

THE MAGSAT MAGNETOMETER BOOM SYSTEM

The boom connecting the sensor platform with the Magsat spacecraft provided position and tilt adjusting capabilities for the remote mirrors referenced to the vector magnetometer. Once set in orbit, the mirror positions were to be maintained passively. Only vanishingly small angular deviations caused by thermally and dynamically induced structural distortions were permissible, which made the design and test problems extremely difficult.

INTRODUCTION

The need for a simple, extendable, lightweight, precisely alignable, virtually distortion-free structure for Magsat, capable of overcoming the stiffness of sizable multiconductor electrical cabling, presented a most difficult design requirement. The critical requirement was the need to position with precision magnetically sensitive instruments at a considerable distance from sources of magnetic contamination in the spacecraft. The problem was particularly acute because the magnetometer sensors were designed to measure a 60,000 nanotesla ($1 \text{ nT} = 10^{-9}$ weber per square meter) magnetic field with a precision of $\pm 1 \text{ nT}$.

Very precise knowledge of the vector magnetometer sensor's angular orientation was important. Because of the extremely narrow bandwidth of the attitude transfer system (ATS), which measured the angular orientation of the magnetometer, special

precautions were taken to control thermal distortions, mechanical misalignments, and dimensional instabilities in the design of the structural system that supported the sensors and separated them from the spacecraft instrument section.

SYSTEM DESCRIPTION

The magnetometer boom system consisted of a 14-link scissors boom, a 3-axis gimbal, and the sensor platform (see Fig. 1). The platform was connected to the instrument module electrically with multiconductor cabling that was routed through the interior of each boom link. Two independent, pyrotechnically actuated caging systems were used during launch to contain and protect the boom and platform in their stowed configurations. The 3-axis gimbal located at the boom base provided the boom with pitch, yaw, and roll capabilities of ± 2 ,

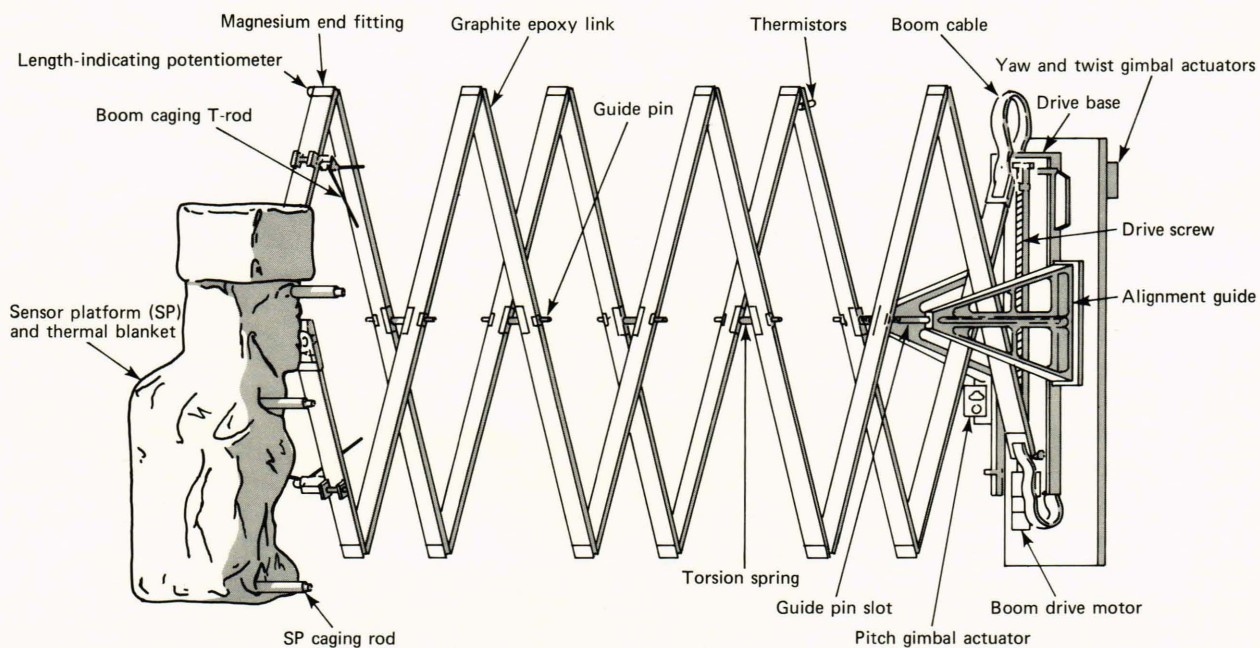


Fig. 1—Magnetometer boom system (partially extended).

