Unique Mechanism Features of ATS Stabilization Boom Packages*

R. A. Lohnes and D. N. Matteo
General Electric Company
Valley Forge Space Technology Center
King of Prussia, Pennsylvania

E. R. Grimshaw
SPAR Aerospace Products, Ltd.
Toronto, Canada

This paper describes the unique mechanism of the motorized primary boom packages and the damper-borne self-erecting secondary boom package utilized on the Applications Technology Satellite (ATS) gravity-gradient experiment. The spacecraft failed to achieve the required orbit, but the mechanism performed as planned.

I. Introduction

In April 1967, NASA placed in orbit the ATS-2, a gravity-gradient-stabilized satellite that was the second of a series of spacecraft known as *Applications Technology Satellites*. A primary purpose of the ATS series is to evaluate the characteristics of gravity-gradient stabilization as a means of satellite attitude control.

Gravity-gradient satellite attitude control makes use of the differences in gravitational forces acting on the distributed masses of the primary stabilization booms to maintain a constant attitude with respect to earth. Gravity-gradient stabilization is possible only if existing oscillatory motions of a spacecraft can be damped out by some form of energy dissipation.

The ATS-2 (Fig. 1) medium-altitude spacecraft attained a highly elliptical orbit, instead of the planned circular orbit. Accordingly, gravity-gradient stabilization was precluded. Nevertheless, the mechanisms described in this paper functioned successfully in orbit.

The General Electric Company (GE) designed the gravity-gradient stabilization systems for this series of experimental satellites. Each system utilizes four 132-ft primary gravity-gradient booms (deployed in the form of an X) rigidly attached to the satellite, as well as a secondary, or damping, boom (consisting of two 45-ft collinear rods) coupled to a damping mechanism and a torsional spring.

*This work was performed by the General Electric Company for the NASA Goddard Space Flight Center under Contract No. NAS5-9042.

