LANGLEY
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FINAL REPORT

NASA GRANT

NAG-1-405

Dr. Elias G. Abu-Saba

(NASA-CR-183205) DYNAMICS AND CONTROL OF THE ORBITING GRID STRUCTURES AND THE SYNCHRONOUSLY DEPLOYABLE BEAM Final Report (North Carolina Agricultural and Technical State Univ.) 62 p CSCL 20K G3/39

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Department of Architectural Engineering

North Carolina Agricultural and Technical State University

Greensboro, North Carolina 27411

FINAL REPORT

NASA GRANT

NAG-1-405

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NASA TECNICAL MONITOR

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TABLE OF CONTENT

INTRODUCTION

The research being conducted under NASA grant NAG-1-405 entitled "Dynamic Analysis of Orbiting Grid Structures and The Joint Dominated Beam" has a number of objectives. One, the research conducted at the school of engineering at North Carolina Agricultural and Technical State University serves an essential need for NASA Langley Research Center. Analytical results obtained by the faculty and students can be used by NASA scientists in their space effort. Two, North Carolina Agricultural and Technical State University is an historically black university. The university community will acquire a tremendous amount of benefits from NASA's association. Third, students, both graduates and under graduates, will benefit technically from the research conducted the faculty. Fourth, NASA's recruitment effort from the historically university will be improved from the joint effort of the faculty and NASA personnel involved in the research.

Analytical models have been provided for the orbiting grid structure and the joint dominated beam and computational procedures used in determining the eigen value characteristics. Several presentations were made by Dr. Abu-Saba and student assistants at NASA Langley Research

Center and other workshops. The result of the joint dominated beam analysis has been presented at the space conference sponsored by the American Society of Civil Engineers in Albuquerque on August 29-31, 1988. The paper is published in the proceedings of the conference. Annual reports on the progress of the research were submitted regularly. The section entitled "Appendices" contains the documents relevant to all the research activities covered by this grant.

North Carolina Agricultural and Technical State University School of Engineering considers research as an important part of the academic effort. As a result, the faculty of the School of Engineering is actively involved in research. NASA grants, along with other funding organizations, provide the needed financial resources. Since January of 1984 four graduate and six undergraduate minority students have been associated with this research. One of the graduate students submitted a master's thesis dealing with the analysis of joint dynamic behavior.

As part of the objectives of this grant, the principal investigator encourages minority students, particularly those who are associated with the project, to consider working for NASA after graduation from North Carolina Agricultural and Technical State University. Students are brought face to face with NASA personnel during visits to NASA facilities and at workshops sponsored by NASA.

INVENTORY OF EQUIPMENT

1. Digital Professional 350 with Modums, Disk Drives, Printers, Fortran 77 kits, Word Processors, files and Report Storage and Reproduction. Two such equipments are located in McNair Hall, rooms 455 and 456.
2. AI170-H CPU Chassis with a port card slots and power supply for 110 VAC 60 Cycle and A1171-E Four Port Asynchronous Interface module with 25 pins connectors for the Electrical Engineering Department, McNair Hall.
3. MS780- HC 11780 256K MEM 8MB + CTL 120V (Committed $2500.00 from this grant) for the Electrical Engineering Department, McNair Hall.

STUDENT ASSISTANTS

The field of architectural engineering per se does not match NASA's research needs. However, faculty in architectural engineering with a specialty in structures and dynamics are well qualified to do research in stability, dynamics and plate theory, subjects that are essential to NASA's space exploration. Architectural students who were selected by the principal investigator had to be specially trained to handle dynamics problems. Both graduate and undergraduate students were involved in this project from beginning to end.

GRADUATE STUDENTS

In January of 1984, Mr. Vernal Alford, III joined this project as a graduate assistant to the principal investigator. He stayed with the project till he graduated in May of 1985. Mr. Alford spent part of the summer of 1984 at NASA Langley research center working on the dynamics and control of an orbiting grid. In December of 1984 he and Mr. Harris, another graduate student who joined the team in October of 1984, spent a week at NASA facility in Hampton, Virginia learning how to use computer equipments there. Mr. Alford wrote a summary of his activities with the project on May 10, 1985.

Mr. Sherwood Harris joined the project in October of 1984. He left in June of 1986. Mr. Harris spent the summer of 1985 and part of the summer of 1986 at NASA Langley research center in Hampton virginia. In the summer of 1985, he conducted research on the dynamic damping of joints. The result of his work was included in the proceedings of the workshop on the control of flexible structures held at NASA Langley in August of 1985. Mr. Harris began working on a thesis on this subject as part of the requirement for the master's degree at North Carolina Agricultural and Technical State University. It was not finished by the time he left the university. Mr. Harris made two presentations. One presentation was made at a workshop held by NASA at Langley on November 8, 1985. The second presentation was made at Atlanta University in Atlanta on April 20, 1986.

In August of 1986, two graduate students joined the project. Mr. Hebrew L. Dixon and Ms. Vicki Forbes spent the academic year 1986-87 as graduate assistants on the project. Mr. Dixon made a presentation on November 7, 1986 at a workshop held at NASA Langley research center. Ms. Forbes wrote a report on the research and submitted it to the principal investigator. Both candidates left the University before completing their work for the master's degree in architectural engineering.

UNDERGRADUATE STUDENTS

The academic background of the architectural engineering student on the undergraduate level at North Carolina Agricultural and Technical State University does not provide him/her with the required tools for meaningful research involvement in space technology. However, some of the objectives of the grant call for their involvement such as travel to NASA facilities, meeting with NASA's personnel and interaction with graduate assistants and the principal investigator. In the fall of 1985, three undergraduate students received stipends ranging from five to nine hundred dollars from this project. These students were Mr. Ken Baxter, Mr. Shelton Howard, and Roger Riddick.

In the fall of 1985 three of these students visited Langley research center. In the summer of 1988, two other undergraduate students worked on the project for a period of five weeks. These students were Ms. Monica McLaughlin and Mr. Creighton Barber.

TECHNICAL REPORTS

DYNAMICS AND CONTROL OF AN ORBITIG GRID

ABSTRACT

The dynamic analysis of a grid structure hung from the ceiling by two steel wires is simplified by using a discrete mass model system. The concept of the bifilar pendulum is used in writing the equation of motion. Assumptions are made with regard to the stiffness in the vertical and horizontal planes. The discrete masses are assumed to be connected by inextensible massless strings that do not provide any torsional or flexural resistance. The modal frequencies obtained by this method are compared with those obtained from the finite element model. For details see Appendix A.

Dynamic Analysis of the Joint Dominated Beam

ABSTRACT

A method is presented herein to determine the vibration modes of the Joint Dominated Beam. An example of a cantilever beam is selected for this purpose. The truss type beam is analysed as a homogeneous section with the equivalent moment of inertia derived from the contribution of the chords only. Such an assumption is justified for slender beams for which the deflections due web strains are negligible.

Based on the above assumptions, a lumped mass system is selected as a model. The flexibility of the system is derived from the deflection equation of the cantilever beam. Maxwell's law of reciprocity is used to minimize the computational procedure, and a set of algorithmic statements is obtained.

First, the joints in the beam are considered to be an integral part of the beam. The flexibility matrix is obtained and the equation of motion written. Given N as the number of bays, a computer program has been written to provide the natural frequency constant of the beam. The values of the frequencies for the first ten modes are compared with those obtained by the classical method. The results from the method used herein are compared with the results of a number of examples performed by other methods and authors.

Second, the joint flexibility is denoted by k, and a new

set of algorithmic statements is obtained which involves the behavior of the joints. A modified flexibility matrix is obtained and another set of natural frequencies is derived. Various values of k are used and the frequency output is recorded. Some conclusions are drawn based on these results. For the full report on the Joint Dominated Beam see Appendix B.

APPENDICES

APPENDIX A.

