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DAA/Langley

# DYNAMICS AND CONTROL OF ORBITING GRID AND THE SYNCHRONOUSLY DEPLOYABLE BEAM

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PROJECT INVESTIGATOR: DR. ELIAS G. ABU-SABA

JULY, 1985

SEMI-ANNUAL REPORT

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Appendix

I. Presentation of technical report
October, 1984 at NASA Langley Research Center

II. Presentation of Project achievements,
expected achievements to NASA Personnell and A&T
Administrators at A&T Campus, April 9, 1985.

III. Student Reports

IV. Budget 84,1985-86

SEMI-ANNUAL REPORT

Dynamics and Control of Orbiting Grid and the Synchronously Deployable Beam

Beginning of October 1, 1984, the following list show the accomplishments of Year II up to June 30, 1985.

A. Student Involvement

Two graduate students became involved in this project. Messrs. Harris and Alford are graduates of the Arch. Engineering Program. Both carried on special studies under my supervision in the area of Structural Dynamics as part of their preparation to do research in this area. Both students made several trips to NASA-Langley Research Center and met with the project monitor. Mr. Harris is presently at the NASA-Langley Center, full time. He is assisting in the Flight Dynamic Control. Mr. Alford was terminated last May since he graduated.

B. Undergraduate Students

Three undergraduate students came aboard on October 1, 1984 and were kept on the project till the end of the Fall Semester of 1984-1985. Two of these students visited NASA at Hampton in October of 1984.

C. The project director had no release time in 1984-1985. He managed the project in addition to a full load of teaching. However, he made a presentation of his research in October of 1984. A copy of the technical report of that presentation is enclosed in the appendix.

In April of 1985 the project director made a presentation to a combined NASA personnel and A&T faculty and administrators meeting. A synopsis is enclosed in the Appendix.

The project director is spending three days a week for ten weeks during this summer. He is utilization his time in consultation with the project monitor and using the NASA Library facilities to complete a literature review on Grid Sturctures. He hopes to compile a report on his research finding by Septemter 30, 1985.

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
- $\sigma$ = Angular displacement in vertical plane
- $\theta$ = 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 properties 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 obtained 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 |
| 1 | 0.364 | 0.366 |
| 2 | 0.625 | 0.844 |
| 3 | 1.398 | 1.335 |
| 4 | 2.299 | 1.844 |
| 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.