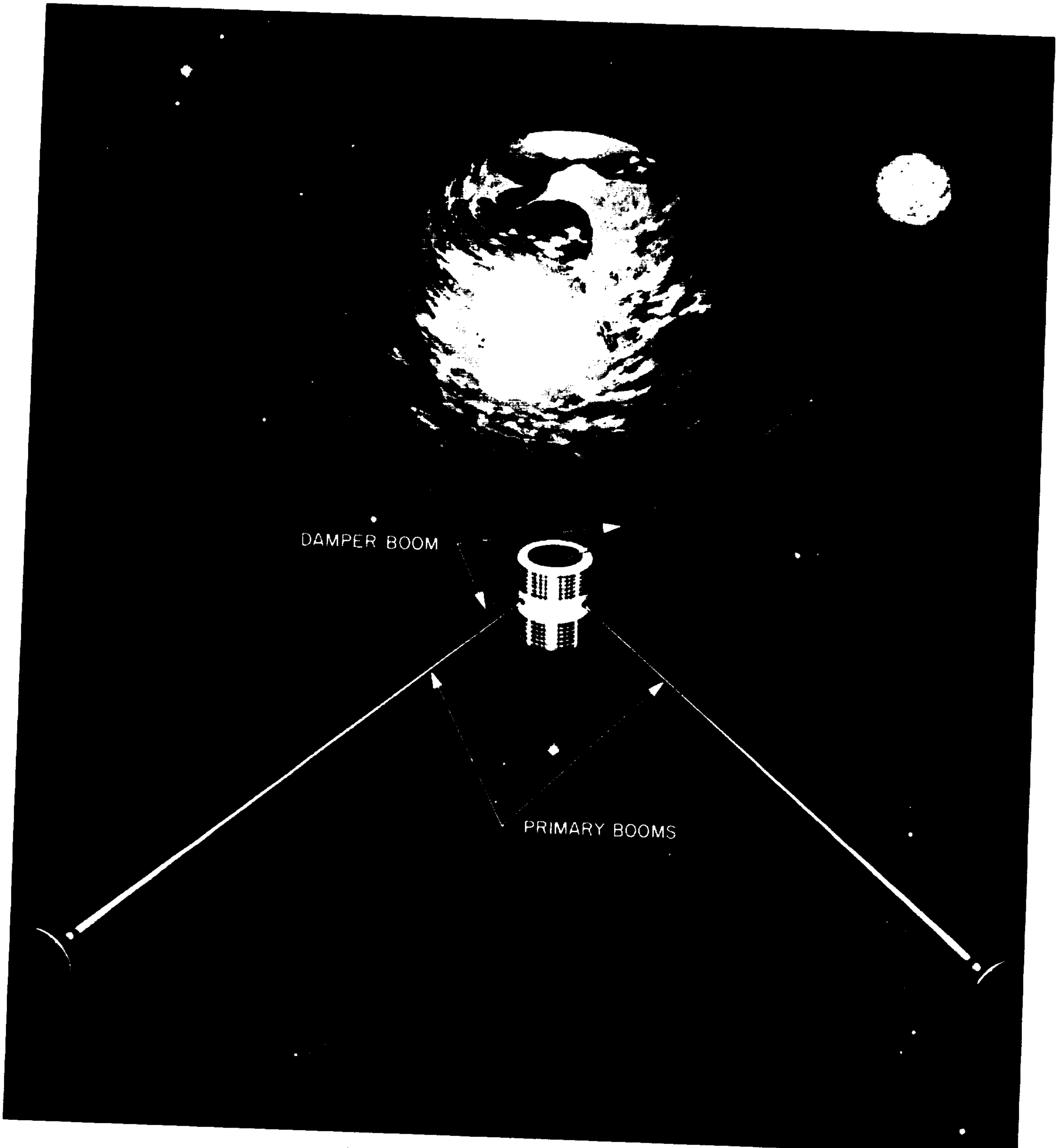

Fig. 1. Artist's conception of the gravity-gradient-stabilized ATS, with booms deployed

The components that deploy both the primary and damper booms were provided by deHavilland Aircraft of Canada, Ltd., Special Products & Applied Research (SPAR) Division (now SPAR Aerospace Products, Ltd.) under a subcontract to the General Electric Company. The basic extendible boom selected for this mission is the storable tubular extendible member (STEM).[1] The STEM technique involves the formation of a tubular section from a flat metal strip which is formed and heat-treated in the tubular form, then flattened under stress and wound onto a storage drum. Subsequent erection in orbit is accomplished by paying out the stowed strip through a set of guides that allow the boom to form into its natural tubular shape. The edges of the metal strip overlap each other to render stiffness to the deployed section.

II. Primary Boom Packages

Each gravity-gradient experiment contains two primary boom half-systems (Fig. 2). To provide boom extension, retraction, and angular variation capability after injection into orbit, each half-system employs two separate motors: one to drive the storage drums and one to scissor the erection units that contain the storage drums.

In addition to storing, guiding, and electrically isolating the booms, the erection units provide a means of caging the tip masses, which are installed at the boom tips, to achieve a prescribed set of inertias about the principal axes of the spacecraft. The pair of erection units in each half-system, their associated drive train, motors, and scissoring linkage are all mounted within the single framework shown in Fig. 2. The erection units are pivoted to this framework. Motion between the two half-systems is coordinated electrically.

A. Torque Transmission

Each half-system is equipped with one transmission unit, which provides the torque required by the scissors bell-crank and the deployment gear train. Each transmission unit contains two brush-type dc motors, one for boom extension drive (via gear train) and one for scissors

[1]STEM is a trade name for these deployable booms (see Ref. 1).