DYNAMICS AND CONTROL OF ORBITING GRID STRUCTURE

TITLE OF RESEARCH: DYNAMICS AND CONTROL OF ORBITING GRID AND THE SYNCHRONOUSLY DEPLOYABLE BEAM

PROJECT DIRECTOR: DR. ELIAS G. ABU-SABA

GRANT NO: NAG-1-405

"PROGRESS MADE IN SPAR PROJECT"

FINAL REPORT

Vernal Aford,III
Architectural Engineering
Department

Date: May 10, 1985

DYNAMIC AND CONTROL OF ORBITING GRID STRUCTURES

by

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ABSTRACT

This report describes the dynamic analysis of a grid structure hung from the ceiling by two steel wires. The method of approach uses the discrete mass model system. The concept of the bifilar pendulum is used in writing the equation of motion. Assumptions are made with regard to the bar stiffnesses in the vertical and horizontal planes. The discrete masses are assumed to be connected by inextensible massless strings that do not provide any torsion or bending. The modal frequencies obtained by this method are compared with those obtained from the finite element model.

NOMENCLATURE

H = Inertial torque in horizontal plane
L = Strain torque in horizontal plan
I = Mass moment of inertia
σ = Angular displacement in vertical plane
θ = Angular displacement in horizontal plane
r = Distance from the center of the bar to the support
s_1 = The length of the sring from the ceiling to the top bar
s_i = the distance between the ith bar mass and the (i + 1)th mass
b = The horizontal distance from one extremity of the bar to another

INTRODUCTION

Large, flexible space structures are becoming a common aspect of the space exploration effort of NASA. Putting such structures in orbit requires atitude adjustment and control. The problem of controlling large, flexible structures requires the determination of the basic dynamic characteristics of these structures.

A number of approaches are used in determining dynamic characteristics of flexible structures. The finite element method is most commomnly used because of the ease with which it lends itself to computer programming. As the sturcture gets larger computer time, and thus cost, becomes significant. In the early stage of the design process trial structures are suggested, analyzed, and then corrected. Thus an iterative process is adopted in reaching the final form.

To reduce the cost of design simpler approaches will be used initially. Once the designer establishes a certain degree of confidece in the selected structure, a more sophisticated method of analysis will be resorted to in acquiring the final results. Mathematical modelling is an approach when used with reasonable assumptions can provide such a tool.

GRID ANALYSIS

The grid is shown in Figure 1. It consists of eleven by eight aluminum bars having a cross section of 2"x1/4". The bars are rigidily conected with the flat sides oriented back to back. The structure is hung from the ceiling by steel wires as shown in Figure 1.

As a first attempt, the structure is perceived as a rigid body hanging from the ceiling by the two wires. In that case it behaves like a bifilar pendulum. the exact equation of motion for the bifilar pendulum yields a natural frequency of

$$\omega = \frac{2r}{b}\sqrt{\frac{3g}{s}} \qquad (1)$$

where r, b, and s are as indicated in Figure 2.

Successive division of the grid into multi-mass models that have the characteristics of a rope-ladder helps to develop the theoretical approach to the solution. In these models the bars are considered to have no twist characteristics. They restrict the vertical motion in the same manner as an inextensible wire. This will manifest itself by one degree of freedom for each body in the model.

A generalized equation of motion can be written for the multi-mass model.

$$H_j + gr \left[\sum_{i=j}^{N} m_i \sigma_j - \sum_{i=j}^{N} m_i \sigma_{j+1} \right] = 0 \qquad (2)$$

where

N = number of masses in the model

J = 1, N

The angles from the position of equilibrium are shown in Figure 3. the relationship between these angles is given in Equation (3).

$$\sigma_j = \frac{r}{s_j} (\theta_j - \theta_{j-1}) \qquad (3)$$

Also from the concepts of vibrations the angular accelaration can be written as follows:

$$\ddot{\theta}_j = - \omega^2 \theta_j \qquad (4)$$

Using the relationship expressed in Equation (4) in Equation (3) and then substituting the result in Equation (2) yields the following results.

$$A \omega^2 [\theta] = [K] [\theta] \qquad (5)$$

where A is a scalar quantity that is determined from the geometrical and physical proerties of the grid, and K is a square matrix representing the stiffness of the model.

Using an eight mass model and obtaining the fundamental frequencies for this model yields a set of values which compare relativly well with the results onbtained from a finite element model. Table 1 gives the model frequencies for both methods.

CONCLUSIONS AND REMARKS

The application of the bifilar pendulum concepts has been presented in the case of a grid structure. This approach permits the utilization of a theoretical analysis to obtain the modal frequencies of a grid structure with a minimum of computer time. Assumptions have been made with regard to the behavior of the structure and constraints have been utilized based on these assumptions. The elastic properties assumed herein have been less than total. In other words, the torsional and bending properties of the bars have been neglected in this method. Thus frequencies obtained by this approach while they compare very favorably at the lower end of the frequency band, they diverge from the finite element results at higher frequencies. As a next step, the resewarcher will introduce bending and torsional stiffnesses of the bars into the generalized model. The same procedural steps will be followed to obtain new results for the modal frequencies.

Table 1. Comparison of modal frequencies obtained by two separate methods : finite element and lumped mass system

Mode Number	Frequency (Hz)		
	Finite element	Lump Mass System	Ref. 2
1	0.364	0.366	0.368
2	0.625	0.844	0.580
3	1.398	1.335	1.420
4	2.299	1.844	2.128
5	3.067	2.377	
6	4.791	2.947	
7	5.933	3.576	
8	6.297	4.323	

REFERENCES

1. Montgomery, R. C. ; Abu-Saba, E. G. : Adaptive and Learning Control During Assembly For Large Space Structures; Proceedings of the 1979 IEEE Conference On Decision and Control, Fort Lauderdale, Florida, December 12-14, 1979.

2. Montgomery, R. C. ; Williams, J. P. : The Use of Distributed Microcomputers in the control of Structural Dynamics system; Conference on Mini and Microcomputers in contreol, Fitering, and Signal Processing; December 12-14, 1984, Las Vegas, NV.

3. Housner, J. M. : Convected Transient Analysis For Large Space Structures Maneuver and Deployment; AIAA/ASME/ASCE/AHS 25th Structures, Structural Dynamics and Materials Conference, AIAA Paper No. 84-1023-CP, Palm Springs, California

4. Rauscher, M. : Introduction to Aeronautical Dynamics; John Wiley and Sons, Inc.. New York, 1953, pp 540-545

ACKNOWLEDGEMENT

The authers like to acknowledge Mr. Vernal Alford, a graduate assistant at North Carolina Agricultural and Tecxhnical State University in Greensboro, North Carolina, for the numerical computations.