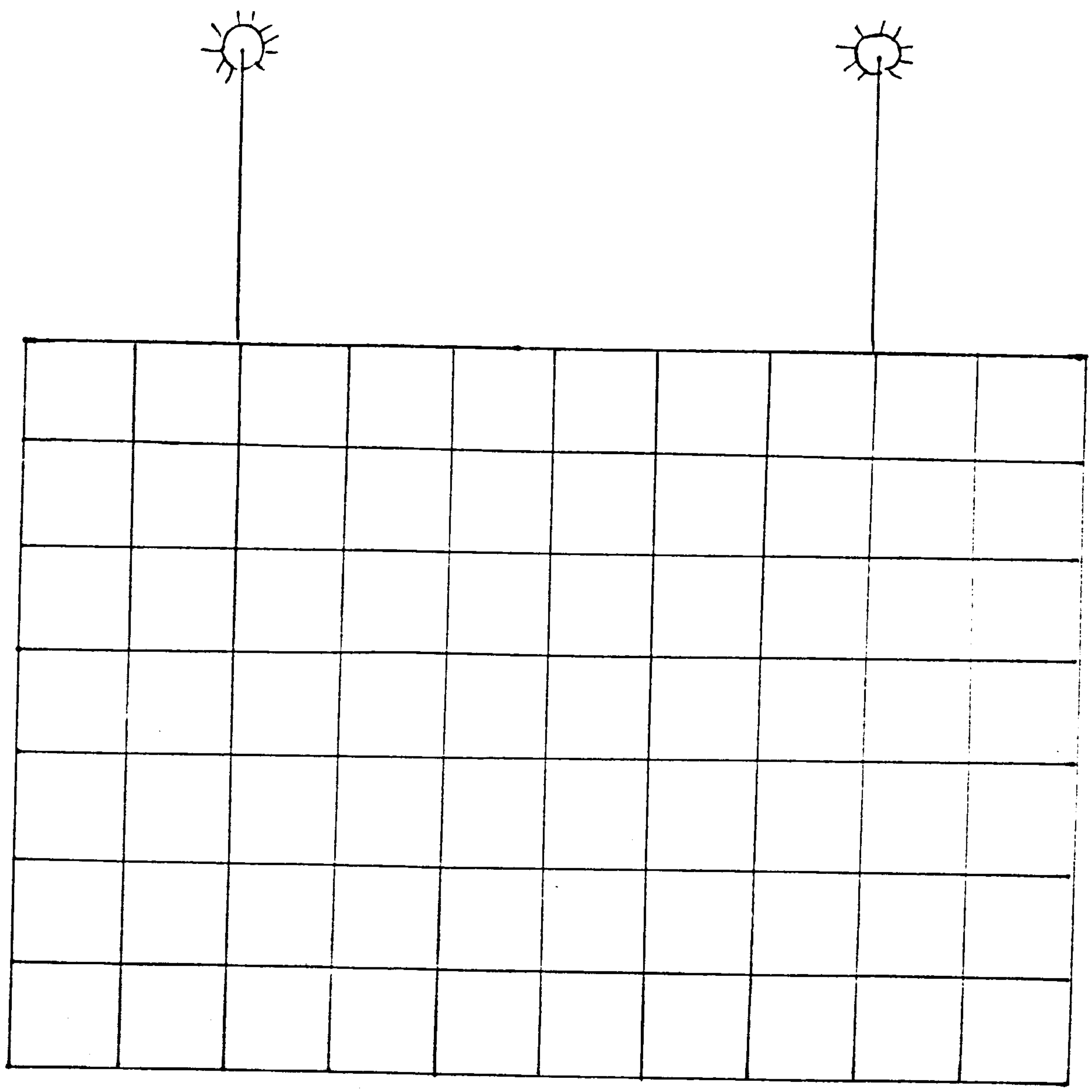

FIGURE 1. GRID STRUCTURE

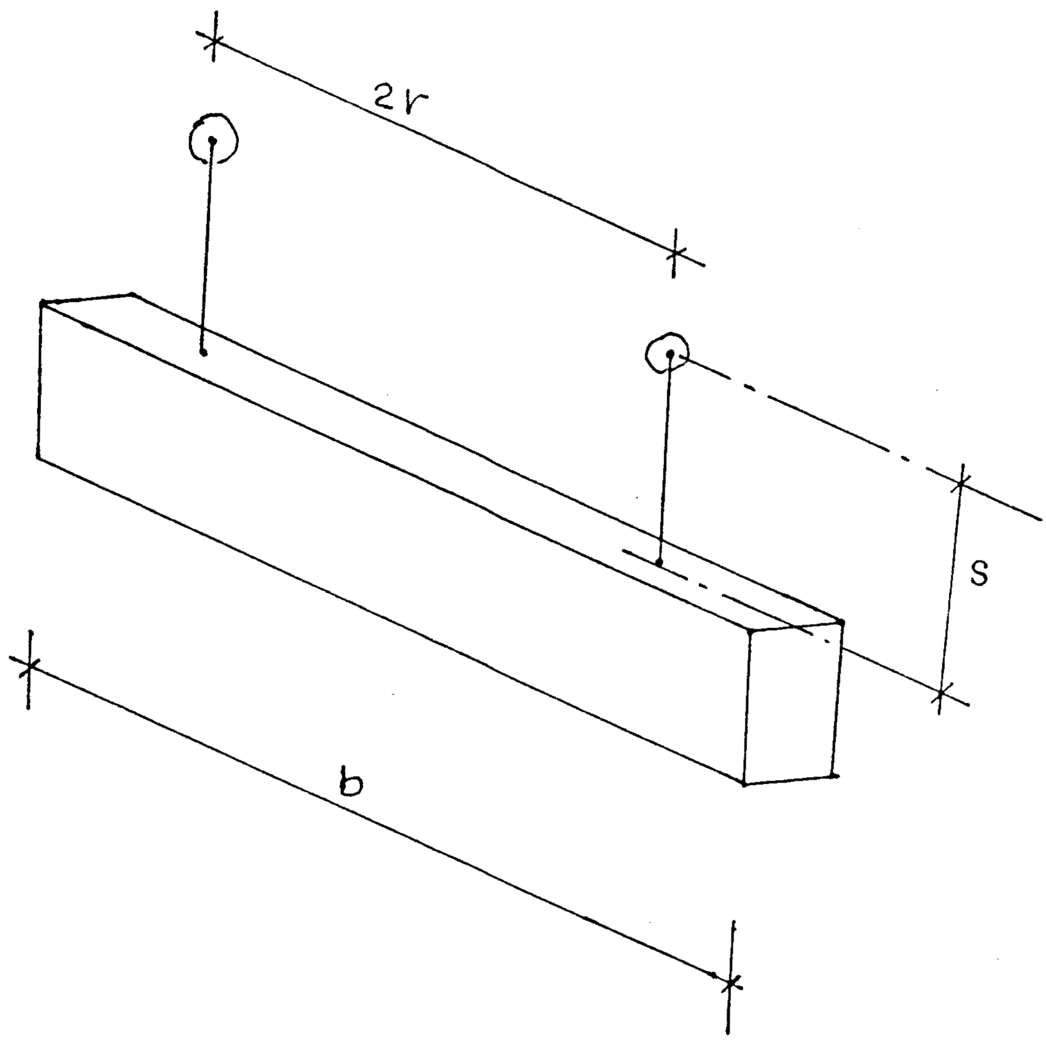


