EXPERIMENTAL THERMAL MECHANICS OF DEPLOYABLE BOOM STRUCTURES

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Metal ribbons are processed with a heat forming treatment that enables them to form tubelike structures when deployed from a roll. The size, thickness, perforations, metals interlocking seams, and surface coatings are designed to provide the thermal-mechanical and mechanical structural properties required for the particular spacecraft system. Over a dozen varieties of deployable booms, which range in diameter from 0.6 cm to 5 cm and in length up to 230 m, have been developed, tested, and flown. The deployable booms have been utilized for gravity gradient stabilization on the RAE, ATS, and Nimbus D satellites, and for antennas and instrument probes on the OGO, RAE, and IMP spacecraft. They will be used for instrument support structure on Apollo, Skylab, and for a space flight interferometer presently under development.

The analytic and experimental description of the mechanical behavior and thermal-mechanical behavior of a deployable boom structure has to be developed for each boom design to assure the structural performance required by the spacecraft system. The experimental mechanics and thermal-mechanics studies are conducted with short booms because of the large gravity induced effects on long booms. The anticipated behavior of the long booms on the spacecraft is then scaled from short-boom measurements using an analytic boom model. The technology developed consists of the unique apparatus for thermal distortion measurements shown in Figure 1, the calibration procedure, and all of the thermal static bending plus twist measurements.

The thermal-mechanics test facility is shown in the cutaway drawing in Figure 1. The 5-m-long, massive rigid vacuum chamber supports the 3-m boom test element from an Invar mandrel with the introduction of a minimum of thermal and mechanical background distortion. The space thermal environment is simulated with a collimated tungsten halogen solar simulator and black vacuum chamber walls cooled below -190°C. The thermal static distortion of the tip is optically measured and reported in terms of the in-sun-plane bending component, the out-of-sun-plane bending component, and the thermal static twist. The thermal static distortion values are measured as a function of boom perimeter by rotating the boom stepwise in the solar simulator field, as shown in Figures 2 and 3. The distortion values measured at each step are corrected for gravity effects and solar spectrum heating effects.

The thermal mechanics of a seamless tube has been accurately analyzed. Frequently, it is utilized to scale thermal distortion of deployable booms on spacecraft because of its simplicity. Consequently, the tip distortion of a 3-m seamless BeCu tube was measured (Figure 2), found to agree with the analysis, and used to calibrate the test facility. Heat is absorbed on the front of the tube and conducted around the perimeter to the back, which is then at a lower temperature. The thermal expansion of the front is greater than that of the back and causes the in-sun-plane bending. The thermal expansion is equal on each side of the tube; thus, neither out-of-sun-plane bending nor thermal static twist is observed.

The advantages of reduced in-sun-plane bending and thermal static twist provided by the perforated, interlocked Westinghouse boom over the original BeCu overlap STEM are shown in Figure 3. The thermal distortions of the 3-m overlap STEM show large in-sun-plane bending, out-of-sun-plane bending, and large thermal static twist. The out-of-sun-plane bending results primarily from differences between the thermal expansions on either side of the sun plane. The large thermal static twist is characteristic of the overlap element and was predicted by H. Frisch's analysis, presented in the 1969 Science and Technology Review. The perforations and the thermal coatings on the Westinghouse boom are designed to produce a minimum of in-sun-plane bending by obtaining approximately equal heat absorption and equal thermal expansion on both the front and back of the boom. The interlocking seam provides larger torsional stiffness to reduce the thermal static twist.

Table 1 shows several examples of spacecraft applications of thermal static distortion measurements on 3-m deployable booms. Thermal static twist measurements on a 5-cm silver-plated Bi-STEM for Apollo 15 showed that it would twist through a much greater angle than the required ±15-deg. Measurements on the full scale 7.5-m Bi-STEM at NASA–Manned Spacecraft Center showed a 40-deg twist. Design changes will be made to correct the problem. Thermal static distortion tests on 1.8-cm-diameter interlocked and overlap booms for Nimbus D showed essentially no thermal static twist for the interlocked boom and provided an accurate measure of the thermal static bending. These measurements, along with the spacecraft stability calculations, led to the selection of the interlocked boom for the flight spacecraft. Several designs of the 1.2-cm perforated, interlocked Bi-STEM boom have been tested to develop a flight boom with minimum in-sun-plane bending for a Navy satellite. At present, several deployable boom elements are being tested to optimize the ATS F and ATS G antenna rib design for minimum thermal distortion.