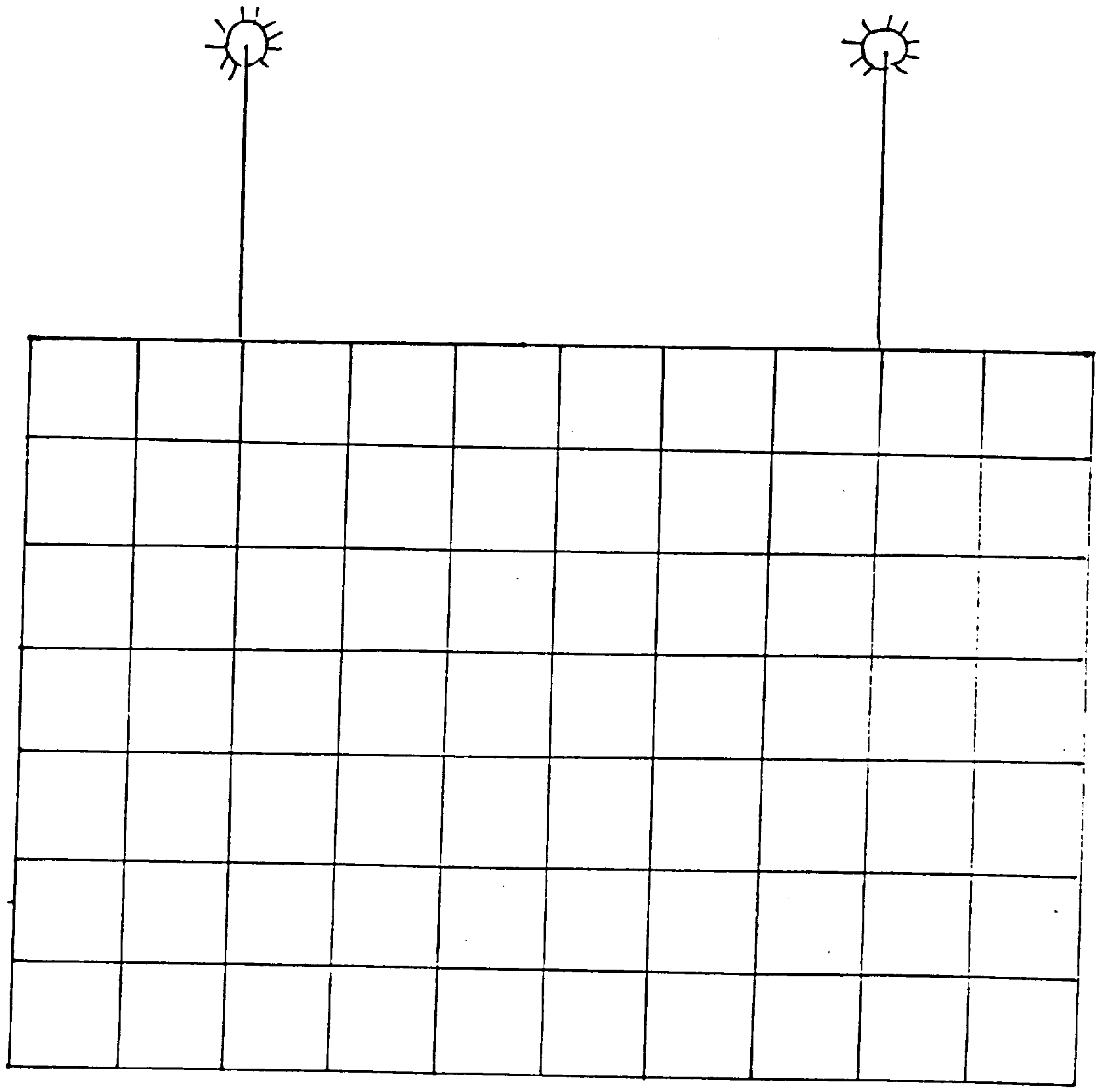

FIGURE 1. GRID STRUCTURE

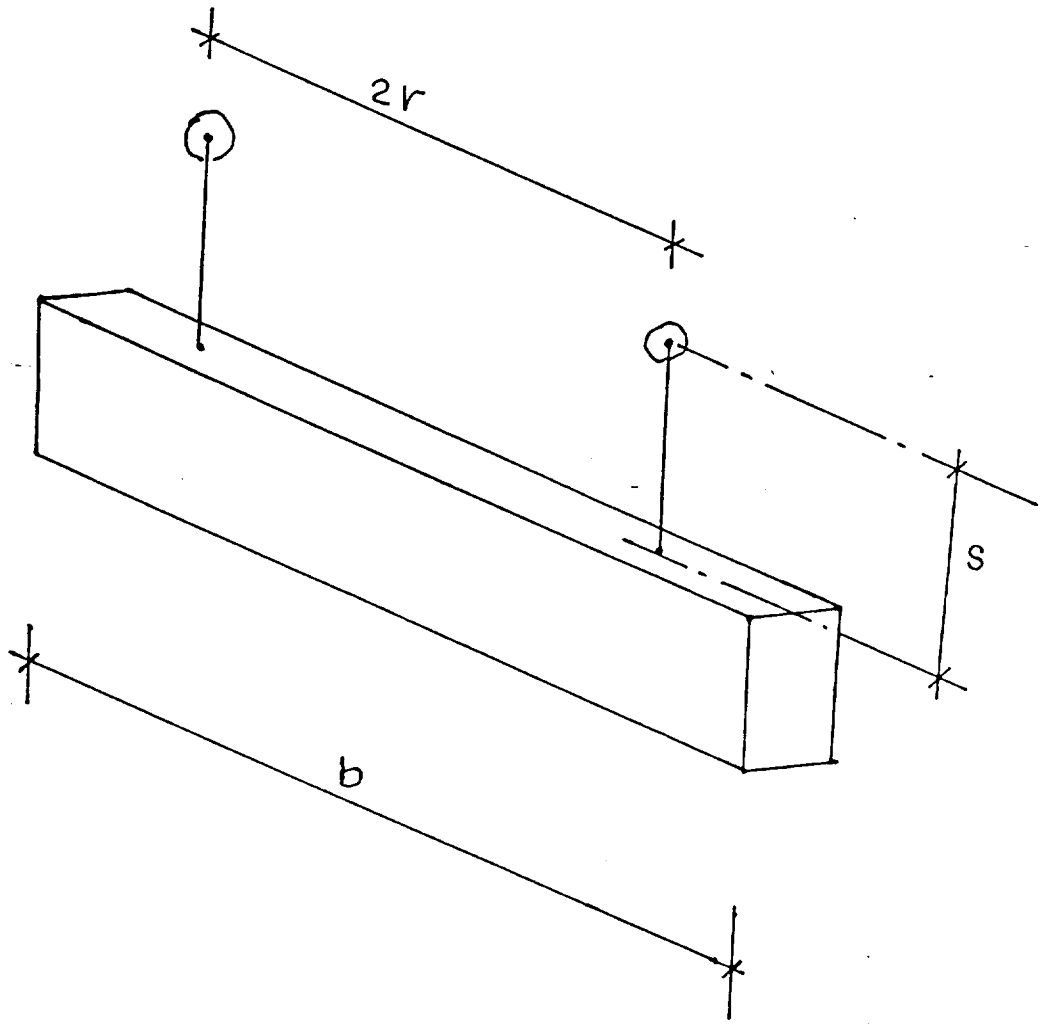

FIGURE 2. GRID MODEL: SINGLE MASS

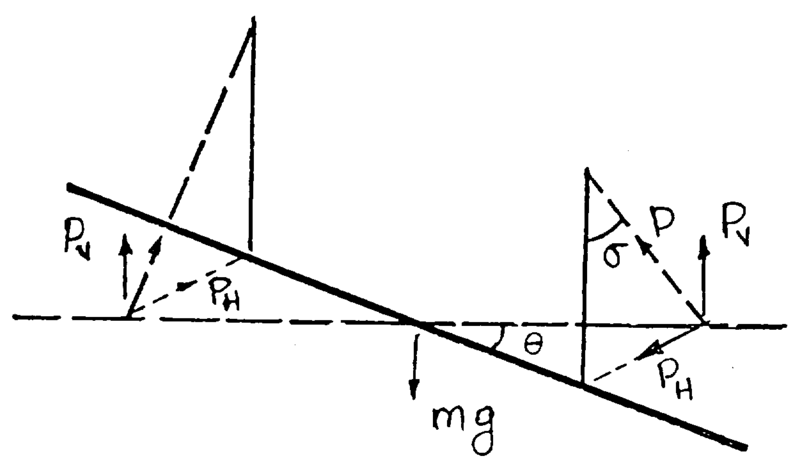

FIGURE 3. EQUILIBRIUM DIAG.