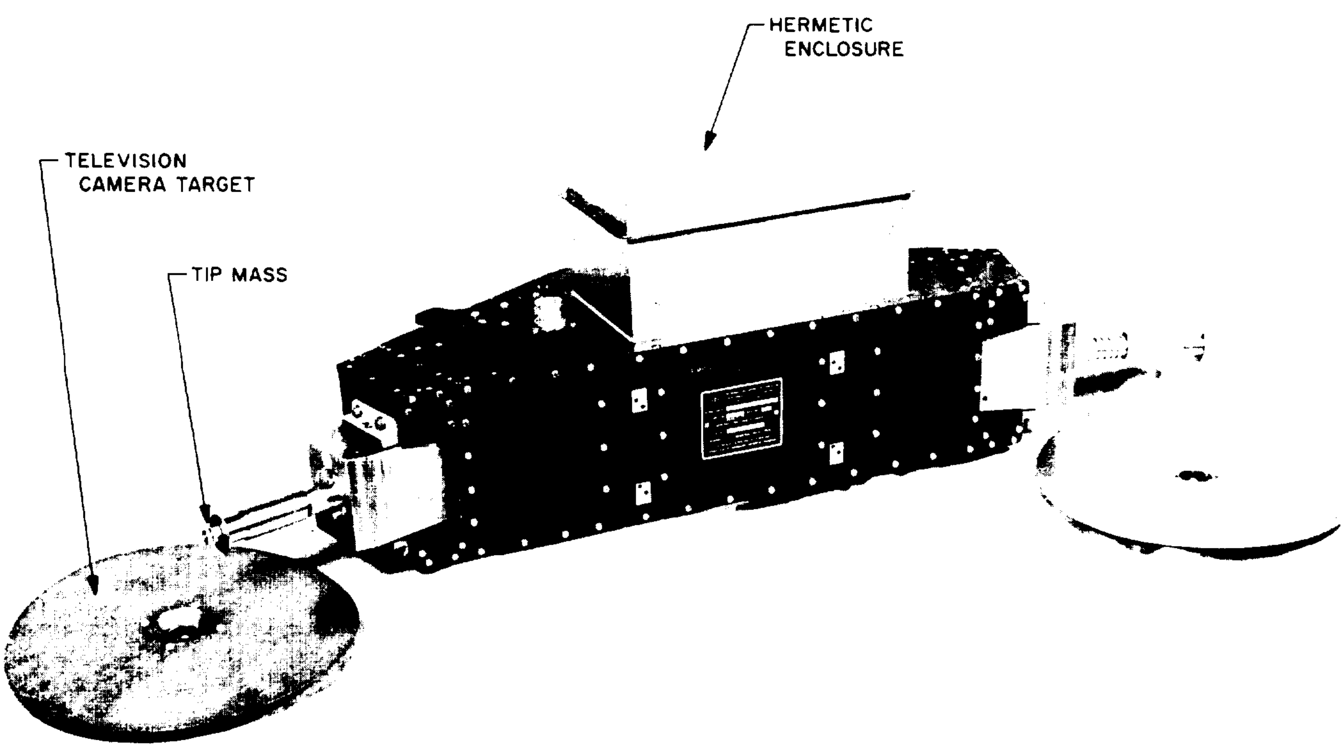

Fig. 2. Primary boom package. The television camera targets, also shown on the deployed booms in Fig. 1, were provided to allow a camera in the satellite to record the boom deployment configuration

drive (via bell-crank linkage). The scissors drive motor is equipped with an integral gear reducer to reduce the speed to that required for a proper scissoring rate.

The transmission unit enclosure confines the motors and drive trains in a vacuum-tight envelope to preserve their useful life in space and uses beryllium copper bellows-type couplings to deliver both the extension and scissor torques through the pressure-tight shell. Two drive shafts protrude from the enclosure: one for the deployment gear train and one for the scissors bell-crank.

The output drive shaft for the deployment gear train is collinear with the input shaft that is within the hermetic enclosure. The rotary motion of the eccentric input shaft within the "wobble" bellows (Fig. 3) provides the necessary external torque for primary boom deployment.

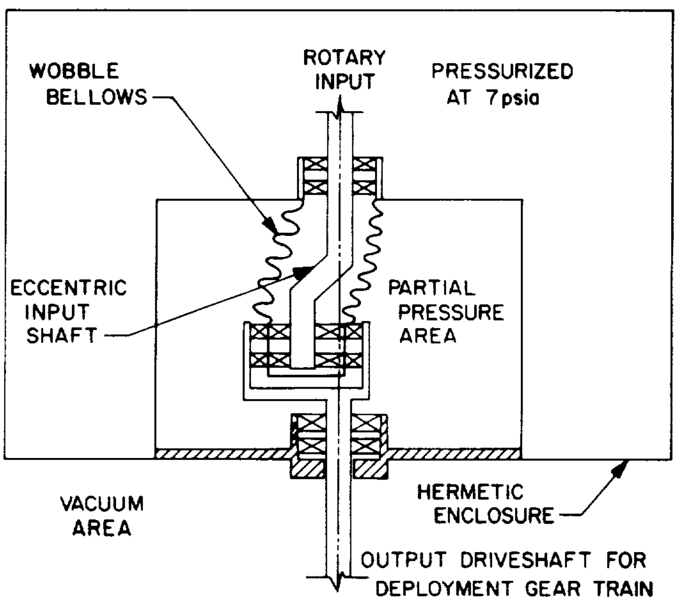

Fig. 3. Bellows drive mechanism

The scissoring output drive shaft is connected to the scissors bell-crank, which transmits linear push-pull motion through a pair of compression bellows (Fig. 4) to provide the required torques to the scissor plates attached to each erection unit.