FIGURE 2. GRID MODEL: SINGLE MASS

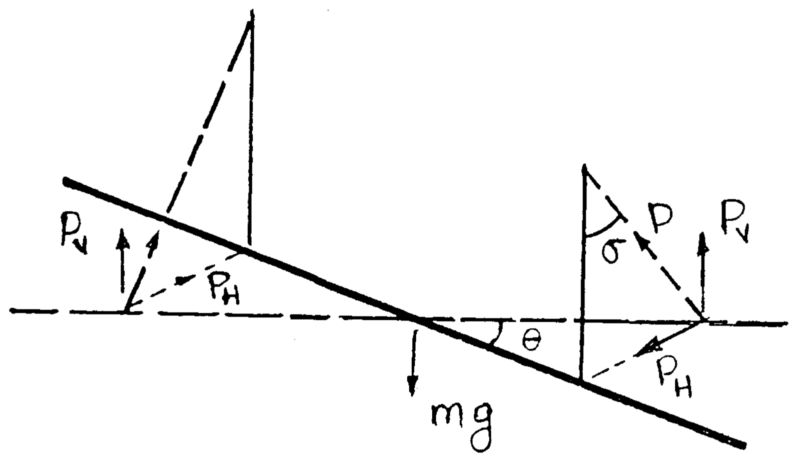


FIGURE 3. EQUILIBRIUM DIAG.

