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Development of a Modeling Framework to Support Control Investigations of Sailcraft Missions

A First Cut: ABLE Sailcraft Dynamics Model

Prepared By:	Dr. Sriprakash Sarathy
Academic Rank:	Associate Professor
Institution /Department:	Clark Atlanta University/ Engineering
NASA/MSFC Directorate:	Transportation (GNC)
MSFC Colleague:	Dr. Mark S. Whorton

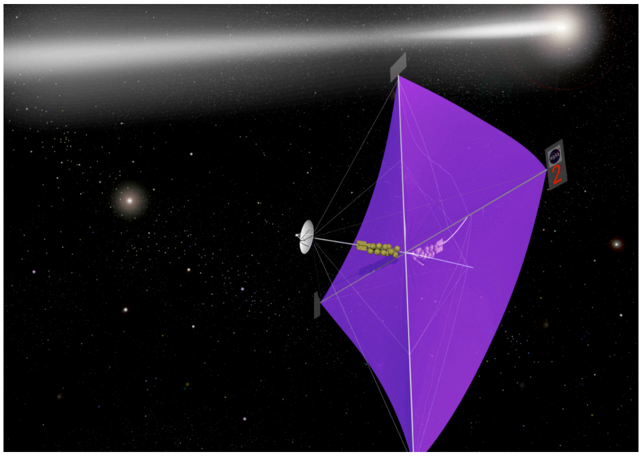


Figure 1: Artist's Depiction of Solar Sailcraft Mission

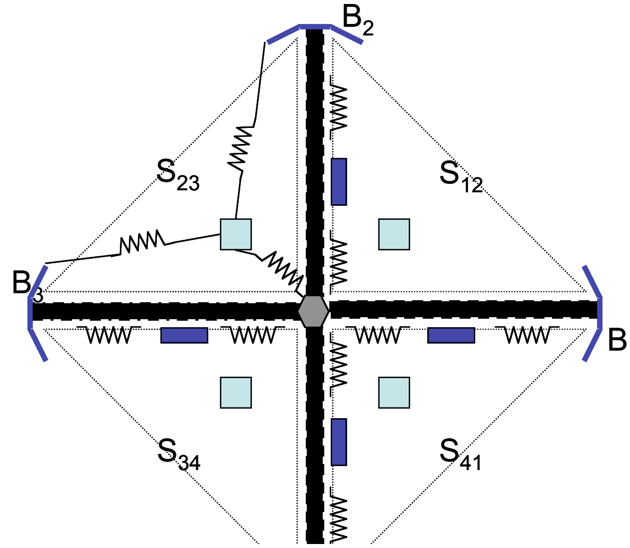


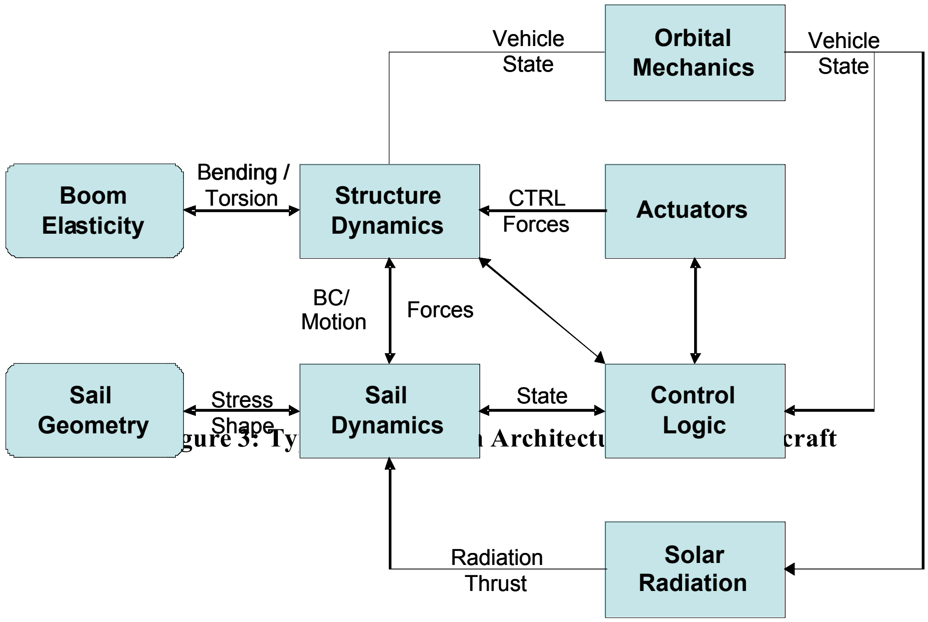
Figure 2: Example of Solar Sail Dynamic Model

