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Certification of A Hybrid Parameter Model of the Fully Flexible Shuttle Remote Manipulator System

Final Report

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Section 3 not used.

ABSTRACT

The development of high fidelity models of mechanical systems with flexible components is in flux. Many working models of these devices assume the elastic motion is small and can be superimposed on the overall rigid body motion. A drawback associated with this type of modeling technique is that it is required to regenerate the linear modal model of the device if the elastic motion is sufficiently far from the base rigid motion. An advantage to this type of modeling is that it uses NASTRAN modal data which is the NASA standard means of modal information exchange. A disadvantage to the linear modeling is that it fails to accurately represent large motion of the system, unless constant modal updates are performed. In this study, which is a continuation of a project started last year, the drawback of the currently used modal snapshot modeling technique is addressed in a rigorous fashion by novel and easily applied means.

INTRODUCTION

In the spirit of continuous improvement, dynamic models of complex systems continue to improve. Included in this improvement is the current ability to model flexible systems in a modal snapshot/linear fashion. The literature is bulging with ever-improving ways to model the distributed effects [1]. There are a diverse cross-section of techniques. Some are intuitive to a design engineer [2, 3, 4, 5], while others are mathematically elegant but beyond the training of many practicing engineers [6, 7]. The purpose of this study is to further examine the efficacy of the author's attempt at developing a rigorous yet usable method for modeling complicated systems [5].

During the summer of 1993, the author began work on a rigorous quasi-automated means to model large motion [8]. This summer the task was continued and the algorithms have been more fully developed. Actual simulation and animation of simplified Remote Manipulator Systems (RMS) were generated by the quasi-automated method. Increasingly complex RMS models are being developed as a shake down tool for the algorithms.

METHODOLOGY

Present Capabilities

Based on discussions,[1] the author understands that the fidelity of the model for the present Shuttle Remote Manipulator System (RMS) simulation is limited to small amplitude vibrations about any "snap shot" configuration of the system. This limitation manifests itself because of the linear finite element (NASTRAN) model used as the progenitor for the modal basis functions. Therefore, RMS slewing maneuver studies are not within the fidelity of the linear model. There exist techniques which allow an analyst to study the slewing maneuvers of systems like the RMS, but these modeling techniques are computationally expensive and/or hard to understand [1], therefore they are not always implemented by practicing engineers. The author believes the technique discussed below gives analysts a familiar yet powerful modeling tool.

New Capabilities

The main motivating factor for the development of another modeling method was the need to easily derive complete models of complex elastic systems [1, 4, 9, 10, 11, 12, 13]. Although the method discussed herein is still relatively mathematically intense (compared to an equal number of rigid bodies), it has a predisposition (as demonstrated in the work) for symbolic manipulation. Another impetus for this work is that a simpler method may make it possible to bring rigorous flexible system modeling out of the academic domain and into use by product designers. Another catalyst for this effort is that a simple (ultimately an automated) method will make it possible for researchers to rapidly regenerate models based on new continuum assumptions.

[1] Orientation meetings with various engineers from the Structures and Mechanics Division of JSC.

The approach is variational in nature. It retains most of the attributes of the analytical approach (i.e. Hamilton's principle), but eliminates most of the pitfalls, such as the need to use Lagrange multipliers for constraints, and excessive algebra. The methodology is vector based and requires the analyst to perform operations comparable to the operations required for implementing Lagrange's equations. However, it is claimed that the net algebra with the method herein will be less than the net algebra associated to Hamilton's principle or Lagrange's equations. Analysts familiar with Kane's [14] form of d'Alembert's principle will find the technique affable. The complete derivation of the method is shown elsewhere [1, 5].

Closed Form Model

Why should an analyst develop closed form models when there exist other tools that seem to adequately model these systems? The author believes that using tools that are traditionally from the structural analysis realm such as NASTRAN models unnecessarily limit the model to the linear motion about some configuration. It is felt that if the approach of writing complete models first (then reducing to linear if desired) is feasible, in a timely manner, then engineers will utilize these more exact models. In order to facilitate the clock, computer aided modeling is desired; *Mathematica* [15] is an excellent tool for this process. Another advantage to working directly with the closed form model is that the "zero times zero" multiplications that arise in straight out matrix models are avoided. Also repetitive multiplications and additions are readily recognized and can be assigned to a memory location for instant recall. This tight code will make running these complicated models more feasible.

Mathematica Algorithms

Mathematica [15] algorithms were developed to mimic the procedure outlined in the previous work [5]. The standard notation for *Mathematica* was adjusted so as to mimic engineering vector notation. Then algorithms were developed that recognize the vector dot and cross products, the triple products, and other identities. Differentiation of vectors in multiple coordinate frames was defined. Standard order for the symbols was defined so symbolic cancelation was facilitated. Functions that aid in the gathering of terms, the distribution of terms, and general manipulation were developed. At this point these algorithms are used via a *Mathematica* notebook running on a NeXT computer. They are not limited to this computer system because the notebooks are portable across multiple computer systems. An example of how one enters symbols for manipulation is shown in the report [8].

