A NEW TYPE OF SELF-RIGIDIZABLE SPACE INFLATABLE STRUCTURE

Interim Report

JPL Task 966

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A. OBJECTIVES

This research effort focuses on the development of a new type of self-rigidizable inflatable structure, called the spring-tap-reinforced (STR) aluminum laminate boom, for applications to space missions that require in-space deployment of large ultra-lightweight membrane structures.

Space-inflatable structures technology is an emerging technology that can revolutionize the design of large space-deployable systems. Many currently planned NASA missions need to use space inflatable/rigidizable structures to meet stringent launch volume and mass goals. This is especially true for missions of which the flight systems have large in-orbit configurations. Compared to mechanically-deployed structures that are traditionally used on these missions, space inflatable/rigidizable structures have many advantages, including lower mass, smaller launch volume, simpler design, higher deployment reliability, and lower life-cycle cost. In the past several years, NASA has been actively developing inflatable structures and has made significant progresses in this important technology area. However, space rigidization remains a significant obstacle that prevents inflatable structures from being implemented in near-term flight missions. Successful development of the self-rigidizable STR aluminum laminate boom can potentially meet this urgent technology challenge.

B. PROGRESS AND RESULTS

We completed in the past year the formulation and analysis of the baseline design of the STR aluminum laminate boom. Several sample booms of the baseline design, with a diameter of 3 inches and a nominal length of 5 meters, were fabricated. Figures 1 through 3 show a baseline STR boom in the stowed, deployed, and test configurations, respectively. Actual measurements of the sample booms indicated that the average weight of each boom, including two end caps, is 1.25 kg. The sample booms were subjected to a series of buckling and modal tests. The test results were used to correlate with the corresponding analytical predictions. A comparison of the dynamic analysis and test results is shown in Table 1.

During the fabrication and testing of the baseline STR booms, we observed that structural integrity of a deployed boom deteriorates over time. An investigation into this observation discovered that after the internal pressure used to deploy the boom is vented out, the aluminum laminate skin of the boom wall will undergoes stress relaxation. When the stress relaxation reaches a certain degree, the boom's cross-section will change from a circular shape to a near-square shape that has the four longitudinal spring tapes at its four corners. It was experimentally

proven that a boom with such a distorted cross section would have a substantially lower load-carrying capability. To remedy this deficiency of the baseline boom, we decided to add circumferential rings to the boom, such that the shape stability of its cross sections can be maintained (see Figure 4). The following requirements were established for the design of the circumferential rings:

1) They must be able to be flattened such that the boom can be rolled up for stowage.
2) They must be able to autonomously assume and maintain a circular shape after the boom is deployed by inflation pressure.
3) They must have sufficient stiffness in the hoop direction of the boom to resist shape changes in cross-sections of the boom.
4) They must be lightweight and not require any complicated mechanisms for deployment.

Several ring design concepts, including an extensive search of suitable materials, were developed, analyzed, and tested. The final selection is the design shown in Figures 5 and 6. This ring consists of two semi-circular halves that are connected by two hinges. The ring halves are made of high-modulus spring steel strips and the hinge material is Kevlar. Figure 7 shows the rings being installed onto the inner wall of a boom. Finite-element analyses of the modified STR boom design (i.e., the design with reinforcing rings) were performed to optimize the ring dimensions, as well as the distance between the rings. It was determined from the analysis results that a distance of 10 inches will give sufficient structural support in the hoop direction and yield an acceptable weight increase.

Three sample booms of the modified STR boom design were fabricated. Structural tests of these sample booms are currently in progress. Preliminary dynamic test results confirmed that although the modified booms are slightly heavier (1.4 kg each) than the baseline boom, their fundamental frequencies have noticeably increased (see Table 2).

We will complete the ongoing test program of the modified STR boom and perform additional structural analyses to optimize selected design features of the boom. These include the hinge design and material as well as the design of the ring/boom interfaces. We will also document for publication in open literature the design, analysis, and test results produced by this DRDF research effort.

C. SIGNIFICANCE OF RESULTS

The modification of adding circumferential rings to the STR boom design greatly improves the boom's long-term configuration stability and structural integrity. The circumferentially-reinforced boom can also carry lateral and bending loads. Preliminary analysis results indicated that the modified STR booms, even keeping the same diameter of 3 inches, could have a working length of over eight meters and, thus, a much wider range of applications. For example, the longer STR booms can potentially enable the development of a 5- to 7-meter-aperture Ka-band inflatable reflectarray antenna currently being planned by the JPL Interplanetary Network Directorate (IND).

D. FINANCIAL STATUS

The total fund for this task was$100,000, of which $$62,000 has been expended.

E. PERSONNEL

Professor Lih-Min Hsia of California State University at Los Angeles (CSULA), as well as his students Ubalso O. Quijano, Giovany A. Pelaez, and Elvis P. Garay, contributed to this effort.

F. PUBLICATIONS

1. H. Fang, M. Lou, J. Huang, L. Hsia, and G. Kerdanyan, "An Inflatable/Rigidizable Ka-Band Reflectarray Antenna", AIAA 2002-1706, *Proceedings of the 43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit,* Denver, Colorado, 22-25 April 2002.
2. H. Fang, M. Lou, J. Huang, L. Hsia, and G. Kerdanyan, "Design and Development of an Inflatable Reflectarray Antenna," *The IPN Progress Report,* Issue 42-149, May 2002. http://ipnpr.jpl.nasa.gov/
3. H. Fang, M. Lou, J. Huang, "Inflatable/Self-Rigidizable Reflectarray Antenna," *JPL IND News,* Issue 16, September 2002.
4. M. Lou, H. Fang, and L. Hsia, "Development of A New Type of Space Inflatable/Rigidizable Booms," accepted for publication by the *AIAA Journal of Spacecraft and Rockets.*

G. FIGURES AND TABLES

Fig. 1 A 5-meter STR boom stowed on a six-inch-diameter mandrel

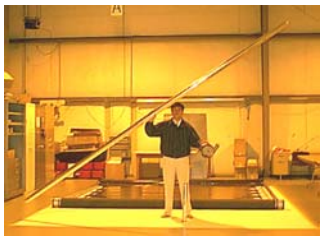

Fig. 2 A fully deployed five-meter STR boom

Fig. 3 Setup for buckling and dynamic tests

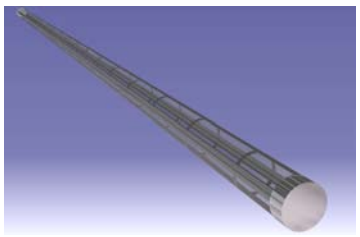

Figure 4. STR boom with circumferential rings

Fig. 5. A two semi-circular halves ring made with high-modulus spring steel strip

Fig. 6 A partially-flattened circumferential ring

Figure 7. Circumferential rings being installed onto the boom

Table 1. Comparison of dynamic test and analysis results of the baseline STR boom

	1st frequency	2nd frequency	3rd frequency
Test	1.46 Hz	11.30 Hz	34.31 Hz
Analysis	1.47 Hz	11.54 Hz	34.21 Hz
Differences	0.7%	1.3%	0.3%

Table 2. Dynamic test results of the modified STR boom

Boom #	1st frequency	2nd frequency	3rd frequency
1	1.63	11.25	32.38
2	1.63	11.00	31.56
3	1.63	11.19	32.44