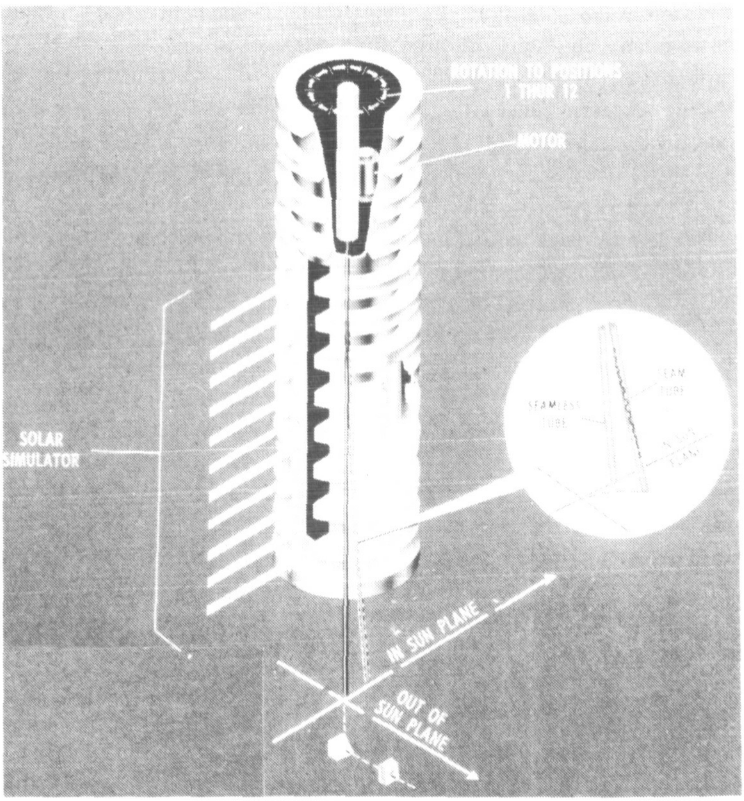

Figure 1–Diagram of the thermomechanical test facility for thermal distortion measurements on the 3-m deployable boom elements.

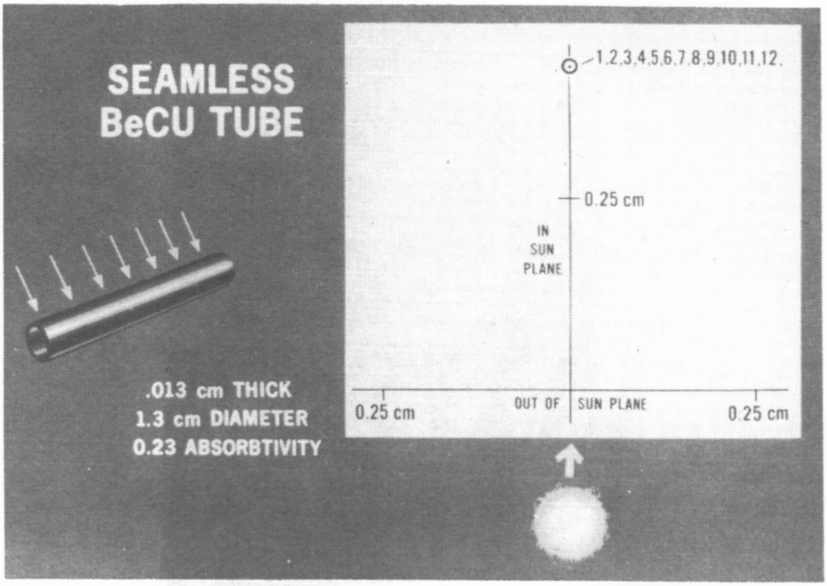

Figure 2–Thermal static bending.

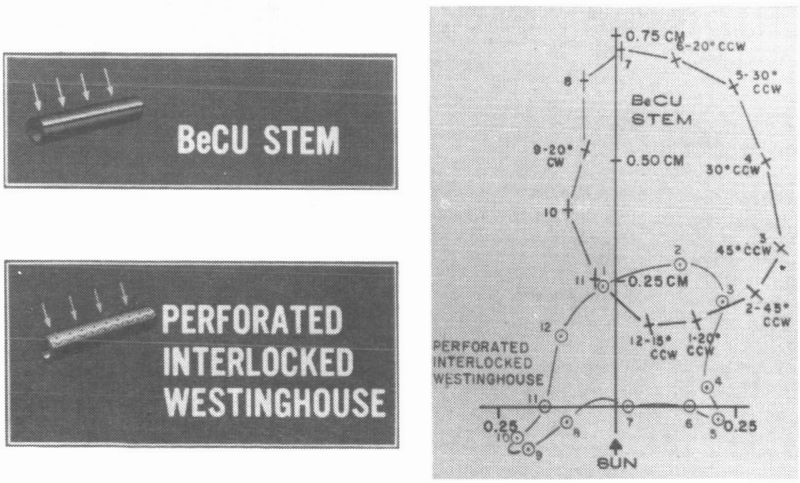

Figure 3–Thermal static bending and twist of the BeCu stem and the perforated interlocked Westinghouse booms.

Table 1 – Applications of thermal static distortion measurements.

DEPLOYABLE BOOM	PROGRAM	STRUCTURAL REQUIREMENTS	EXPERIMENTAL RESULTS	REMARKS
Ag 5 cm BI-STEM	APOLLO 	SUPPORT AND POINT MASS SPECTROMETER $\pm 15°$	THE BOOM WAS CLAMPED-SEMIFREE WITH ANTICIPATED THERMAL STATIC TWIST $\pm 30°$	FULL SCALE TEST IN MSC SES CHAMBER - DIRECT MEASURE OF WORST CASE TWIST
1.8 cm Intlk BeCu ALLOY OVERLAP	NIMBUS-D 	GRAVITY GRADIENT WITH TIP DEFLECTION LESS THAN 30 cm	SHOWED INTERLOCKED BOOM TO HAVE NO TWIST AND 25 cm THERMAL STATIC BENDING	
1.2 cm Perf.-Intlk BI-STEM	NAVY 	GRAVITY GRADIENT STABILIZATION	SHOWED THERMAL BENDING TO BE MINIMUM FOR DEVELOPMENT BOOM	BOOM DESIGN SELECTED FROM TEST BOOMS
9.14 meter Antenna RIB	ATS F&G 	ANTENNA RIB DESIGN	SELECT PERFORATION PATTERN AND THERMAL COATING FOR MINIMUM BENDING AND TWIST	FUTURE WORK