Introduction

Solar Sailcraft, the stuff of dreams of the H.G. Wells generation, is now a rapidly maturing reality. The promise of unlimited propulsive power by harnessing stellar radiation is close to realization. Currently, efforts are underway to build, prototype and test two configurations. These sails are designed to meet a 20m sail requirement, under guidance of the In-Space Propulsion (ISP) technology program office at MSFC. While these sails will not “fly”, they are the first steps in improving our understanding of the processes and phenomena at work. As part of the New Millennium Program (NMP) the ST9 technology validation mission hopes to launch and fly a solar sail by 2010 or sooner.

Though the Solar Sail community has been studying and validating various concepts over two decades, it was not until recent breakthroughs in structural and material technology, has made possible to build sails that could be launched. With real sails that can be tested (albeit under “earth” conditions), the real task of engineering a viable spacecraft has finally commenced. Since it is not possible to accurately or practically recreate the actual operating conditions of the sailcraft (zero-**G** , vacuum and extremely low temperatures), much of the work has focused on developing accurate models that can be used to predict behavior in space, and for sails that are 6-10 times the size of currently existing sails. Since these models can be validated only with real test data under “**earth**” conditions, the process of modeling and the identification of uncertainty due to model assumptions and scope need to be closely considered.

Sailcraft models that exist currently, are primarily focused on detailed physical representations at the component level, these are intended to support prototyping efforts. System level models that cut across different sail configurations and control concepts while maintaining a consistent approach are non-existent. Much effort has been focused on the areas of thrust performance, solar radiation prediction, and sail membrane behavior *vis-à-vis* their reflective geometry, such as wrinkling/folding/furling as it pertains to thrust prediction. A parallel effort has been conducted on developing usable models for developing attitude control systems (ACS), for different sail configurations in different regimes. There has been very little by way of a system wide exploration of the impact of the various control schemes, thrust prediction models for different sail configurations being considered.



gure 3: Ty … Architectu … craft

The Vector Graph Object Modeling (VGOM) method offers a simple paradigm to model even complex dynamical systems using a graph-tree representation. By reducing each model to the absolute minimal set of generalized coordinates and by uncoupling any discretization and coordinatization effects, a wide variety of models can be compared and integrated. This would provide a viable framework for evaluating the impact of various choices on the system dynamics, controllability and risk associated with the sail missions.

Approach

This effort is not aimed at developing new models *per se*, rather the emphasis is on developing a way to bring in different existing models, representing them within a common framework, and being able to compare them. More important is the ability to model, not just components or sub-systems, but an entire spacecraft system. This can be achieved if *any* (physical continuous dynamic) model can be reduced to its essential elements. The graph theoretic approaches that form the basis of the VGOM, allow us to do just that. Simply put, the problem is stripped of the geometry, and specific coordinate frame information, as well as the constraints, leaving only the generalized coordinates represented on a graph through nodes and edges. Such a graph can be shown invariant to coordinate choices, nature of joint interaction models, force driver models or even motion variable choices. This is not to say that these do not affect the model, only that the ***graph*** remains the same. All the other information such as material, kinematic, geometric and constraint information, is included *after* the graph is formed. A second important advantage is that a *systems-of-systems* approach can be implemented by allowing individual sub-systems or systems to be independently modeled and integrated within this framework. This approach, while not new, is a natural extension of the VG method, and is a manifestation of the principles of *diakoptics*. This implies that, the interactions between different parts of the overall model can be explicitly identified once the sub-parts (for example see Figure 3) are defined. This is critical in managing uncertainty of the overall model, since improper modeling of the interactions between sub-parts can drastically degrade the overall model even if each of the sub-parts are accurately represented.