B. Drum Synchronization

The primary boom erection units require externally applied torque at the boom storage drums for deployment. This torque is provided by a train of four gears in each half-system. One of the center gears of this train is

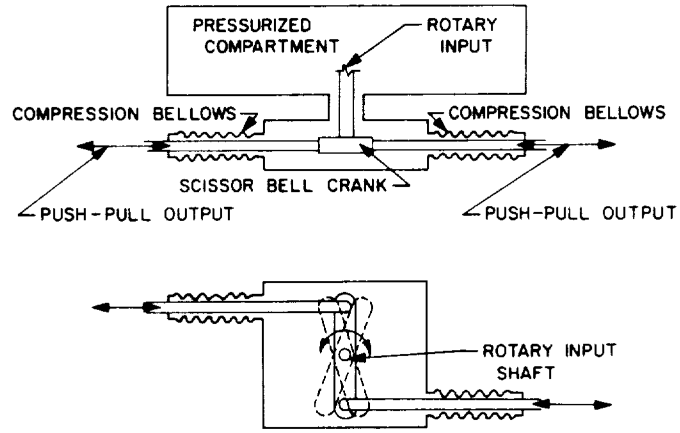

Fig. 4. Scissor drive mechanism

driven by the output drive shaft from the transmission unit. This gear, in turn, drives the boom storage drum of one erection unit directly and drives the boom storage drum of the second erection unit by means of an idler gear. Thus both erection units are driven by a single motor, and their drum rotations are mechanically synchronized by the gear train.

The center of the erection unit drive gear is concentric with the axes about which the erection units are pivoted, to allow the gear train to remain engaged during scissoring motion.

C. Electrical Isolation

An ATS spacecraft experiment required dc electrical isolation of the primary booms from the spacecraft and required that the capacitance between the boom and the spacecraft be reduced to a minimum. The following parts were made of polycarbonate materials to accomplish the required electrical isolation:

(1) Drive gears internal to the erection units connecting to the storage drum.

(2) Drive gears external to the hermetic enclosure connecting with the erection unit.

(3) Support standoff rings between the scissor plates and each associated erection unit.

(4) Support housings for the erection unit flexure pivots.

III. Secondary Boom Package

Each gravity-gradient-stabilized spacecraft incorporates one self-erecting secondary boom package. This unit is different from the primary boom system in that it uses the strain energy in the stowed metal strip to rotate the storage drums contained in the boom tip masses and, thus, erect the booms. The tip masses (required to provide prescribed inertias for spacecraft damping) on this package are, in actuality, the erection units; they store and guide the booms and they can be caged to a center body section. The center section is mounted on the damper portion of the GE-constructed combination passive damper (CPD) (Ref. 2).

The two damper-borne secondary booms extend along the same straight line in opposite directions, and their tip masses provide the proper inertia for the operation of the damper. In addition to the main assembly containing the booms, the secondary package includes a separate housing that contains the explosive portion of the tip mass release system (Fig. 5).

A. Tip Mass Caging

A ball-lock mechanism, lever arm, electroexplosive cartridge, and mechanical linear actuator combination are used for the damper-boom tip-mass release system. The linear actuator and lever arm are mounted in a separate actuator assembly on the base plate of the CPD.

The receptacles at the ends of the ball-lock mechanism (Fig. 6) provide the coupling between the tip mass and the center body when the damper boom is in the stowed position. The plunger movement is initiated by either or both of the electroexplosive squib–linear actuator devices,