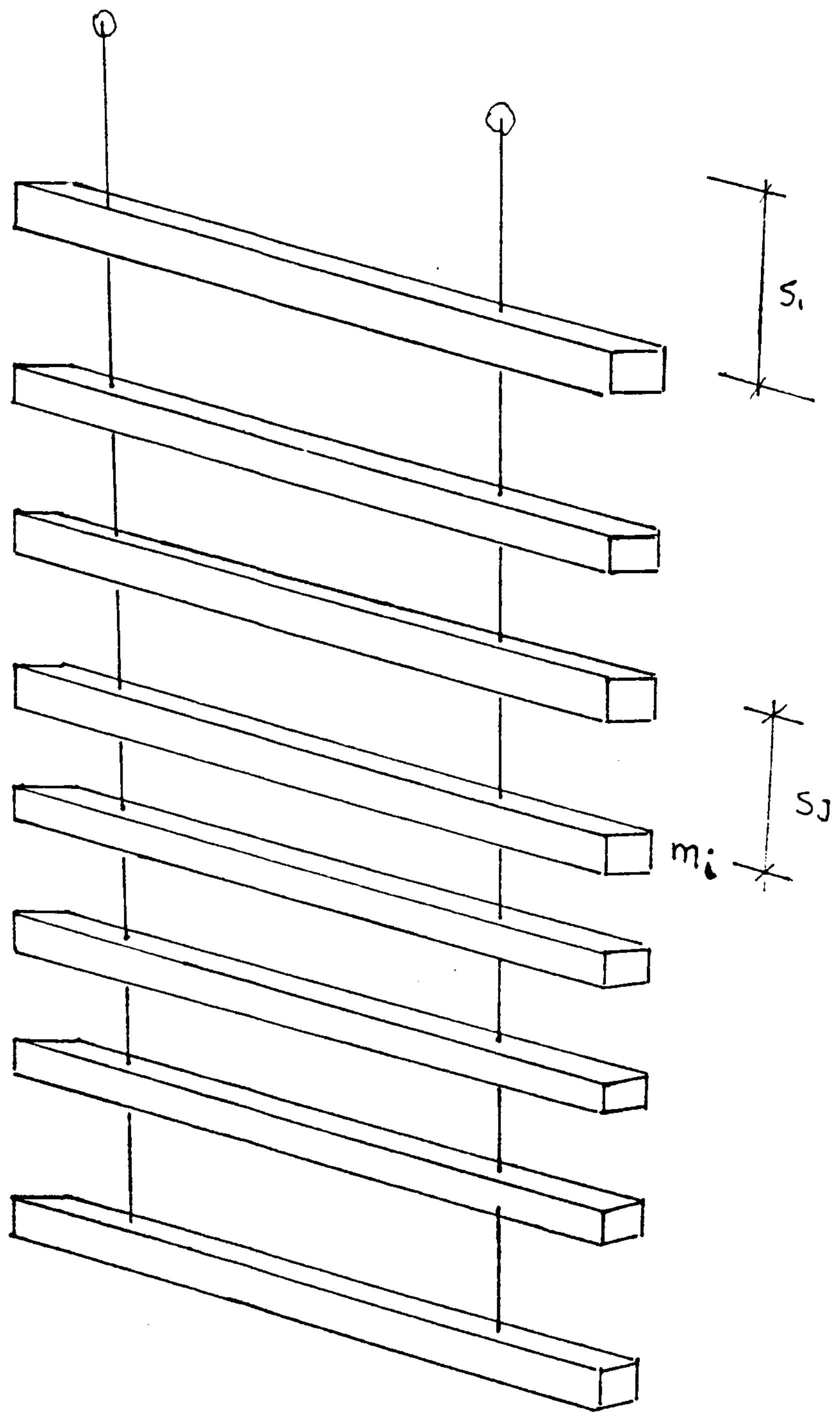


FIGURE 4. 8-MASS MODEL

Project Director: Dr. Elias G. Abu-Saba
Assoc. Prof. Arch. Eng.

# DYNAMICS AND CONTROL OF ORBITING GRID STRUCTURES AND THE SYNCHRONOUSLY DEPLOYABLE BEAM

## Synopsis

Grid structures have been utilized in space technology in many areas of application such as solar collectors, antenas, and space platforms. Functional reliability of these structures is intimately related to their dynamic properties. Attitude control of orbiting grids depends on the clear understanding of their respone to inertial as well non-inertial forces. The stated objective of the structural engineer in these cases is to delineate and then assess the impact of the various components as related to the dynamic behavior and provide this information to the control scientist. Then, course correction or behavior modification of the orbiting structure may be achieved by ground or on board commands.

