82, ESCAP Headquarters, Bangkok, Thailand, May 30-June 3, 1983.
5. Session Chairman, Space Communication Session, United Nations Regional Seminar on Remote Sensing and Space Communication for Development, Jakarta, November 1981.
6. Chairman, Working-Group on Technical Aspects, LAPAN- NIVR Joint Workshop on Tropical Earth Resources Satellite, Jakarta, 1983.
7. Session Chairman, LAPAN Seminar on Space Research, Bandung, 1978.
8. Steering Committee Chairman, LAPAN Seminar on Sounding Rockets, March, 1976.
9. Chief Organizer, LAPAN Wind Energy Workshop, Jakarta, 1980.
10. Chief Organizer, LAPAN-DFVLR Joint Workshop on Wind Energy Systems, Jakarta, March 1980.
11. Steering Committee Member, Workshop on Higher Education, organized by Institut Teknologi Bandung, 1970.
12. Steering Committee Member, LAPAN Supersonic Windtunnel Project, 1980-1983.
13. Chairman, Working Group on Space Transportation, Indonesian National Consultative Committee for Aerospace Affairs (PANTARNAS Antariksa/LAPAN), since 1980.
14. Vice Chairman, Committee for Energy, National Research Workshop, Ministry for Research and Technology, Jakarta, 1982.
15. Chief Designer, LAPAN Low Speed Windtunnel Project, 1978-1983.
16. Member, Committee for Curriculum Development, Department of Mechanical Engineering, Institut Teknologi Bandung, Bandung, 1983.

6. PROFESSIONAL STANDING AND PERFORMANCE

Membership in Professional Societies:

American Institute of Aeronautics and Astronautics, member
American Association for the Advancement of Science, member
International Solar Energy Society, member
British Wind Energy Association, member
Indonesian Association of Engineers (PII), member
Indonesian Society of Automotive Engineers (IATO), member

Sigma Xi, member
New York Academy of Science, member

Awards, Listings:

Fellowship, US Agency for International Development, 1963-1966
Fellowship, The British Council, January-April 1972
Fellowship, International Center for Theoretical Physics, September-November 1974
and September-November 1976
Travel Grant , The Ford Foundation , January 1974

Listed in Marquis' Who's Who in the World, 1982
Listed in ESCAP Directory in Wind Energy, 1982
Listed in Dictionary of International Biography, 1983
Listed in Men of Achievement, Tenth Edition, International Biographical Centre, 1983
Listed in 5000 Personalities of the World, to be published, 1984.
Listed in Community Leaders of the World, First Commemorative Issue, to be published in 1984.

Professional Activities:

Editor of Majalah LAPAN
Reviewer of Proceedings ITB
Chief Editor, Bulletin for Computer Sciences, ITB Computer Center, 1972-1975

7. CIVIC ACTIVITIES:

Lions Club of Bandung Raya, Bandung, charter member since 1976, vice-president,
1978-1980, president, 1980-1981.
Lions Club of Bandung Utara, Bandung, guiding Lion, 1981-
Lions Club of Bandung Selatan, Bandung, advisor.
Community (Rukun-Tetangga) Chairman, 1975

8. LANGUAGES:

Native Speaker of : Indonesian
Foreign Languages: English (fluent), German, Dutch (Fair), French (reading)

R E S U M E

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1. Personal Data

Name: Kailash C. Pandé

Date and Place of Birth: [REDACTED]

Marital Status: Married

Citizenship: Indian

Visa Status: J-1 Visa

Address: Visiting Professor
Department of Mechanical and Aerospace Engineering
Arizona State University
Tempe, AZ 85287, U.S.A.

Off. (602) 965-4115
Res. (602) 829-1702

2. Academic Qualifications

<u>Degree</u>	<u>Institution</u>	<u>Year</u>	<u>Field of Study</u>
Ph.D.	University of British Columbia, Vancouver, Canada	1974	Dynamics and Control Systems
M.Sc.	University of Saskatchewan, Saskatoon, Canada	1969	Control Systems
B.Sc. Eng. (Hons.)	Banaras Hindu University, Varanasi, India	1966	Mechanical Engineering

3. Academic Awards

University of British Columbia Postdoctoral Fellowship	1974-75
University of British Columbia Postgraduate Fellowship	1971-73
Research Assistantship, Department of Mechanical Engineering, University of British Columbia	1970-71
Research Assistantship, Department of Mechanical Engineering, University of Saskatchewan	1967-69
B.H.U. Gold Medal (for <u>First Rank</u> in the Faculty of Technology, Banaras Hindu University)	1966
Prince of Wales Gold Medal (for <u>First Rank</u> in the College of Engineering, Banaras Hindu University)	1966
National Merit Scholarship (Government of India)	1961-66