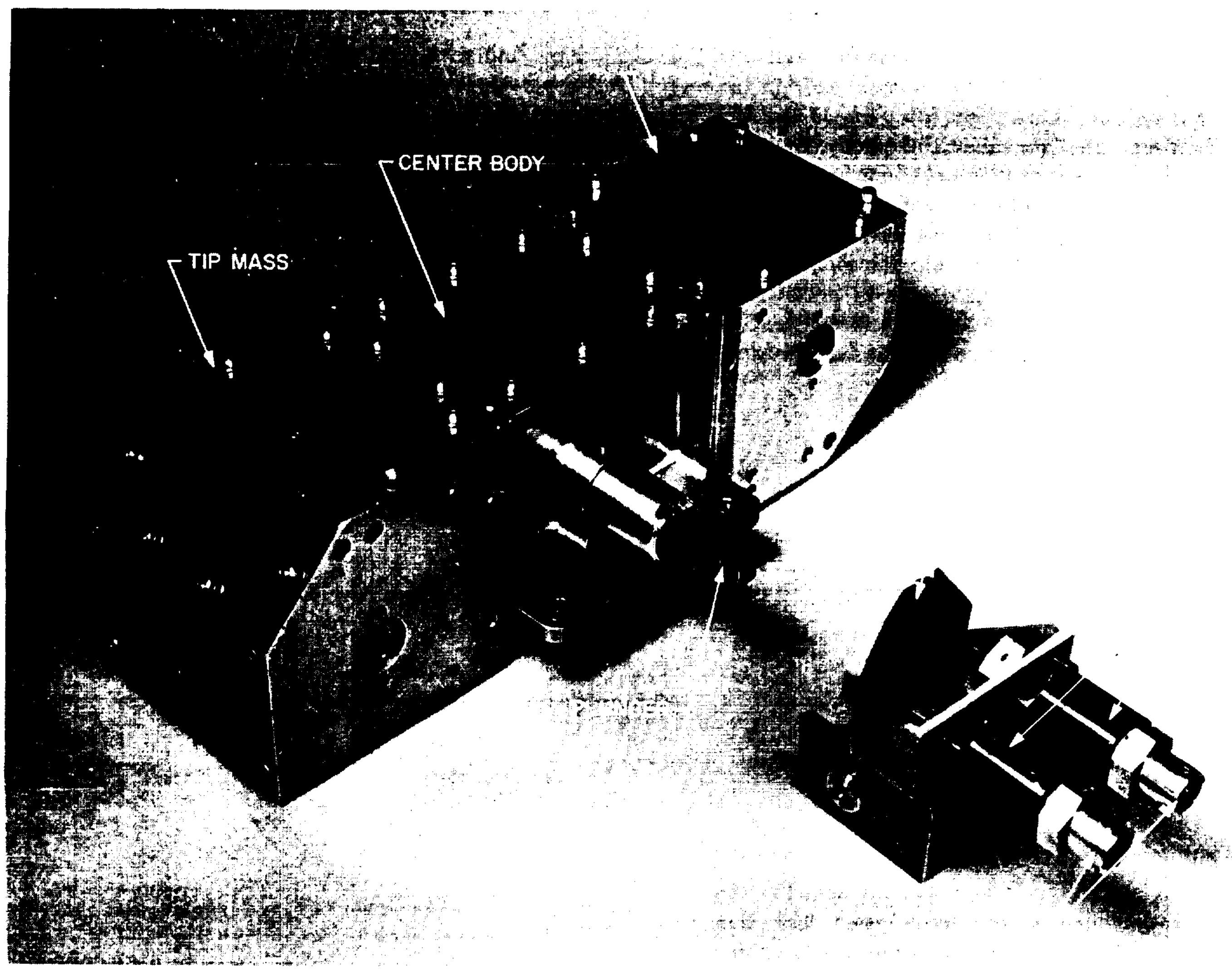

Fig. 5. Damper boom package

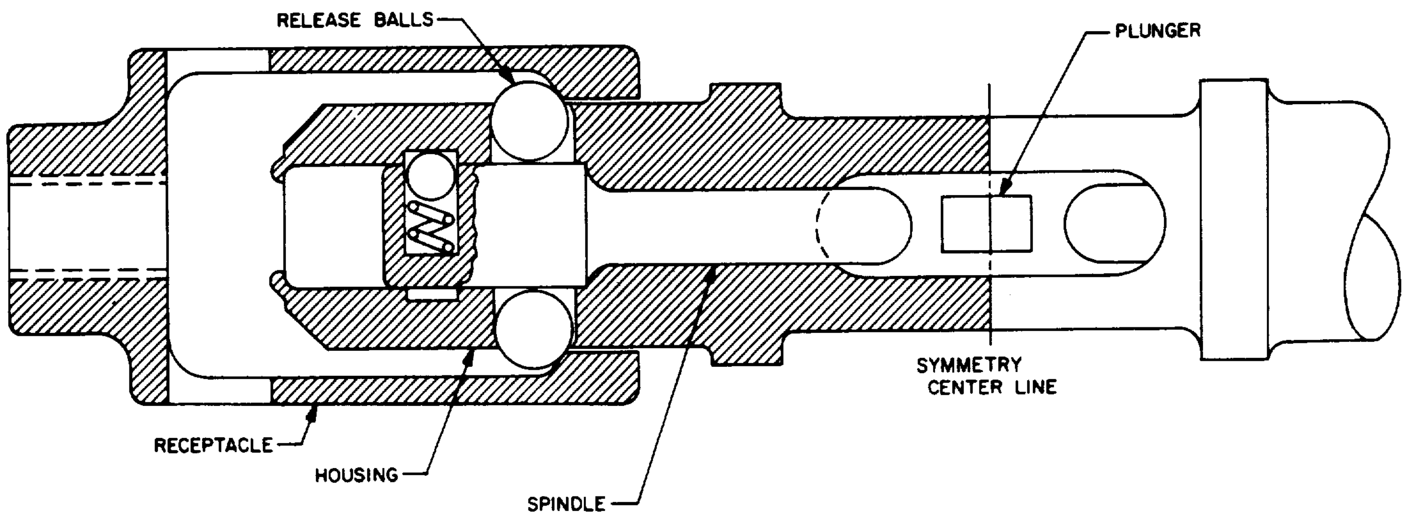

Fig. 6. Ball-lock mechanism

thus depressing the plunger and making contact with the two spindles which permit the release balls to depress inside the housing and release the receptacles. The tip mass then separates from the center body. In the actual system, the end of each boom element is secured to the center body. A liftoff spring at the end of the center body (Fig. 7) provides the initial separation force for the tip mass, and guide pins ensure coaxial separation. Then, the elastically wound boom begins to erect itself and continues to propel the tip assembly to full length. The tip assembly is restrained at the end of the fully erected boom.

