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THE UNIVERSITY OF ALABAMA

# VERIFICATION OF COMPONENT MODE TECHNIQUES FOR FLEXIBLE MULTIBODY SYSTEMS



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## INTRODUCTION

Since the 1960's, a significant amount of theoretical work has been undertaken in the area of modeling and simulation of multibody systems. However, for systems having flexible components, there still seems to be no well defined method for selecting component modes for systems, in which due to large displacements, the boundary conditions of the original assumed modes varies. Furthermore, there has been very limited experimental verification of the existing modeling and simulation techniques. Hence, over the past fifteen months, research has been initiated with NASA/MSFC and Auburn University in the flexible multibody modeling and verification area [1-3]. The emphasis of the work is focused on the lack of experimental verification of current modeling and simulation techniques. In particular, analytical and experimental data is to be used in addressing the question of which boundary conditions and corresponding component modes should one use in describing the dynamics of flexible multibody systems. Other issues of interest are the gravity loading effects on geometric stiffing and the effects of configuration changes on assumed inertia values used in mode selection.

## PROJECT DESCRIPTION

The proposed summer research activities were a continuation of last summer's project with NASA/MSFC. One of the selected tasks was to conduct further investigations in the modeling aspects of flexible multibodies undergoing large angular displacements. Models were to be generated and analyzed through application of computer simulation packages employing the 'component mode synthesis' techniques. The primary task set forth was the implementation of Phase I of the Multibody Modeling, Verification and Control Laboratory (MMVC) plan [1]. This was to include running experimental tests on flexible multibody test articles. From these tests, data was to be collected for later correlation and verification of the theoretical results predicted by the modeling and simulation process. The theoretical and numerical modeling techniques are being used in deriving a functional relationship and/or trends for as many of the issues stated above as possible.

## MODELING ASPECTS

In addressing the modeling task, the work concentrated on the design of the first test article for Phase I of the MMVC experiments. This involved extensive NASTRAN analyses. In addition, ADAMS and TREETOPS numerical models were used to determine some preliminary estimates. Various materials, configurations and dimensions were considered in the design process. After exhaustive study, a test article exhibiting low frequency characteristics, high modal density, a degree of dynamic coupling, and small static deflections due to gravitational loading was designed (see Figures 1-2 and Table 1). The resulting test article, currently under fabrication by NASA/MSFC, has the following material and dimension specifications.

Material of all members: $\text{Aluminum}_{6061}$
Young's Modulus, $E=68.95e9\ N/m^2$
Density = $2{,}768\ kg/m^3$

Dimensions:

Link 1: Length = 2.440m
Box Beam: Width, b = 0.0762m
Height, h = 0.0254m
Wall Thickness, t = 0.0032m

Link 2: Lengths (Two Branches) $L_a = 1.500m$, $L_b = 1.450m$
Solid Beam: Width, b = 0.0335m
Height, h = 0.0090m

Links 3, 4, 5, 6:
Lengths: $L_3 = 0.8200m$, $L_4 = 0.8000m$
$L_5 = 0.7800m$, $L_6 = 0.7600m$
Solid Beam: Width, b = 0.0050m
Height, h = 0.0020m

With the addition of motor, joints and sensors, the first seven frequencies dropped approximately 1 Hz in value. In addition, there was approximately a 52 per cent reduction in modal density range of these frequencies. The cost for the fabrication of two test articles is under $5,000.

The first generation of the test article's joints were designed to be light-weight and rigid. They were also designed using a pipe clamp approach to allow ease in changing body configurations. Since the initial testing will be for different static configurations of the test article, the joints will be fixed in each given configuration using a frictionless locking approach. Future improvements will be needed for the next phase of dynamic testing.

## PHASE I IMPLEMENTATION

The implementation of Phase I of the MMVC Laboratory plan was not completed. However, important progress was made. Preliminary details and arrangements have been outlined for implementation once the test article is received (late September). The sensor and instrumentation specifications have been given. The base support which is to cantilevered off a platform in the west high bay area of building 4619 has been located and awaits mounting. In addition, the Base Excitation Table is in the process of being designed and fabricated between now and early November 1990. The joints will be fabricated once the test article has been received.

The above items will be carried out by NASA employees. According to their schedules, our first experimental testing is expected to be conducted between November and December.


**REFERENCES**

1. Wiens, G. J., "Multibody Modeling and Verification", Final Report, NASA/ASEE 1989 Summer Faculty Fellowship Program, Contract No. NGT-10-008-021, Marshall Space Flight Center, Huntsville, AL.

2. Tsai, H.-D., "Normal Modes and Static Analysis of MMV Design 1: Part I", edited by G. J. Wiens, NASA/MSFC Report, May 29, 1990.

3. Wiens, G. J., "Flexible Multibody Modeling and Mode Selection Dependencies", Six Months Technical Progress Report, Contract No. NASA/NAG8-123, August 27, 1990.


