Modeling and Control of SPIDER Satellite Components

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Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Mechanical Engineering

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July 29, 2005
Blacksburg, Virginia

Keywords: membrane mirror, adaptive optic, functional gains, thin plate, smart materials, pressure augmentation, distributed control

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ABSTRACT

Space satellite technology is heading in the direction of ultra-large, lightweight structures deployable on orbit. Minimal structural mass translates into minimal launch costs, while increased satellite bus size translates into significant bandwidth improvement for both radar and optical applications. However, from a structural standpoint, these two goals are in direct conflict with one another, as large, flexible structures possess terrible dynamic properties and minimal effective bandwidth. Since the next level of research will require active dynamic analysis, vibration control, and shape morphing control of these satellites, a better-suited name for this technology is Super Precise Intelligent Deployables for Engineered Reconnaissance, or SPIDER. Unlike wisps of cobweb caught in the wind, SPIDER technology will dictate the functionality and versatility of the satellite—much like an arachnid weaving its own web.

In the present work, a rigorous mathematical framework based on distributed parameter system theory is presented in describing the dynamics of augmented membranous structures. In particular, Euler-Bernoulli beam theory and thin plate theory are used to describe the integration of piezoelectric material with membranes. In both the one and two dimensional problems, experimental validation is provided to support the developed models. Next, the linear quadratic regulator (LQR) control problem is defined from a distributed parameter systems approach, and from this formulation, the functional gains of the respective system are gleaned. The functional gains provide an intelligent mapping when designing an observer-based control system as they pinpoint important sensory information (both type and spatial location) within the structure.

Further, an experimental investigation into the dynamics of membranes stretched over shallow, air-filled cavities is presented. The presence of the air-filled cavity in close proximity to the membrane creates a distributed spring and damping effect, thus creating desirable system dynamics from an optical or radar application perspective. Finally, in

conjunction with the use of a pressurized cavity with a membrane optic, a novel basis is presented for describing incoming wavefront aberrations. The new basis, coined the clamped Zernike polynomials, provides a mapping for distributed spatial actuation of a membrane mirror that is amiable to the clamped boundary conditions of the mechanical lens. Consequently, based on the work presented here and being carried out in cooperation with the Air Force Research Laboratory Directed Energy Directorate (AFRL / DE), it is envisioned that a 1 m adaptive membrane optic is on the verge of becoming a reality.