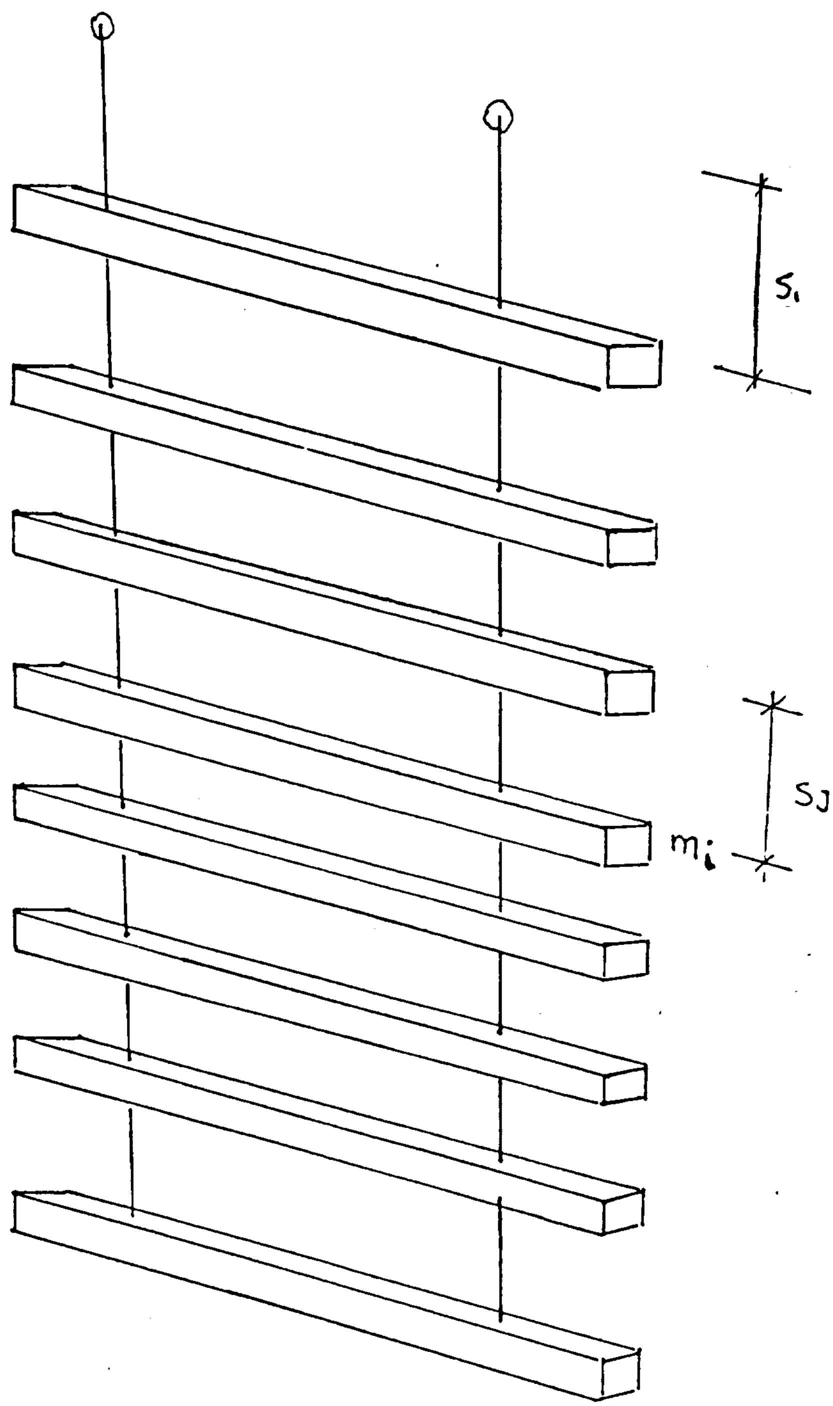

FIGURE 4. 8-MASS MODEL

APPENDIX B.

DYNAMIC ANALYSIS OF THE JOINT DOMINATED BEAM

DYNAMIC ANALYSIS OF THE JOINT DOMINATED BEAM

NAG-1-405

Project Director: Dr. Elias G. Abu-Saba
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NASA Monitor: Dr. Raymond Montgomery
NASA LANGLEY RESEARCH CENTER
Hampton, VA

ANNUAL REPORT: October 1, 1985 - September 30, 1986

DATE: October 31, 1986

DYNAMIC ANALYSIS OF THE TRUSS BEAM

INTRODUCTION:

The Truss-Beam as a cantilever has numerous applications in the space construction field. When constructed of N-bays with equal length and having chords of equal cross section, the determination of the dynamic characteristics of such a beam may be readily accomplished. The Maxwell receprocity theorem along with a set of alogorithms help to generate the flexibility matrix of the structure which in turn is used in the dynamic equation of motion of the system.

DYNAMIC EQUATION

The general equation for the displacement of a linear structural system can be written in the matrix form as follows:

$$\{Y\} = [A]\{Q\} \tag{1}$$

where $\{Y\}$ = Displacement Vector

$\{Q\}$ = Force Vector

$[A]$ = Flexibility Matrix

In the absense of any external forces, a body in motion will experience its own inertial foreces. These forces may be neatly expressed by the following expression.

$$\{Q\} = - [M]\{\ddot{Y}\} \qquad (2)$$

where

$[M]$ = The mass matrix

$\{\ddot{Y}\}$ = Acceleration Vector

A joint dominated beam (truss-beam) is not homogeneous because of the joints. The response of the joints is complex, but for the sake of simplicity, the Truss Beam will be considered as homogeneous and linear for the moment. Thus the motion of the beam will be linear and periodic. Using the periodicity of the motion, a relationship between the maximum displacement and the acceleration is written as:

$$\{\ddot{Y}\} = - w^2 \{Y\} \qquad (3)$$

Where w is the frequency of the motion in radians per second.

Substituting Equations (2) and (3) in Equation (1), one obtains

$$\{Y\} = w^2 [A] [M] \{Y\} \qquad (4)$$

Since the bays in the beam are equal, the nodal masses can be assumed to be equal. If m is the mass of one bay, the mass matrix m can be expressed by:

$$[M] = m [I] \qquad (5)$$

where $[I]$ = Identity matrix

Equation (4) can be simplified as

$$\{Y\} = w^2 m \, [A] \, \{Y\} \tag{6}$$

or

$$0 = \left[[A] - \frac{1}{w^2 m} [I] \right] \{Y\} \tag{7}$$

Furthermore, let the matrix

$$[A] - \frac{1}{m\omega^2} [I] = [B] \tag{8}$$

Finally, the equation of motion of the system is expressed by the equation

$$[B] \{Y\} = 0 \tag{9}$$

In a conservative system, the determinant of the matrix [B] must vanish in order to have a solution. The roots of the polynomial generated from $|B| = 0$ will provide the eigen characteristics of the system. Therefore the generation of matrix [A] is crucial to the dynamic analysis of the above structure.

FLEXIBILITY OF THE TRUSS BEAM

Consider that the truss beam behaves as a cantilever beam. See Figure 1. For a slender Truss-Beam the transverse nodal displacements will be mainly attributed to the axial strain in the chords. Thus the contribution of the web elements can be neglected.

When the joint response is not considered in the analysis, the flexibility of the structure is obtained from the following alogarithms:

$$
\begin{aligned}
A_{ii} &= (2i - 1)^3 \quad , i = 1 , N \\
R_i &= 3\,(2i - 1)^2 \quad , i = 1 = N \\
A_{ij} &= A_{ij-1} + R_i, \quad j = 1+1, N
\end{aligned}
\tag{10}
$$

A computer program is written with N, the number of bays, as input. The elements of the [B] matrix are

$$
[B] = \frac{ml^3}{24\ EI} \begin{bmatrix} 1-\lambda & 4 & 7 & 10 & 13 & \cdots \\ 4 & 27-\lambda & 54 & 81 & 108 & \cdots \\ 7 & 54 & 125-\lambda & 200 & 275 & \cdots \\ 13 & 108 & 200 & 343 & 490 & \cdots \\ \cdot & \cdot & \cdot & \cdot & \cdot & \\ \cdot & \cdot & \cdot & \cdot & \cdot & (2N-1)^3-\lambda \end{bmatrix} \tag{11}
$$

FLEXIBILITY OF TRUSS BEAM INCLUDING JOINT RESPONSE

In this analysis the non-linear behavior of the joint will be excluded. Once the linear contribution of the joint has been verified in comparing theorectical and experimental results, additional work will be done to include the non-linear behavior of the joint.

The flexibility of the joint is obtained from the static force acting on the joint as shown in Figure 2. Let this flexibility be denoted by k. The new alogrithm will have the following form:

$$A^*_{ij} = \frac{\ell^3}{24EI} (2i - 1)^3 + si\ (2j-1) \qquad \begin{matrix} i = 1, N \\ j = 1, N \end{matrix} \tag{12}$$

where

s = $\dfrac{24EI}{\ell^3} \quad \dfrac{k(\ell)^2}{h}$

I = Moment of inertia of the Truss-Beam

H = Depth of the Truss-Beam

E = Modulus of elasticity of the chords

A^* = Represent the flexibility matrix which includes the joint flexibility.

Then

$$B^* = \begin{bmatrix} A^*_{ii} - \lambda & - & - & - & - & - \\ - \ - \ - & A_{22} - \lambda & A_{ij}^* & - & - & - \\ \vdots & & & & & \\ \vdots & A_{ji}^* & - & - & - & AN,N-\lambda \end{bmatrix} \tag{14}$$

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APPLICATION OF THE METHOD

Applying the method used in this report to a joint dominated beam and neglecting the joint contribution, the results are shown in Table I & II for the ten modes of a truss beam of ten bays as shown. Note the close agreement with the results obtained for a continuous cantilever beam.