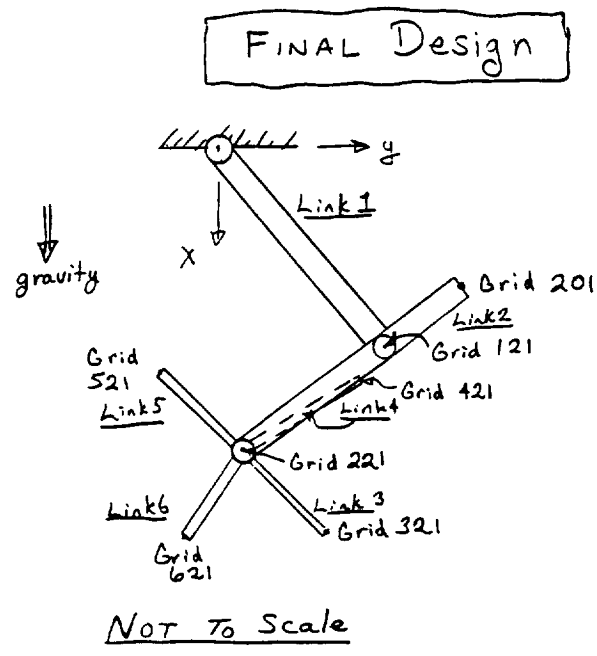


*Figure 1.*

## FINAL DESIGN

### TABLE 1.

### NORMAL MODE ANALYSIS FOR MMV DESIGN 12-NATURAL FREQUENCY

TEST ARTICLE 1: $\theta_1=0$ AND $\theta_2=0$

| | |
|---|---|
| LINK1: A1(HOLLOW-R, AL) | LINK4: A3(SOLID-R, AL) |
| LINK2: A2(SOLID-R, AL) | LINK5: A3(SOLID-R, AL) |
| LINK3: A3(SOLID-R, AL) | LINK6: A3(SOLID-R, AL) |

| MODE NO. | SYSTEM MODE | COMPONENT MODE: LINK1 | LINK2 | LINK3 | LINK4 | LINK5 | LINK6 |
|---|---|---|---|---|---|---|---|
| 1 | 1.379 | 1.672 | 2.578 | 2.397 | 2.518 | 2.649 | 2.790 |
| 2 | 2.250 | 21.801 | 3.452 | 15.021 | 15.782 | 16.601 | 17.486 |
| 3 | 2.416 | 69.198 | 17.251 | 42.060 | 44.190 | 46.485 | 48.963 |
| 4 | 2.539 | 143.586 | 21.637 | 82.425 | 86.598 | 91.096 | 95.953 |
| 5 | 2.591 | 223.398 | 50.042 | 136.269 | 143.168 | 150.604 | 158.635 |
| 6 | 3.100 | 245.037 | 60.598 | 203.604 | 213.912 | 225.022 | 237.021 |
| 7 | 3.458 | 373.588 | 100.456 | 284.471 | 298.873 | 314.396 | 331.162 |
| 8 | 14.202 | 529.314 | 118.830 | 378.940 | 398.124 | 418.802 | 441.135 |
| 9 | 15.160 | | | | | | |
| 10 | 15.896 | | | | | | |
| 11 | 15.972 | | | | | | |
| 12 | 17.372 | | | | | | |
| 13 | 20.658 | | | | | | |
| 14 | 23.057 | | | | | | |
| 15 | 40.295 | | | | | | |
| 16 | 42.420 | | | | | | |
| | (Hz) | (Hz) | (Hz) | (Hz) | (Hz) | (Hz) | (Hz) |

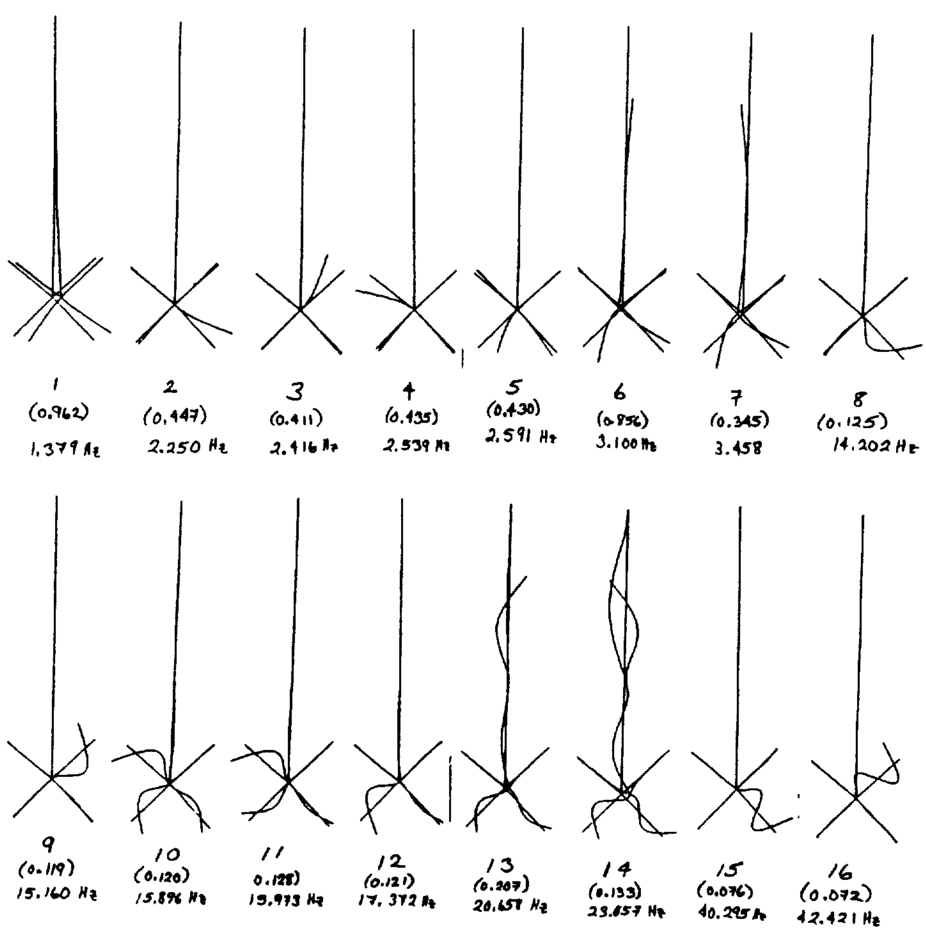


Figure 2. Mode Shapes



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