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4. Professional Experience

Visiting Professor, Department of Mechanical and Aerospace Engineering, Arizona State University, Tempe, Arizona, U.S.A.	1983-Present
Professor, Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, India	1982-Present
Assistant Professor, Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, India	1977-82
Lecturer, Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, India	1975-77
Postdoctoral Fellow, Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada	1974-75
Research Engineer, Saskatchewan Research Council, Saskatoon, Canada	1969-70

5. Courses Taught/Developed at IIT Kanpur and Arizona State University

Undergraduate Courses:	Dynamics, Mechanics of Solids, Vibrations, Automatic Control Systems, Space Systems Engineering
Postgraduate Courses:	Advanced Dynamics, Modern Control Theory, Nonlinear Vibrations, Spacecraft Dynamics and Control

6. Theses/Projects Supervised at IIT Kanpur

M.Tech. Theses:

'Design and Analysis of a Mechanical Drive Unit with Two Degrees of Freedom' by M.S. Prasad, 1983.

'Optimal Attitude and Vibration Control of a Flexible Spacecraft' by A. Kumar, 1983.

'On Magnetic Attitude Control of Gravity Gradient Satellites' by P. Raut, 1979.

'Pitch Attitude Control of Spacecraft by Means of Solar Radiation Pressure' by D.K. Pathak, 1978.

'Optimal Aerodynamic Attitude Control of Spinning Satellites' by R. Venkatachalam, 1977.

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Ph.D. Thesis:

'Optimal Attitude Stabilization and Control of
Spacecraft by Solar Radiation Pressure' by
R. Venkatachalam, 1980.

Sponsored Project:

'Three-Axis Attitude Control of Satellites by Semi-
passive Methods', a three year project supported by
the Indian Space Research Organization, Bangalore,
India, 1978-81

7. Special Seminars Delivered

1. 'On Inertial Stabilization and Large Angle Attitude
Maneuvers of Spacecraft by Solar Radiation Pressure',
at the Flight Dynamics and Control Division, NASA
Langley Research Center, Hampton, U.S.A., August 1982.
2. 'On Semipassive Attitude Control of Spacecraft', at
the Department of Mechanical Engineering, McGill
University, Montreal, Canada, August 1982.
3. 'On the Rotational Motion of a Spinning Spacecraft
during Unsymmetrical Deployment of Hinge-Connected
Appendages', at the Institut fur Mechanik, Technische
Hochschule, Darmstadt, West Germany, July, 1979.
4. 'On Solar Pressure Stabilization of Satellite Attitude
in Earth and Space Orientations', at the Institute
for Flight Systems Dynamics, German Aerospace Estab-
lishment, Oberpfaffenhofen, West Germany, July 1979.
5. 'On Solar Pressure Stabilization of Satellite Attitude
in Earth and Space Orientations', at the European
Space Operations Center, Darmstadt, West Germany,
July 1979.
6. 'On Attitude Control of Earth-Pointing Spacecraft by
Means of Solar Radiation Pressure', at the Depart-
ment of Mechanical Engineering, Howard University,
Washington, D.C., U.S.A., June 1979.
7. 'On Magnetic Attitude Control of Satellites', at the
Indian Space Research Organ ization, Bangalore,
India, October 1975.

8. List of Publications(a) Publications in Reviewed Journals

1. Pande, K.C., "Parametric Excitation of a High Altitude Gravity Gradient Satellite", Celestial Mechanics, Vol. 29, 1983, pp. 101-106.
2. Pande, K.C. and Venkatachalam, R., "Optimal Solar Pressure Attitude Control of Spacecraft - Part I: Inertially Fixed Attitude Stabilization", Acta Astronautica, Vol. 9, No. 9, 1982, pp. 533-540.
3. Venkatachalam, R. and Pande, K.C., "Optimal Solar Pressure Attitude Control of Spacecraft - Part II: Large Angle Attitude Maneuvers", Acta Astronautica, Vol. 9, No. 9, 1982, pp. 541-545.
4. Pande, K.C. and Venkatachalam, R., "Solar Pressure Attitude Stabilization of Earth-Pointing Spacecraft", IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-17, No. 6, November 1981, pp. 748-756.
5. Pande, K.C. and Venkatachalam, R., "Inertially Fixed Pitch Stabilization of Satellites by Solar Radiation Pressure", Acta Astronautica, Vol. 7, 1980, pp. 155-167.
6. Pande, K.C. and Venkatachalam, R., "Semipassive Pitch Attitude Control of Satellites by Solar Radiation Pressure", IEEE Transaction on Aerospace and Electronic Systems, Vol. AES-15, No. 2, March 1979, pp. 194-198.
7. Pande, K.C. and Venkatachalam, R., "On Optimal Aerodynamic Attitude Control of Spacecraft", Acta Astronautica, Vol. 6, 1979, pp. 1351-59.
8. Pande, K.C., "Attitude Control of Spinning Spacecraft by Radiation Pressure", Journal of Spacecraft and Rockets, Vol. 13, No. 12, December 1976, pp. 765-768.
9. Pande, K.C., Modi, V.J., and Misra, A.K., "Solar Pressure Induced Perturbations of Orbital Elements for the Communications Technology Satellite", Astrodynamics 1975 - Advances in the Astronautical Sciences, Vol. 33, 1976, pp. 1-25.
10. Modi, V.J. and Pande, K.C., "On the Periodic Solutions and Resonance of Spinning Satellites in Near-Circular Orbits", Celestial Mechanics, Vol. 11, 1975, pp. 195-212.