When the flexibility of the joint is taken into consideration, the frequency of the system will drop as indicated in Table I for a variety of k-valves. It is noticed that the frequencies do not vary significantly from one valve of k to another.

CONCLUSIONS & RECOMMENDATIONS

- The method used herein yields results very close to those obtained by the classical method for a uniformly distributed mass of cantilever beam
- When joint flexibility is entered into the solution the lowest frequency seems to go up by about nine percent.
- Higher mode frequencies drop significantly
- Frequencies are not sensitive to variations in joint flexibility
- Free play is not part of this method
- Viscous damping is ignored

We recommend as a continuation of this research that the following procedure be used:

- Model the joint for axial forces and then determine its flexibility theoretically

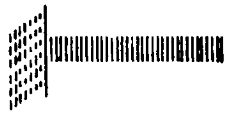
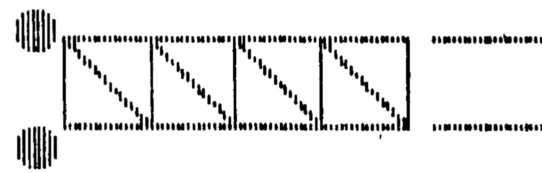
- Check the dynamic characteristics of the joint dominated beam by entering the information about the joint as established above

- Model the joint for linear and non-linear behavior and then use that information in determining the dynamic characteristics of the Joint-Dominated Beam

- Compare the final results for the dynamic behavior of the Joint Dominated Beam with results obtained by the previous approaches

APPENDIXES

TABLE I:

OMEGA (ω)	 C. L. BEAM	 TRUSS BEAM NO JOINT ACTION	 TRUSS BEAM / JOINT ACTION				
			k-values in/lb				
			1.0E-7	1.3E-7	5.0E-8	1.0E-9	1.0E-10
1	3.52	3.53	3.85	3.81	3.92	3.99	3.99
2	22.03	22.21	9.90	9.87	9.95	10.01	10.01
3	61.70	62.50	15.34	15.32	15.45	15.54	15.54
4	120.90	123.03	21.71	20.14	20.23	20.30	20.30
5	199.86	203.03	24.60	24.36	24.68	24.76	24.78
6	298.56	304.33	30.50	30.43	30.63	30.78	30.78
7	416.99	420.65	39.99	39.86	40.24	40.56	40.55
8	555.17	542.99	57.93	57.64	58.54	59.32	59.34
9	713.08	647.84	103.77	102.78	106.12	109.63	109.70
10	890.73	886.79	392.35	391.57	412.96	496.20	499.24

APPENDIX: 1

Table II. Comparizon of results by different methods

Mode		w^a		w^b		w^c		w^d
	3		3		3		3	
1	3	1.465	3	1.443	3	1.461	3	1.454
2	3	9.236	3	8.754	3	9.159	3	8.827
3	3	25.991	3	23.410	3	25.650	3	23.600
4	3	51.162	3	43.200	3	50.260	3	43.540
5	3	84.816	3	66.680	3	83.070	3	67.250
6	3	126.555	3	92.510	3	124.100	3	93.530
7	3	174.927	3	119.600	3	173.300	3	121.500
8	3	225.802	3	147.100	3	230.800	3	150.500
9	3	269.403	3	----	3	----	3	----
10	3	368.770	3	----	3	----	3	----

a. Abu-Saba Method
b. exact method
c. Euler-Bernouilli beam, analytical
d. Timosheuko beam, FEM
References: C.T. Sun, B.J. Kim, J.L. Bogdunoff,AIAA, 1981 #81-0624

APPENDIX: 2

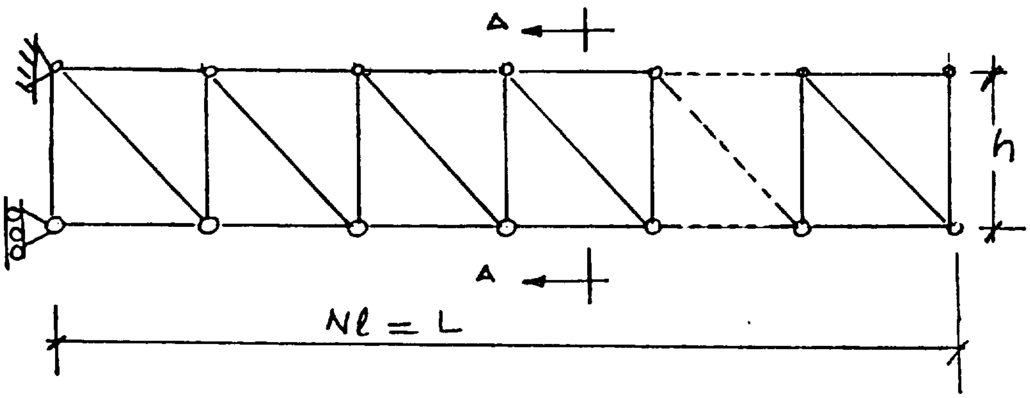


Fig 1. a
Truss Cantiler

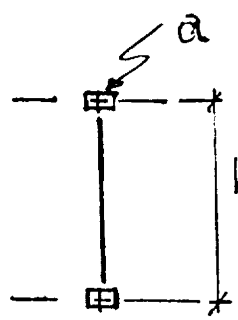


Fig 1. b
Section of beam truss

APPENDIX: 3

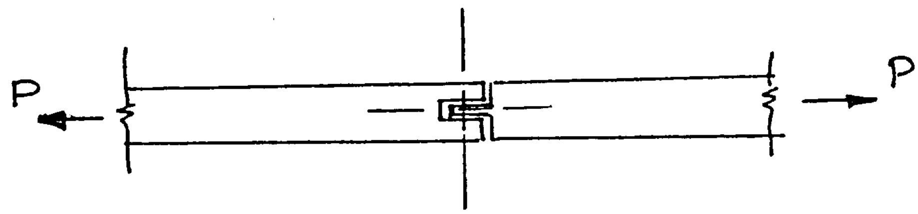


Fig. 2.a
Axial load in Chord

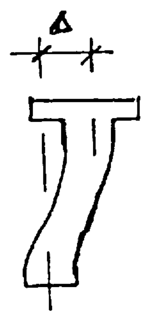


Fig 2.b
PIN

FIG.2 TYPICAL JOINT

APPENDIX: 4

APPENDIX C.

WORK DONE BY MR. SHERWOOD HARRIS AS A GRADUATE RESEARCH ASSISTANT ON THIS PROJECT.

GRANT NO: 4-43069

CHARACTERIZATION OF FREE PLAY IN DEPLOYABLE TRUSS-JOINTS

(Preliminary)

BY

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September 1985

WHEN SLIP-FIT TYPE ALUMINUM TRUSS JOINTS ARE DEFORMED, ENERGY IS ABSORBED AND DISSIPATED BY THE MATERIAL. THIS HYSTERESIS EFFECT IS DUE TO FRICTION BETWEEN THE PIN CONNECTIONS WHICH SLIP OR SLIDE AS THE DEFORMATIONS TAKE PLACE. THIS FORM OF DAMPING RESULTS IN OFFSETTING THE PARTS OF THE FORCE-DISPLACEMENT CURVE AS SHOWN IN FIG. 1, WHERE P IS THE APPLIED FORCE (TENSION & COMPRESSION), X IS THE DISPLACEMENT, $\underline{X}$ IS THE AMPLITUDE. ALL MATERIALS EXHIBIT THIS TYPE PHENOMENON WITH RUBBERLIKE MATERIALS SHOWING A LARGE LOOP AND METALS DISPLAYING A VERY SMALL ENCLOSURE.

IF ΔU REPRESENTS THE ENERGY LOSS PER CYCLE, THEN

$$\Delta U = \int P\,dx = A_{P,X} \qquad (1.1)$$

THAT IS, THE ENERGY LOSS PER CYCLE IS REPRESENTED BY THE AREA WITHIN THE LOOP.