PROGRESS MADE IN SPAR PROJECT

The start of this project for me was a review of the computer SPAR run given by NASA Langley. I investigated the use of the various processors and sub-processors with the use of the COSMIC manual. Processor TAB allocates joint positions and processor ELD defines the elements. The loop limit format proved to be a very valuable asset in the generation of a grid. An observation was made that the value of E for the steel cable was only 80° of the generally used value of 30E6. Also it was found that authors of this particular data file chose to input rectangular cross-section dimensions under the guise of a Tee Beam.

Derome Dunn, a fellow graduate student, has compiled a table to differentiate between control characters used by the sample problem and those in this school's version of the SPAR program. Other control statements such as "Do SPAR.TAB" have been incorporated into our system.

The library proved to be intriguing. Data sets are compiled with information stored by a processor and recalled by another. The ability of making comments on a line following any command greatly improves the capacity of the engineer for quick and efficient editing.

On A&T's DEC-10 system, a simple problem, a cantilevered beam subjected to loading was analysed by SPAR quite handily. However, during our early investigations, the grid problem hung up in the EIG processor. The code has to be modified to suit the DEC system. Derome and I went through the tedious task of checking all the parameters passed by routines beginning with the library, SP10.SP.

With the departure of Derome to VPI, I was in engaged mostly in reading materials published by NASA. I also upgraded my knowledge of microprocessing and computer procedures by more studying. The late spring was spent becoming familiar with the subject of vibrations.

This familarization led to the investigation of the lattice vibration under the assumption of a bifilar pendulum. Dr. Abu-Saba proposed the assumption and then followed through with the derivation of equations of motion. Models of one, two, four and eight masses were utilized in the investigations. I was responsible for the comuter procedures to solve the equations and find the subsequent eigenvalues. After searching several sources, I decided that the most efficient method RSAN, a computer routine by SANDIA LABS. After much work, the eigenvalues could be extracted from the program quite handily. Fundamental frequencies for the first 4 modes agreed reasonably well with values obtained by Dr.Montgomery using the Finite Element model (SPAR PROGRAM).

During the Fall of 1984 our work started to include damping. We also looked at Rayleigh-Ritz methods and I initiated a computer program employing the Stodola method. Due to difficulties with the computer account setup, this program was not finished.

In October, 3 other students and I accompanied Dr. Abu-Saba NASA Langley at Hampton, Virginia. We witnessed Dr.Abu-Saba's presentation to NASA employees on work which he and I had done on the bifilar pendulum approach in the summer of 1984. A report was made on the trip.

For a few days in December, 1984 Sherwood Harris and I returned to NASA Langley to get first-hand knowledge of the experimental procedures and left a record of our findings at Langley.

For me spring semester of 1985, Harris and I have met regularly with Dr.Abu-Saba to discuss other possible approaches to the solution of the frequencies of the lattice and to review material already published by NASA.

My plans are to continue working and studying procedures of the project until June 26, 1985 at which time I will have graduated.

NASA Grant - NAG-1-405

Title - Dynamics and Control of Orbiting Grid Structures and Deployable Beam

Project Manager - Dr. Elias G. Abu-Saba

| | Original 85-86 Budget | Estimated Carryover with proposed distribution 85-86 | Modified Budget 85-86 |
|---|---|---|---|
| Faculty & Administrative Salaries | 51058 | 23000 | 74058 |
| Clerical Salaries | 14520 | 0 | 14520 |
| Technician Salaries | 1210 | 0 | 1210 |
| Student Wages | 35444 | 8000 | 43444 |
| Fringes | 17667 | 5854 | 23521 |
| Indirect Costs 43.7% of Sal. & Wages | 44675 | 13547 | 58222 |
| Supplies | 1100 | 54 | 1154 |
| Travel | 5973 | 0 | 5973 |
| Computer Services | 911 | 0 | 911 |
| Maintenance | 1500 | 0 | 1500 |
| Office Equipment | 1246 | 0 | 1246 |
| Totals | $175304 | $50455 | $225759 |