11. Modi, V.J. and Pande, K.C., "Magnetic-Solar Hybrid Attitude Control of Satellites in Near-Equatorial Orbits", Journal of Spacecraft and Rockets, Vol. 11, No. 12, December 1974, pp. 845-851.
12. Modi, V.J. and Pande, K.C., "A Bang-Bang Solar Pressure Attitude Control System", The Journal of the Astronautical Sciences, Vol. XXII, No. 1, July-September 1974, pp. 1-20.
13. Modi, V.J. and Pande, K.C., "Aerodynamic-Solar Hybrid Attitude Control of Near-Earth Satellites", The Journal of the Astronautical Sciences, Vol. XXII, No. 1, July-September 1974, pp. 36-54.
14. Pande, K.C., Davies, M.S., and Modi, V.J., "Time-Optimal Pitch Control of Satellites Using Solar Radiation Pressure", Journal of Spacecraft and Rockets, Vol. 11, No. 8 August 1974, pp. 601-603.
15. Modi, V.J. and Pande, K.C., "Solar Pressure Induced Librations of Spinning Axisymmetric Satellites", Journal of Spacecraft and Rockets, Vol. 10, No. 9, September 1973, pp. 615-617.
16. Modi, V.J. and Pande, K.C., "Solar Pressure Control of a Dual-Spin Satellite", Journal of Spacecraft and Rockets, Vol. 10, No. 6, June 1973, pp. 355-361.

(b) Publications in Conference Proceedings

1. Pande, K.C. and Pathak, D.K., "Solar Pitch Control of Earth Oriented Satellites", Proceedings of the Indian National Science Academy Symposium on Servo Systems, Trivandrum, India, February 1980, pp. 263-286.
2. Pande, K.C., "Dynamics of Spinning Spacecraft During Unsymmetrical Deployment of Hinged Appendages With Tip Masses", Proceedings of the Second VPI/AIAA Symposium on Dynamics and Control of Large Flexible Spacecraft, edited by L. Meirovitch, Blacksburg, Virginia, U.S.A., June 1979, pp. 611-624.
3. Modi, V.J. and Pande, K.C., "Libration Damping and Attitude Control of Communications Technology Satellite Using Solar Radiation Pressure", Proceedings of the XIIth International Symposium on Space Technology and Science, Tokyo, June-July 1977, pp. 341-350.

4. Modi, V.J., Pande, K.C., and Kumar, K., "On the Optimized Attitude Control of Space Vehicles Using Solar Radiation Pressure", Proceedings of the VIth Symposium of the International Federation of Automatic Control, Armenia, U.S.S.R., August 1974, Vol. III, pp. 48-62.
5. Modi, V.J., Pande, K.C., and Nicks, G.W., "On the Semi-passive Propulsion of Space Vehicles Using Solar Radiation Pressure", Proceedings of the Xth International Symposium on Space Technology and Science, Tokyo, September 1973, Editor in Chief: S. Kobayashi, pp. 375-382.
6. Pande, K.C., Kumar, K., and Modi, V.J., "On the Attitude Control of Canadian Communication Satellites Using Solar Radiation Pressure", Proceedings of the IVth Canadian Congress of Applied Mechanics, edited by A. Bazergui, Ecole Polytechnique, Montreal, Canada, May-June 1973, pp. 521-522.

(c) Invited Paper

1. Pande, K.C., "Attitude Stabilization and Reorientation of Space-Pointing Satellites by Radiation Pressure", invited for presentation at the 10th IMACS World Congress on Systems Simulation and Scientific Computation, August 1982, Montreal, Canada, to be published in the Congress Proceedings.