IT HAS BEEN FOUND EXPERIMENTALLY THAT THE ENERGY LOSS IS INDEPENDENT OF THE FREQUENCY BUT IS PROPORTIONAL TO THE (APPROXIMATE) SQUARE OF THE AMPLITUDE. IT IS ALSO CONSIDERED TO BE DIRECTLY RELATED TO THE STIFFNESS OF THE MEMBER. THE ENERGY LOSS PER CYCLE CAN BE EXPRESSED AS

$$\Delta U = \pi b K_{AVG} \underline{X}^2 \qquad (1.2)$$

WHERE b IS THE SOLID DAMPING CONSTANT FOR THE MATERIAL. THE FACTOR Kb THEN RELATES THE ENERGY LOSS TO THE SIZE AND SHAPE OF THE MEMBER AS WELL AS TO THE MATERIAL CHARACTERISTICS. INCLUDING THE FACTOR π WAS DONE SO THAT THE FORM WOULD RESEMBLE THE RELATION FOR ENERGY DISSIPATION FOR HARMONIC MOTION WITH VISCOUS DAMPING. THE EXPONENT OF $\underline{X}$ IS FROM 2.0 TO 2.3 FOR CERTAIN METALS, AND IT MAY BE TAKEN AS 2.0 FOR MANY MATERIALS, INCLUDING ALUMINUM.

IN REALITY, EQ. 1.2 BECOMES THE DEFINITION FOR THE HYSTERESIS OR SOLID DAMPING CONSTANT b. IN OUR CASE, OF THE DEPLOYABLE TRUSS JOINT, IT IS ASSUMED THAT ΔU IS SMALL (SEE Fig. 1.) AND THE MOTION IS NEARLY HARMONIC IN FORM. THE LOSS OF AMPLITUDE PER CYCLE MAY BE DETERMINED A CONSIDERATION OF THE ENERGY. REFERRING TO FIG. 2, THE LOSS FOR A QUARTER-CYCLE IS ASSUMED TO BE $\frac{1}{4}(\pi K b \bar{X}_i^2)$, WHERE $\bar{X}_i$ IS THE AMPLITUDE OF THAT PARTICULAR PART.

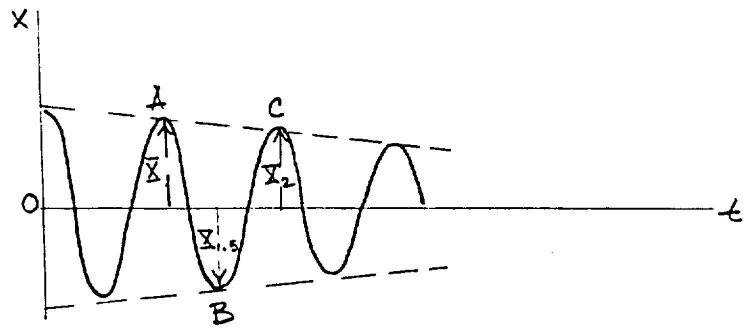


FIG. 2

THE ENERGY EQUATION FOR THE HALF-CYCLE FROM A TO B IS THEN

$$\frac{K\bar{X}_1^2}{2} - \frac{\pi K b \bar{X}_1^2}{4} - \frac{\pi K b \bar{X}_{1.5}^2}{4} = \frac{K\bar{X}_{1.5}^2}{2} \qquad (1.3)$$

WHERE

$$(2-\pi b)\bar{X}_1^2 = (2+\pi b)\bar{X}_{1.5}^2$$

$$\frac{\bar{X}_1}{\bar{X}_{1.5}} = \sqrt{\frac{2+\pi b}{2-\pi b}} \qquad (1.4)$$

SIMILARLY, FOR THE NEXT HALF-CYCLE FROM B TO C,

$$\frac{\bar{X}_{1.5}}{\bar{X}_2} = \sqrt{\frac{2+\pi b}{2-\pi b}} \qquad (1.5)$$

MULTIPLING EQS. 1.4 & 1.5 GIVES

$$\frac{\bar{X}_1}{\bar{X}_2} = \frac{2+\pi b}{2-\pi b} = \text{CONSTANT}$$

$$= 1 + \frac{2\pi b}{2-\pi b}$$

$$\simeq 1 + \pi b \qquad (1.6)$$

SINCE THE RATIO OF THE SUCCESSIVE AMPLITUDES IS CONSTANT, THE DECAY IS EXPONENTIAL. THE LOG DECREMENT IS DEFINED BY

$$\delta = \ln\left(\frac{\overline{X}_1}{\overline{X}_2}\right)$$
$$\simeq \ln(1+\pi b)$$
$$\simeq \pi b \qquad (1.7)$$

THIS EXPRESSION ALSO SUGGESTS A METHOD FOR THE EXPERIMENTAL DETERMINATION OF THE SOLID DAMPING CONSTANT b. THE DECAY CAN BE OBSERVED BY MEASURING SUCCESSIVE AMPLITUDES AND FROM THIS δ CAN BE OBTAINED. THEN b CAN BE CALCULATED BY EQ. 1.7, OR b MAY BE DETERMINED DIRECTLY FROM EQ 1.6. THE VALUE OF b SO OBTAINED WOULD INCLUDE THE EFFECT OF FRICTION BETWEEN THE ADJACENT PART OF THE EXPERIMENTAL SETUP AS SHOWN IN FIG. 3, AS WELL AS THAT WITHIN THE MATERIAL.

THE FREQUENCY HERE IS DEFINED BY THAT OF THE ASSUMED HARMONIC MOTION, OR

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

THE ABOVE-DESCRIBED MOTION CAN BE ASSUMED TO BE REPLACED BY AN EQUIVALENT VISCOUSLY DAMPED MOTION WHICH WOULD EXHIBIT SIMILAR CHARACTERISTICS. THE CORRESPONDING EQUIVALENT VISCOUS DAMPING FACTOR ζ_e AND CONSTANT C_e ARE DEFINED BY EQUATING THE APPROXIMATE RELATIONS FOR δ FOR TWO CASES

$$2\pi\,\zeta_e \approx \delta \approx \pi b$$

WHERE

$$\zeta_e = \frac{b}{2}$$

AND

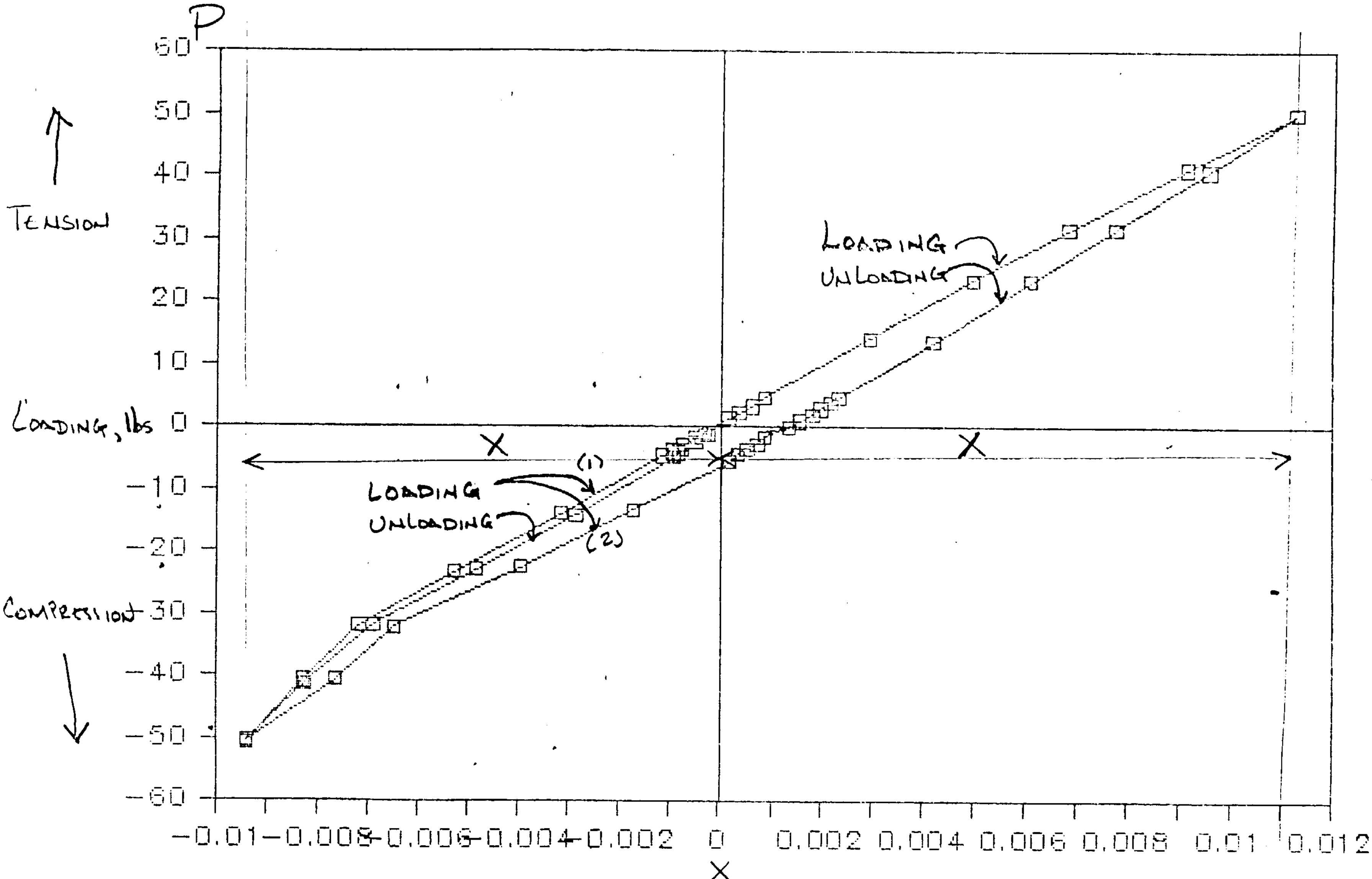
$$C_e = C_c \zeta_e = 2\sqrt{mk}\,\frac{b}{2} = b\sqrt{mk} = \frac{bk}{\omega}$$