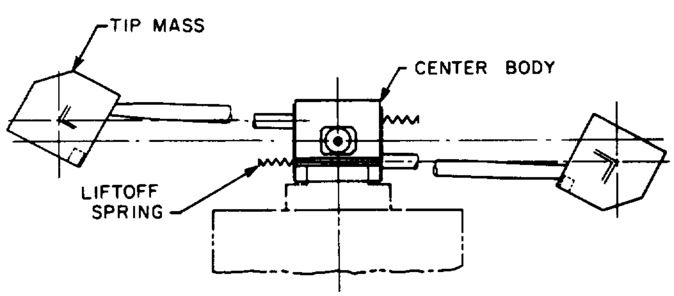

Fig. 7. Damper boom coaxial separation, showing deployment of booms

B. Centrifugal Governor

A governor is used to limit the maximum speed of the self-energized deployment to a speed less than that which would cause failure upon the abrupt stop of the tip mass at the end of deployment. (The specified deployment speed is 1.8 ±0.8 ft/s, or a maximum of 2.6 ft/s. Failure due to the stopping of the tip mass at full deployment would occur at speeds above 4 ft/s.) It has been shown (Ref. 3) that the deployment rate of ungoverned self-erecting booms of this type will continue to increase as a function of deployed length, and the maximum length is, therefore, limited by boom strength and mass at the tip.

The governor consists of two diametrically opposed brake shoes, as sketched in Fig. 8, mounted in the tip mass assembly. The brake pivot points are fixed to the boom storage drum. Each of two brake shoes is hinged

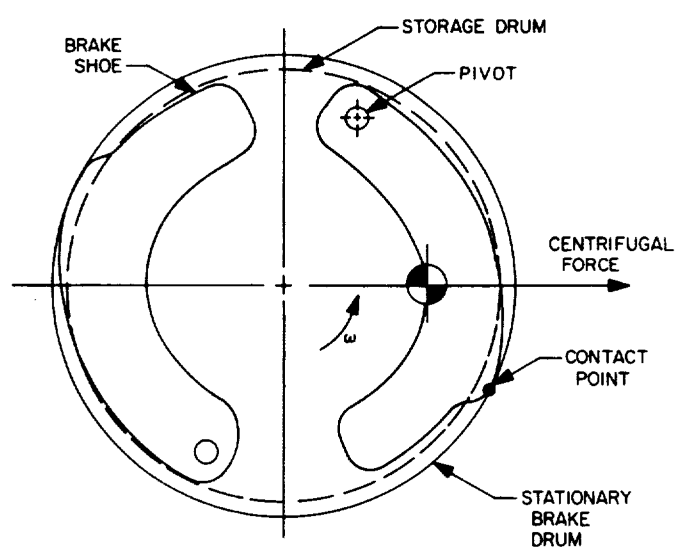

Fig. 8. Damper boom centrifugal governor (ω = angular change)

at the pivot and rotates into contact with the stationary brake drum under the influence of centrifugal force. Upon tip mass release, the drums are free to rotate, and they are propelled by the self-erecting tendency of the strain energy in the booms. The frictional torques developed by the brake and transmitted to the drum via the pivot pins is a function of drum rotation rate. Equilibrium will be established when the brake torque and losses are equal to the torque produced by release of strain energy.

Because the brake is symmetrical, the net frictional torque developed by the brake is the same as that which would be developed in the absence of the 1-g environment. The effect of earth's gravity during testing is a sinusoidal variation from $+1$ to -1 g on each brake shoe, about a mean value of 1.8 g. The two brake shoes of each tip mass assembly experience this sinusoidal variation exactly 180 deg out of phase with each other, and the net effect of gravity cancels out. At no time during the drum rotation (at constant speed) does either brake shoe experience a negative acceleration with respect to the brake drum (i.e., either centripetal or gravitational acceleration).