RMS MODELS

The first model of the RMS studied this summer was a two link rigid model that was used to shake down the modeling algorithms and fine tune the symbolic manipulation functions. It was also used to iron out means to show animations of the device, which is actually trivial with the aid of the *Mathematica* notebook front-end. The model and animation worked well. The simulation was done in *Mathematica*.

The next model studied, was a simple beam model of a single link planar manipulator. The beam neutral axis served as a rotating frame, and all flexibility was referenced to the rotating frame. The weak formulation of the field equations was utilized. The boundary conditions are rigorously supplied by the underlying modeling method. The modeling algorithms worked well. The equations of motion were output in FORTRAN form and simulated external to *Mathematica*. The output variable were then re-loaded into *Mathematica* for plotting and animation.

The third model studied was a two flexible link model of the RMS. The flexibility was modeled with simple beam models (weak formulation), referenced to rotating neutral axes. The automated modeling went well, simulation was done external to *Mathematica*. The simulation consisted of 16 coupled ordinary first order differential equations in the form:

$$A\dot{u} = f$$

where A is a full matrix and is a nonlinear function of time and the configuration coordinates. The right-hand side f is nonlinear function of time, and the coordinates and speeds of the system. Two cases were studied, with data not consistent with RMS data, in a demonstrative fashion. The system is a flexible double pendulum. Snapshots of the simulation are shown in figure 1, figure 2, and figure 3. The progression is from top to bottom than left to right. Figure 1 shows a case where the elastic motion stays within the realm of the simple beam model. Figure 2 shows the motion of the root beam in the rotating frame. Figure 3 shows a case where the elastic motion is large. The accuracy of the beam model is suspect in this case. It is presented to show the large overall motion simulation capability. Both of these cases were run on Motorolla 68040 hardware.

The fourth model was an attempt to bring a NASTRAN modal model of the beams from the model above. This work is still in progress. It is used as a building block to be able to represent the flexible continuum of any body with NASTRAN modal basis functions.

The fifth model is a three link planar system with data from the RMS. This effort is incomplete and will be used to iron out future problems. This will aid in the verification of the full flex model alluded to in the work from last year [8].

SUMMARY

This project was a continuation of an effort to enable computer assisted modeling of systems of flexible bodies. The resulting models are not restricted to linear ranges of slewing maneuvers. An automated means to write the equations of motion is nearing completion. Much progress was made during the last two summers, but much work is still needed.

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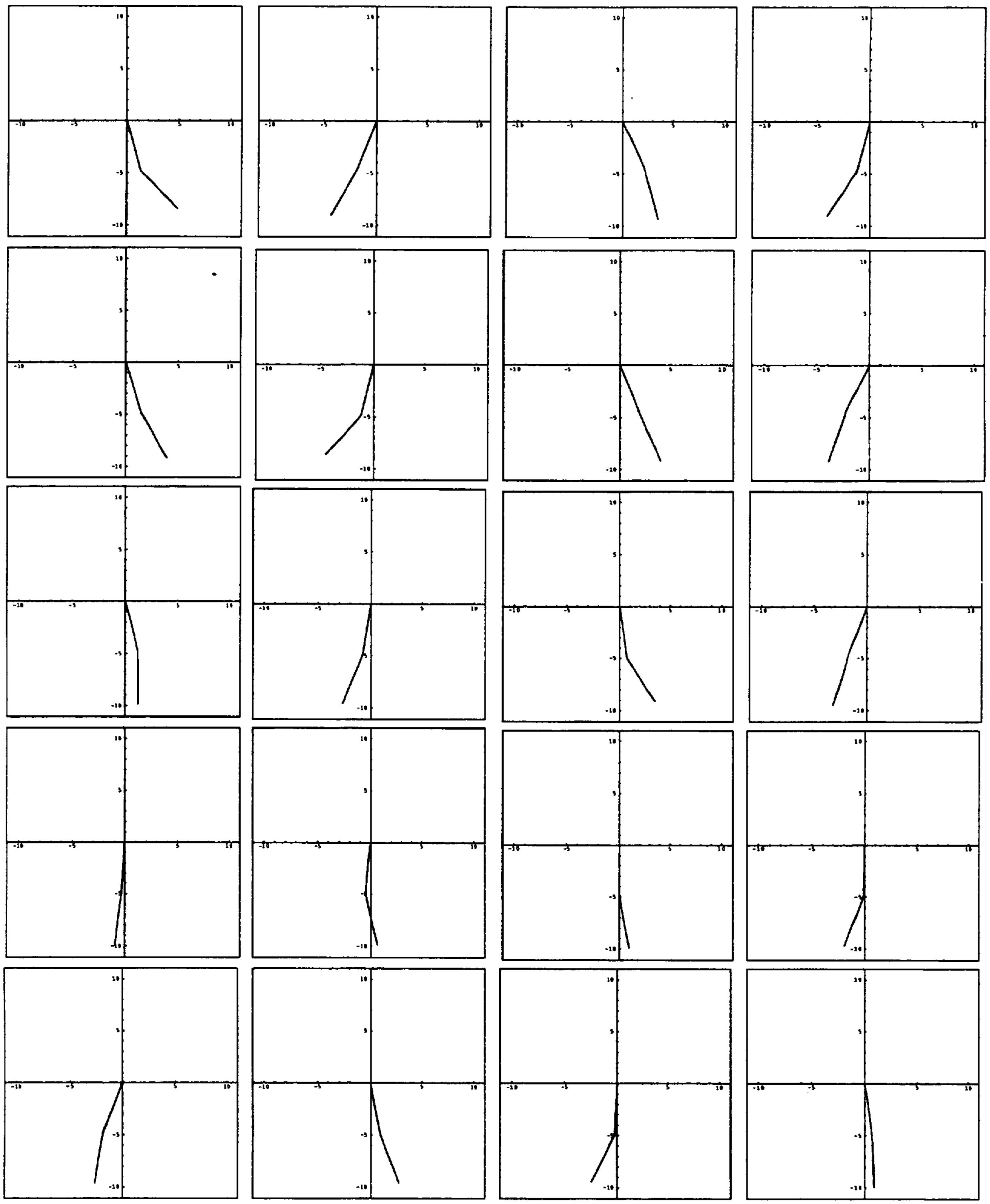