THESE EQUIVALENT VALUES WOULD THEN BE USED IN EQUATIONS FOR VISCOUS DAMPING, RESULTING IN

$$x = \underline{\bar{X}}\, e^{-\zeta_e \omega t} \sin(\omega t + \phi)$$

$$= \underline{\bar{X}}\, e^{-\frac{b}{2}\omega t} \sin(\omega t + \phi)$$

WHERE ω HAS REPLACED ω_d, SINCE ζ IS SMALL. THIS EXPRESSION DEFINES A DECAYING MOTION WHICH IS EQUIVALENT TO THAT FOR THE SOLID DAMPING CASE.



Hinge Deflection, in.
(Slip Fit Pin Connection)
5/16 in. Dia.

Figure 1

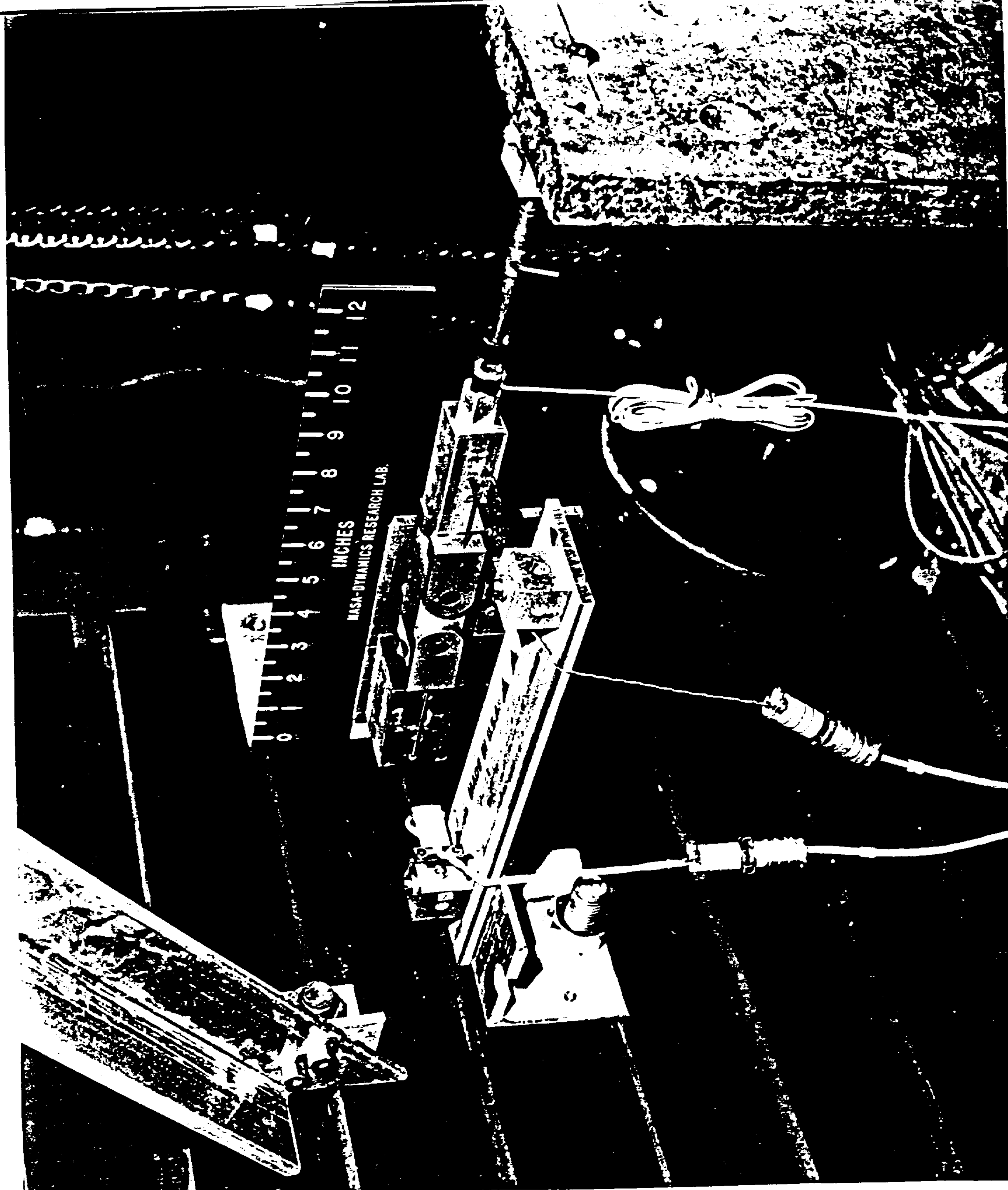


Fig. 3

ORIGINAL PAGE IS
OF POOR QUALITY

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ABSTRACTS

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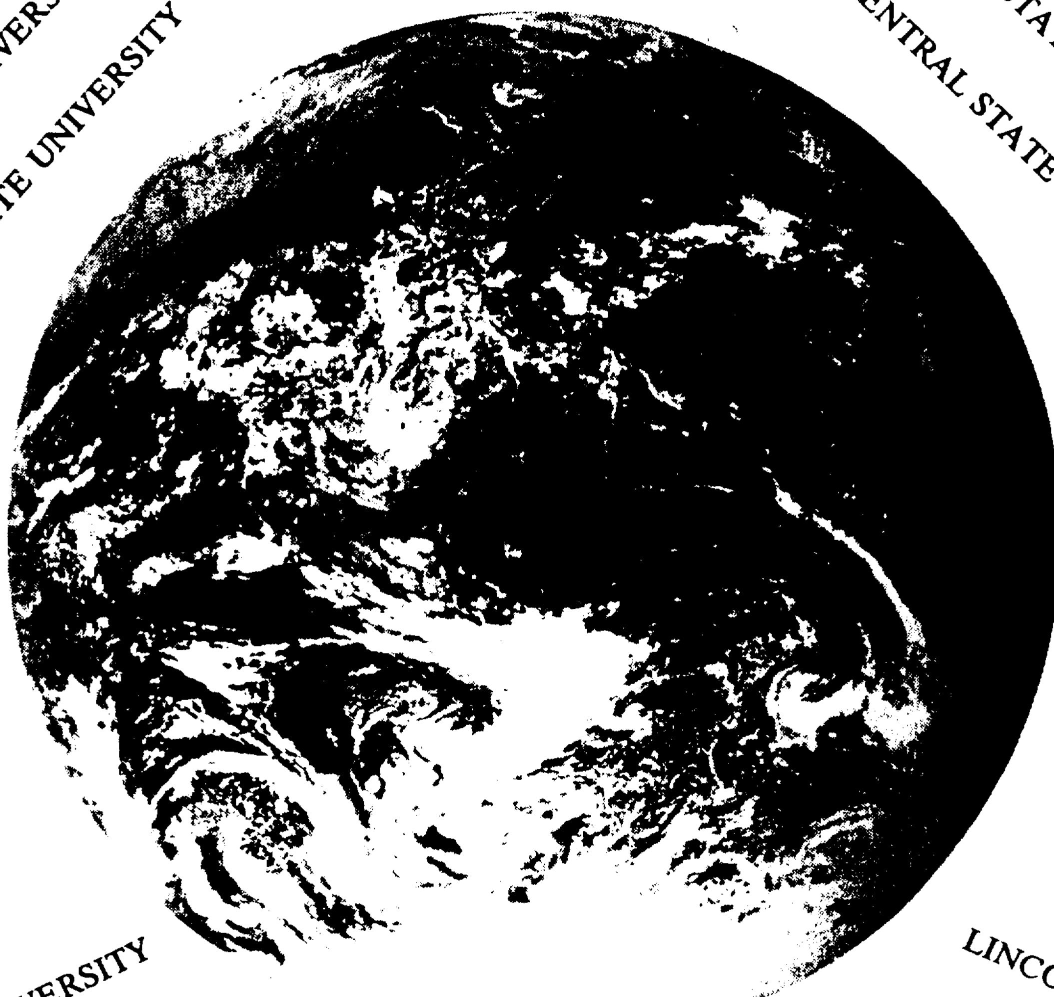

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PRINCIPLE INVESTIGATOR: Dr. Elias G. Abu-Saba

STUDENT: Mr. Sherwood Harris
TECHNICAL MONITOR: Dr. Raymond C. Montgomery (LaRC)

Dynamics and Control of Orbiting Grid Structures and the Synchronously Deployable Beam

ABSTRACT

Large flexible space structures are becoming an essential part of NASA's space effort. Dynamic control of these structures presents a challenge to aerospace scientists. To better understand the dynamic behavior of large space structures, the investigators provide mathematical models for the grid. The grid as a whole behaves like a complex pendulum. The SPAR FEM Computer Program is used to develop the elastic constants and the dynamic characteristics of the model. A set of linear and nonlinear equations are obtained which define the dynamic behavior of the system. Conclusions with regard to the dynamic response of the grid are employed in developing the attitude modification scheme.

Free play in the joints of deployable structures is required to permit smooth deployment using a low drive force deployer. To understand the effect of free play on beam deflections a combined analytical and experimental research is conducted to evaluate the significance of the various joint behaviors that affect the overall stiffness of the beam. Linear and nonlinear aspects of the joints are included.

This approach will be used to evaluate the dynamic behavior of the SOLAR ARRAY MAST which was tested on board of the Shuttle Discovery in Spetember of 1984. Analytical results will be compared with the data compiled from the test.

ELIAS ABU-SABA

HBCU GRADUATE STUDENT WORKSHOP

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LANGLEY RESEARCH CENTER

HAMPTON, VA

November 8, 1985

Sponsored By:
Chief Scientist, Jerry C. South, Jr.,
Office of Director

SHERWOOD E. HARRIS
NORTH CAROLINA A&T STATE UNIVERSITY

RESEARCH TOPIC: Damping characteristics of free play in Deployable Truss Joints

ABSTRACT: The "Next Generation" spacecraft are being conceived that are highly flexible and of large size. The compact storage requirements for launch require subassemblies of large flexible spacecraft to be joined together on orbit to build-up the structure to the required dimensions. Of the structural elements which perform this function, joints are seen to be the major source of the non-linear response of the system.

One potential problem associated with joint dominated structures is free play in the joints. Some free play in deployable structures may be required to permit smooth deployment using a low drive force deployer. The amount of free play is also associated with machine accuracy requirements. To understand the effect of free play on the dynamic behavior of the structure an experiment was performed on a deployable truss joint with hardened steel pivot pins.

The results obtained indicate free play in the range between zero and 50 lbs. This is directly linked to the non-linear behavior of the system. In addition, energy absorption and dissipation by the material augment the non-linearity of the structure. The joint hysteresis is caused by friction of the pins in the connections as they slip or slide during deformation. Based on the experimental data, a mathematical expression is established to predict the solid damping constant. Similarly, another mathematical expression is obtained to define the decaying motion of the system.