IV. Preparation for Space Operation

A. Gear and Bearing Lubrication

The boom subsystem design involves certain gears and bearings which will be at least partially exposed to the space vacuum and will be expected to operate after a long period of such exposure to the hard vacuum in orbit. In the primary boom half-systems, the bearings that are directly exposed to the space vacuum contain Duroid 5813 retainers.[2] The secondary package bearings exposed to the space vacuum contain GE F50 oil but are required to operate only once while in the space vacuum. Primary package transmission unit bearings, which are in the partial pressure area, contain a combination of GE Versilube G300 grease and F50 oil. Bearings inside the hermetic enclosure of the primary boom half-systems contain a combination of G300 grease and F50 oil.

The gears outside the primary package hermetic enclosure, as mentioned previously, are of polycarbonate materials and no lubrication is added. The gears inside the hermetic enclosure are lubricated with G300 grease. The high-speed spiroid in the extension drive train has an MoS_2 dry lubricant mixed with the G300 grease for adherence purposes. The secondary boom package contains no gears.

B. Deployment Tests

The gravity-gradient booms are designed for weightless deployment in space. Accordingly, deploying the booms in the 1-g terrestrial environment requires certain special test equipment to avoid damage to the booms resulting from their own weight. Full-length deployment of the stored boom element necessitates either a full-length test track or a coordinated takeup mechanism.

The self-erecting nature of the secondary boom package precluded use of a takeup mechanism for its deployment. The configuration of the primary boom half-system coordinated pair of erected booms and their extended lengths precluded utilization of two full-length test tracks for their deployment. The resultant facility for deployment tests (Fig. 9) consists of a fixed, 150-ft-long, channel-shaped track and a movable, 10-ft channel-shaped track, angularly positioned about a support pedestal for compatibility with the half-system configuration and its scissoring requirement.

Testing of the primary boom package is accomplished by mounting the unit on the support pedestal and aligning the booms to lie in the center of the test tracks. The end of the boom lying in the long test track is attached to its tip mass, which, in turn, is supported by a deployment trolley on wheels. The end of the boom lying in the short test track is attached to a takeup mechanism on wheels. To minimize friction and boom plating damage during the motorized deployment testing of the primary boom units, the bottom of the channel test track is lined with Teflon. All trolley and takeup mechanism wheels are mounted on ball bearings to reduce friction.

Testing of the secondary boom package is accomplished by mounting the unit in the center of the long test track with deployment trolleys on wheels attached to each tip mass.

Unlocking the ball-lock assembly results in release and launch of the tip mass erection units. As soon as the tip mass kickoff is initiated, the offset tip mass centers of gravity cause rotation of the tip mass about the storage drum support axis (Fig. 7). This oscillation and its resultant boom damage is minimized by incorporating hydraulic oscillation dampers attached to tip mass counterbalance arms on the outboard ends of the tip masses.

[2]An MoS_2-impregnated material, 60% Teflon and 40% glass fibers.