Figure 1: Two Link Flexible Manipulator–Low Elastic Energy

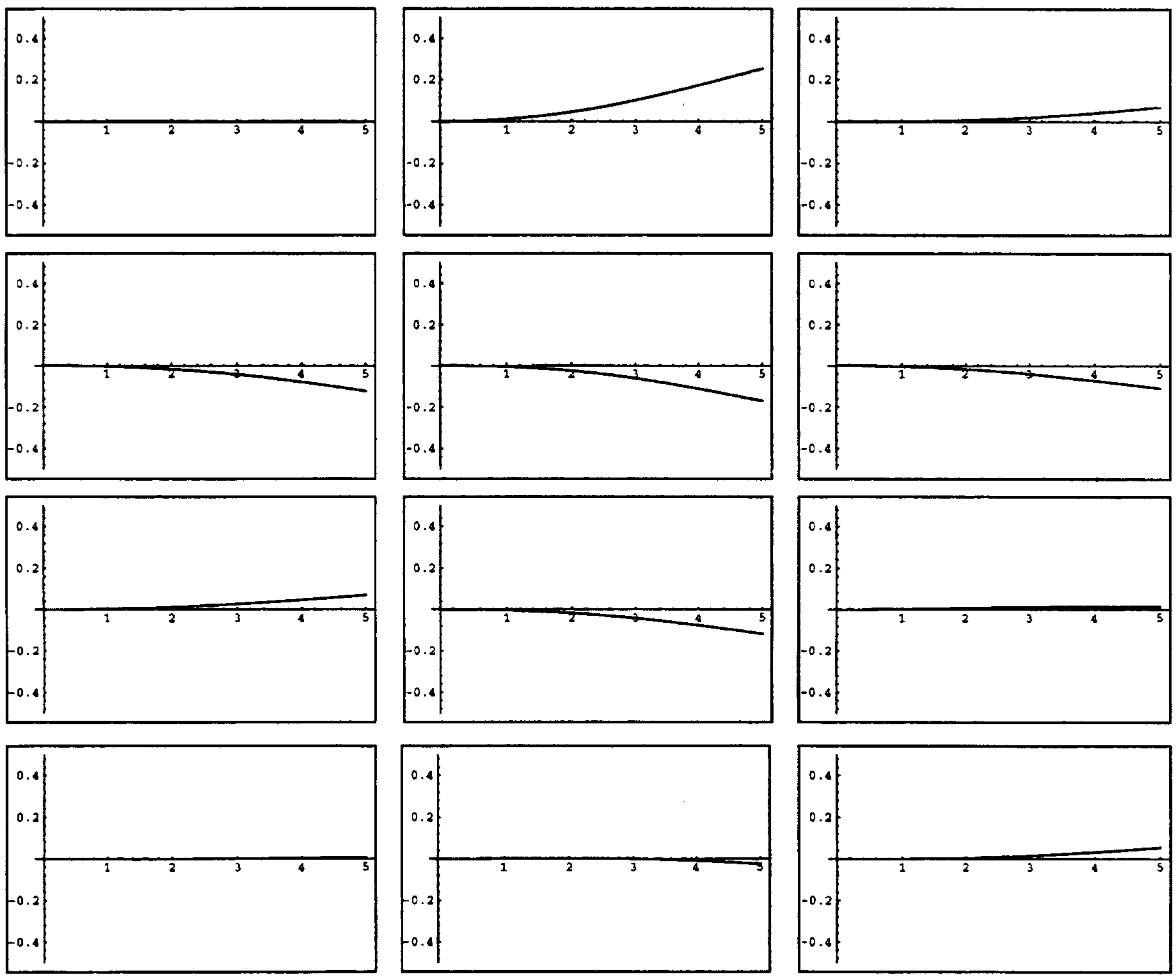

Figure 2: Base Link Flexible Motion–Low Elastic Energy

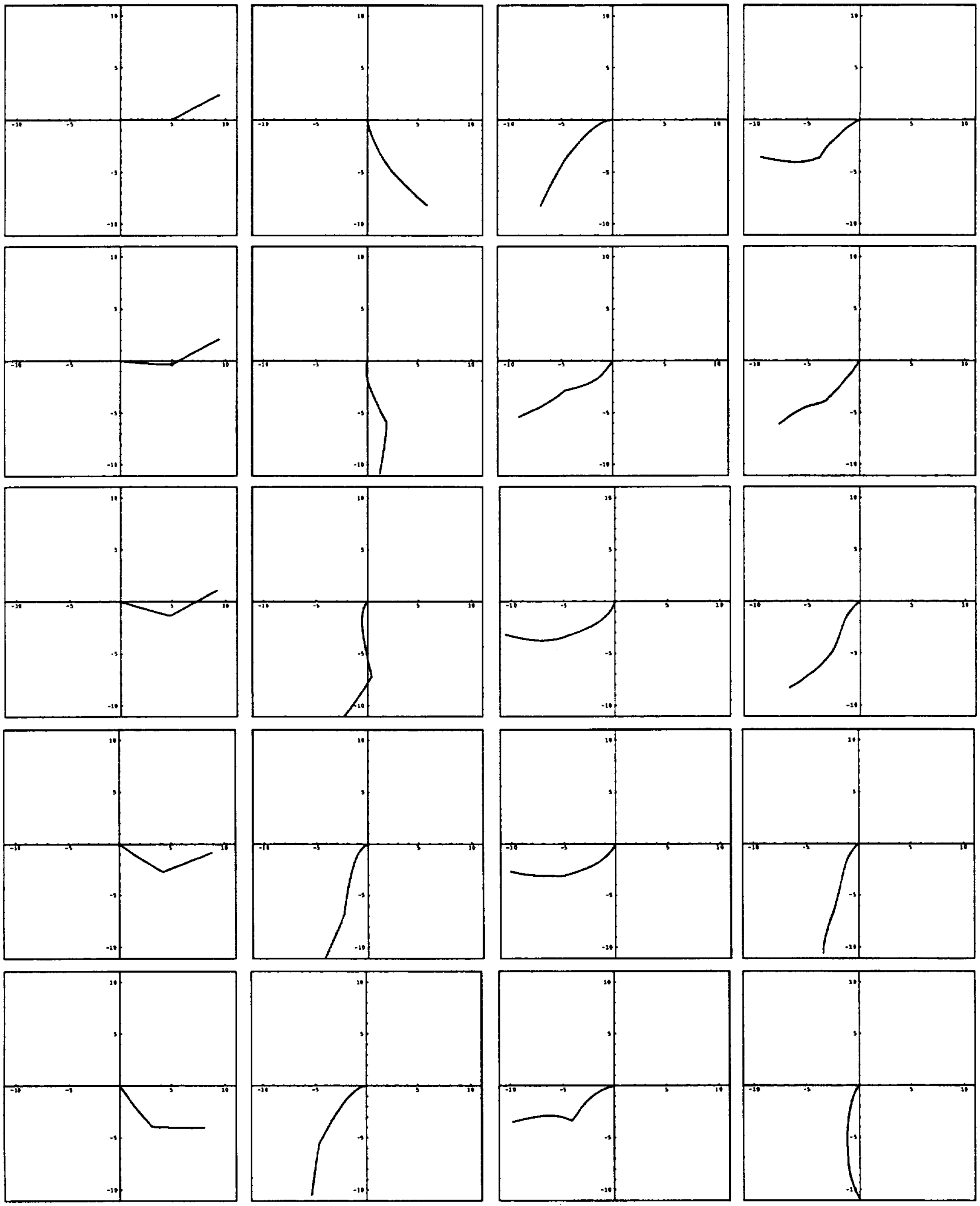

Figure 3: Two Link Flexible Manipulator–High Elastic Energy

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THE ROLE OF THE VESTIBULAR SYSTEM N MANUAL TARGET LOCALIZATION

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