RESUME : B.S., Architectural Engineering, North Carolina A&T State University, 1980; Work experience: Structural Engineer, Niagara Mohawk Power Corporation, Syracuse, New York, currently enrolled in M.S. program, Engineering, North Carolina A&T State University.

FACULTY ADVISOR: Dr. Elias G. Abu-Saba

LARC ADVISOR: Dr. Raymond C. Montgomery

APPENDIX D

PRESENTATION BY MR. HEBREW L. DIXON

HBCU GRADUATE AND UNDERGRADUATE STUDENT
SCIENCE AND ENGINEERING WORKSHOP

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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HEBREW DIXON

NORTH CAROLINA A&T STATE UNIVERSITY

RESEARCH TOPIC: Dynamic Analysis of the Joint Dominated Beam

ABSTRACT: A method is presented herein to determine the vibration mode of the Joint Dominated Beam. An example of a cantilever beam is selected for this purpose. The truss type beam is analysed as a homogeneous section with the equivalent moment of inertia derived from the contribution of the chords only. Such an assumption is justified for slender beams for which the deflections due to web strains is neglegible.

Based on the above assumptions, a lumped mass system is selected as a model. The flexibility of the system is derived from the deflection equation of the cantilever beam. Maxwell's law of reciprocity is utilized in order to minimize the computational procedure. A set of alogarithmic statements is obtained.

First, the joints in the beam are considered to be an integral part of the beam. The flexibility matrix is obtained and the equation of motion written. Given N as the number of bays, a computer program has been written to provide the natural frequency constant of the beam. The valves of the frequencies for the first ten modes are compared with those obtained by the classical method. The results from the method used herein are compared with the results of a number of examples performed by other methods and authors.

Second, the joint flexibility is denoted by k, and a new set of alogarithmic statements are obtained which involve the behavior of the joints. A modified flexibility matrix is obtained and another set of natural frequencies is obtained. Various values of k are used and the frequency output is recorded. Some conclusions are made based on these results.

RESUME: B.S., Architectural Engineering, North Carolina A&T State University; currently for M.S. Degree in Architecture

FACULTY ADVISOR: Dr. Elias G. Abu-Saba

LaRC ADVISOR: Dr. Raymond Montgomery

APPENDIX E.

PRESENTATIONS BY DR. ELIAS G. ABU_SABA:

TO NASA STAFF AT LANGLEY RESEARCH CENTER

TO ASCE: 88 SPACE STRUCTURES

NASA
Langley Research Center

BRIEFING

June 17, 1986
DATE

TRUSS BEAM: DYNAMIC ANALYSIS

Dr. Elias G. Abu-Saba
North Carolina A&T State University
Greensboro, NC

B1268A, R1141
Tuesday, 6/24/86
10:00 a.m.

Abstract

The truss-beam used as a cantilever will be analyzed for dynamic behavior. First, the joints are treated as frictionless and with no damping or slipage. The truss-beam is considered to be linear and with small displacements. The flexibility matrix is thus generated from one basic equation. Second, the joints are included in the analysis. Energy loss of the joints is computed experimentally or at first assumed. The net strain energy of the system is obtained and node displacements are computed. A modified flexibility matrix is arrived at and used to calculate the eigenvalue characteristics. Models will be constructed and tested for dynamic behavior, and the results will be compared with the theoretical values. Conclusions will be drawn to upgrade the theory iteratively until experimental and theoretical results converge. Jeffrey P. Williams, X4591, is coordinating this meeting.

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ENGINEERING, CONSTRUCTION, and OPERATIONS IN SPACE

Proceedings of Space 88

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