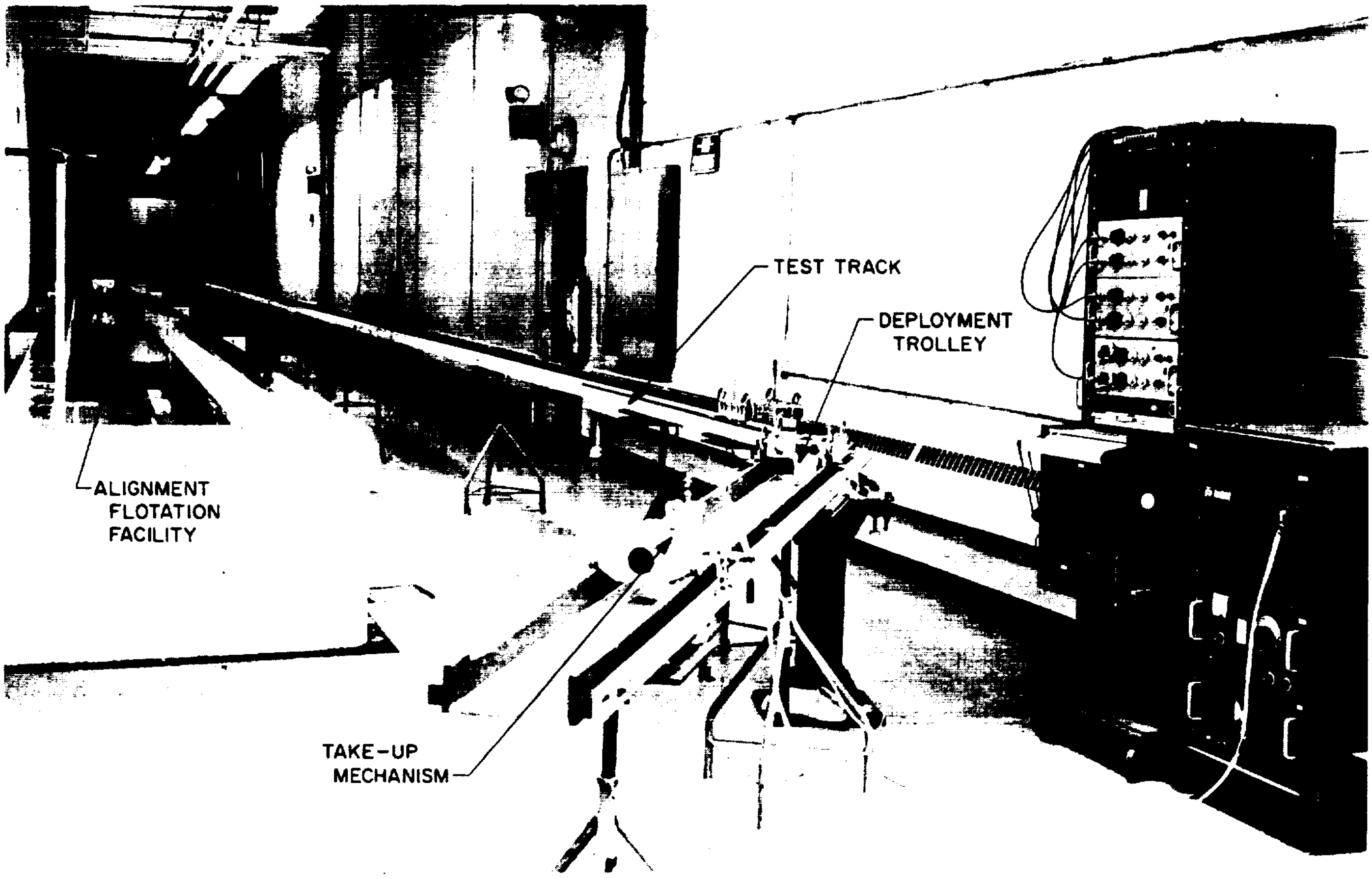

Fig. 9. Boom deployment test track. The alignment flotation facility was not used in the tests described in this paper

V. Flight Performance and Current Status

Although ATS-2 attained a highly elliptical orbit, instead of the planned, medium-altitude circular orbit, all the primary and secondary booms uncaged and extended to full length upon command. Subsequent scissor operations of the primary booms to both extreme limits were accomplished successfully – one 4 months after launch, the other 6 months after launch.

During October 1967, ATS-2 spacecraft power was reduced to a minimum and monitoring was halted for the time, since the ground equipment was needed to cover the ATS-3 launch. Concentration on spin-stabilized ATS-3 has precluded further monitoring to date on ATS-2. Just prior to power reduction, telemetry data indicated no significant degradation in initial hermetic enclosure pressure, primary boom package electrical isolation, or secondary boom package mechanical isolation.

Both the primary and secondary boom packages have passed qualification test programs in both the medium and synchronous altitude configurations, and vibration levels greater than 18 g were sustained by these configurations during qualification. The next gravity-gradient ATS spacecraft to be launched will be designed for synchronous altitude. The main difference in the two configurations is the weight of the tip masses; the synchronous weight is approximately three times that of the medium-altitude weight. Thus the tip mass weight for the primary booms at medium altitude configuration is 2.5 lb each, and, at synchronous altitude configuration, 8 lb each. Comparable tip mass weights for the damper booms are 1.6 and 4.06 lb each.

References

1. MacNaughton, J. D., Weyman, H. N., and Groskopfs, E., "The BI-STEM – A New Technique in Unfurlable Structures," in *Proceedings of the 2nd Aerospace Mechanisms Symposium, Held at the University of Santa Clara, Santa Clara, California, May 4–5, 1967*, Technical Memorandum 33-355, pp. 139–145. Edited by G. G. Herzl. Jet Propulsion Laboratory, Pasadena, California, Aug. 15, 1967.

2. Buerger, E. J., "Development of a Passive Damper for a Gravity Gradient Stabilized Spacecraft," in *Proceedings of the First Aerospace Mechanisms Symposium, Held at the University of Santa Clara, Santa Clara, California, May 19–20, 1966*, AD 638 916, pp. 297–309. Edited by G. G. Herzl. Defense Documentation Center, 1966.

3. Rimrott, F. P. J., "Storable Tubular Extendible Member – A Unique Machine Element," *Machine Des.*, Dec. 9, 1965.

198