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List of References

1. Dr. V. J. Modi
Professor
Department of Mechanical Engineering
University of British Columbia
Vancouver, B.C., V6T 1W5
Canada
(604) 228-2914

2. Dr. Peter M. Bainum
Professor
Department of Mechanical Engineering
Howard University
Washington, D.C. 20059
(202) 636-6612

3. Dr. Richard W. Longman
Professor
Department of Mechanical Engineering
Columbia University
New York, NY 10027
(212) 280-2993

4. Dr. V. K. Stokes
General Electric Corporate Research & Development
K1-3A23
P.O. Box 8
Schenectady, NY 12301
(518) 385-1701

C. EVALUATION OF GRADUATE STUDENT FELLOWS

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1. CHERYL MCKISSACK

Miss Cheryl McKissack earned her bachelor's degree in civil engineering in 1982 from Howard University. She is Howard's first graduate from civil engineering with a major in mechanics. Her undergraduate GPA in this major was 2.90 which included a grade of "A" in Advanced Calculus. In June, 1982, she presented a paper entitled "The Load Correction Method" to the Annual Convention of the NTA in Orlando, FL. In the Fall of 1984 she enrolled in the M.S. program in Civil Engineering at Howard and earned a GPA of 3.00. Though this performance is not exemplary, I am aware of the adjustments to graduate study Miss McKissack had to make. I am pleased with her performance to date and expect her thesis, presently entitled "Extension of the Boussinesq Problem Into the Large Lattice Domain", to be a remarkable achievement. Miss McKissack will spend three weeks residency at the NASA/Langley Research Center in Hampton, VA, this summer.

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2. STANLEY E. WOODARD

Mr. Stanley Woodard, completed his Bachelor's degree at Purdue University's School of Interdisciplinary Engineering Studies in 1983 and is completing his first academic year as a graduate student enrolled in the Aerospace Engineering Master's program in the Department of Mechanical Engineering at Howard University. At the completion of his first semester he has earned a GPA of 3.3/4.0. Mr. Woodard has also worked for General Motors, Detroit Diesel Allison Division, Indianapolis Operations as a co-op student and also has completed a summer internship at the Lawrence Livermore National Laboratory in the Nuclear Physics Division. He is the co-author of a technical paper resulting from this assignment. It is proposed that Mr. Woodard be assigned as a Graduate Fellow under the direction of Professor Bainum commencing with the Summer 1984. He is agreeable to spending part of this summer in residence at NASA Langley and work in the area of space systems dynamics and control. It is understood his project would be mutually agreed upon by Professor Bainum and the NASA Langley contract monitor for this project. After a joint meeting with NASA Langley personnel a mutually agreeable statement of work for Mr. Woodard's task would be prepared.

IV. HU PHYSICAL SUPPORT PLAN
(COMPUTER GRAPHICS)

IV. HU PHYSICAL SUPPORT PLAN

The principal physical need of the LSSI is computer graphics hardware/software. Since last year's need in this area was \$328K and only \$72K was awarded LSSI, some creative use of the available graphics support had to be considered. The plan now in effect is as follows.

Rather than use the \$72K to purchase inferior graphics hardware, these funds are being used in part to support the maintenance contracts on new computer hardware acquisitions made by other areas within the university in return for priority access by LSSI personnel. The Computer Learning and Design Center of the School of Engineering will receive a gift from Data General in the form of a DG MV/4000 computer. This 32 bit super mini computer will have 6 MB of memory and 1 GB in disk storage. This computer will be dedicated to CAD/CAM and graphics research. Thus, the LSSI will need only to purchase a small work station that will be partially supported by the Mechanical and Civil Engineering Departments. Future support is needed for an improved work station and software. If the DOD proposal is approved (see Overview section), the LSSI will use some funds to support acquisition of a university-wide graphics work station dedicated to graphics research in return for priority access by LSSI personnel. Present projections in the period July 11, 1984 - July 10, 1985 are that \$50K is needed to accomplish these aims.

V. HU FISCAL SUPPORT PLAN

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V. HU FISCAL SUPPORT PLAN

(July 11, 1984 - July 10, 1985)

1. SALARIES

Administrative (Director)

Post-Doctoral Fellow

Research Projects

Fringe Benefits @ 28%

TOTAL SALARIES

2. WAGES

Administrative (Assistant)

Administrative (Secretary)

Research Projects

Fringe Benefits @ 28%

TOTAL WAGES

3. TRAVEL

Administrative
(Recruitment, Advisory
Committee, Student Summer
Expenses, etc.)

Research Projects
(Tech. Conferences, etc.)

TOTAL TRAVEL

4. SUPPLIES

Administrative

Research Projects

TOTAL SUPPLIES

5. COMPUTER TIME

6. INDIRECT COST @ 90%

7. GRADUATE STUDENTS

Fellows (6)	114,000.00
Assistants	117,500.00

TOTAL STUDENTS	231,500.00
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8. EQUIPMENT

Administrative (Computer Graphics)	50,000.00
Research Projects	18,726.00

TOTAL EQUIPMENT	68,726.00
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9. SUB-CONTRACTORS

MIT	25,141.00
RPI	25,000.00
Lockheed	5,000.00

TOTAL SUB-CONTRACTORS	55,141.00
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GRAND TOTAL	\$854,329.00
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