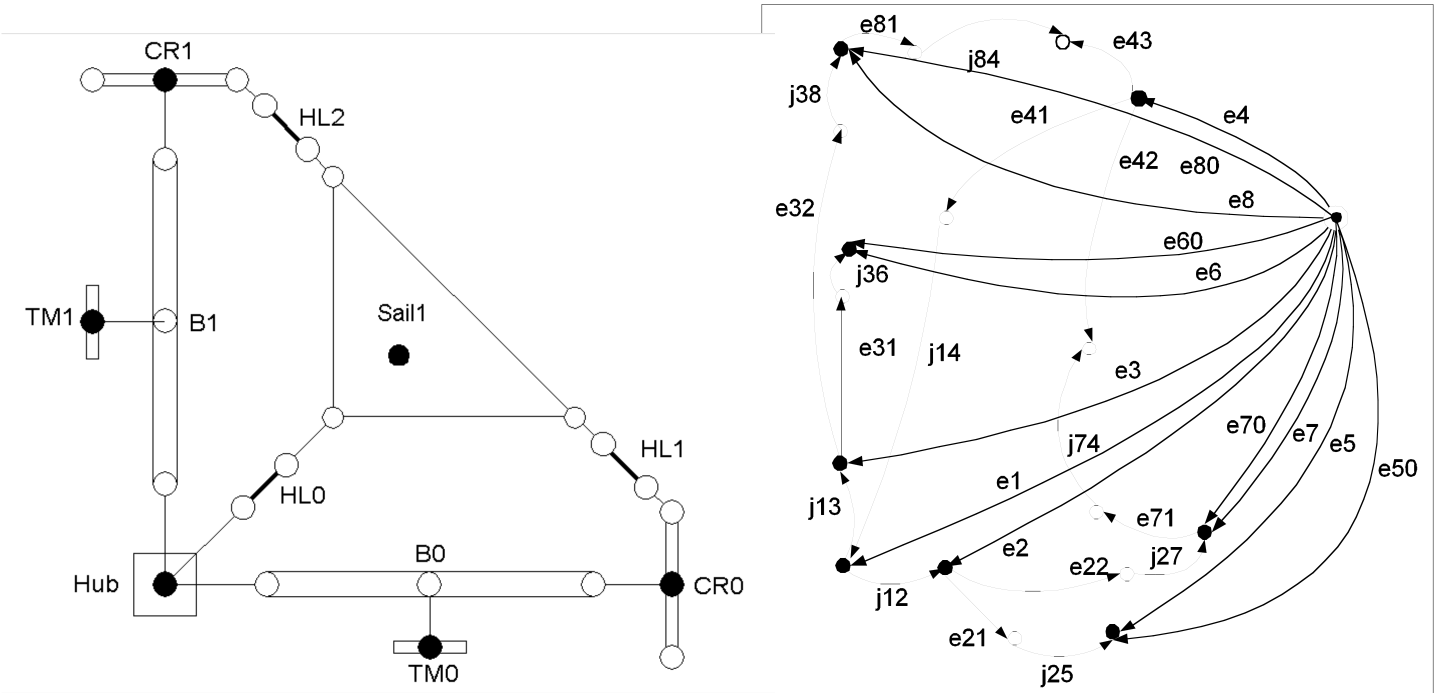


Figure 4 a & b: VGOM based Dynamics Model Development

Results and Conclusions

This approach can be best appreciated when viewing an example. For this reason a significant portion of this effort is aimed at developing a model representation of an existing sailcraft. The ABLE Engineering Inc. is one of the two vendors developing a 20m sailcraft (Figure 2). Based on the available literature, a first cut at a scalable dynamics model has been developed (Figure 4b). This system graph is obtained by following the process outlined earlier, Figure 4a shows an intermediate step that relates the physical model to the system graph. This model can be refined in a transparent manner, by changing the nature of the joint interactions, definition of the external force drivers, as well as constraints on the system. While these changes do not alter the model topology, changes in choices of generalized coordinates will result in a clear change in the system graph signaling a fundamentally different model abstraction. As this example shows, this approach is capable of modeling complex multi-body interactions. It has the capability of including flexible elements as well as arbitrary joint interactions. A MATLAB™ based toolbox is being developed to support such functionality for Solar Sails.

Acknowledgements

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