± 2 , and $\pm 5^\circ$, respectively, for acquisition of the ATS. The drivers for each gimbal actuator, consisting of a 491-Hz square-wave inverter powering two phase-synchronous hysteresis gear motors coupled to gearboxes, provided average pitch, yaw, and roll scan rates of 30 arc-s/s. A pair of tension springs attached to the drive base and the instrument module structure eliminated all unrestrained play in the gimbal actuator adjusting screws. Rotary potentiometers geared to the output shafts of each of these gearboxes were calibrated to give the angular orientation of the drive base.

The boom drive consisted of a right- and a left-handed ball screw that was rotated by a fourth, inverter-driven, synchronous hysteresis gear motor. A rotary potentiometer geared to the output shaft of the gearbox was calibrated to indicate boom length during deployment. Confirmation of total extension was given by a second potentiometer made of nonmagnetic materials and pinned to one of the boom hinges closest to the platform. Total deployment time was about 20 minutes.

Weight and thermal distortion dictated the use of graphite-epoxy material for the boom links. The basic link was 94 cm long and 1.07×5.08 cm in cross section. Magnesium fittings were fastened to the ends and the center of each link with semirigid epoxy to prevent interface cracking caused by differential expansion. Each link was a hollow box with a 0.076 cm thick wall and was covered internally and externally with an aluminum foil moisture barrier to control moisture absorption and desorption — sources of dimensional instability — in the inherently hygroscopic graphite epoxy. A final wrapping of aluminized Kapton coated with aluminum oxide was added for temperature control. The links were hinged to each other with pins that were forced through compliant undersized bushings. This permitted rotation but eliminated all unrestrained mechanical side play.

The aluminum-foiled, graphite-epoxy platform was attached to the tip of the boom through a hollow graphite-epoxy box-like spacer and a “figure-eight” mechanism that enabled the platform to translate while maintaining its attitude normal to the boom axis as the boom extended. Attached to the platform with a kinematic suspension was the temperature-controlled vector magnetometer base, which in turn had attached to it the vector magnetometer sensor, the remote plane and dihedral ATS mirrors, and a precision sun sensor. The kinematic suspension provided a compliant mount for the magnetometer base and isolated it from thermally induced structural distortions that would be detrimental to the alignment of the vector magnetometer and the remote mirrors. The scalar magnetometer was attached to a 1.27 cm thick epoxy-glass thermal isolator that was fastened to the side of the graphite-epoxy spacer.

The weight breakdown for the boom system is shown in Table 1.

Table 1

WEIGHTS OF BOOM SYSTEM COMPONENTS (kg)	
Link structure	2.72
Drive assembly	2.93
Gimbal actuators (3)	3.09
Caging subsystems	1.13
	9.87
Inverters (2)	0.62
Electrical subsystem	0.76
	1.38
Sensor platform assembly	7.03
Boom cable	2.72
	9.75
Total weight	21.00

OPERATIONAL REQUIREMENTS

Magnetic contamination of the magnetometer sensors was avoided by locating the star cameras (which were magnetic) on an optical bench in the spacecraft instrument module. (Since the potential for magnetic contamination of the sensors was so great, the urge to locate the cameras on the sensor platform was dispelled well in advance of any serious design effort.) On command, the boom was to uncage and displace the sensor platform 6 m away from the instrument module. To satisfy requirements imposed by the ATS, which measured the vector magnetometer tilt relative to the star cameras, the boom was to maintain the platform position so that the center of a plane mirror, precisely attached to the backside of the vector magnetometer sensor, remained within a ± 1.91 cm square target zone. This zone was centered on the axis defined by an infrared light beam emanating from an ATS optical head located in the instrument module. The plane mirror had to remain orthogonal to the optical axis within 3 arc-min; this turned out to be the greatest challenge.

AREAS OF MAJOR CONCERN

Although the precision scissors boom was a flight-proven concept, the remote, precisely aligned platform was not. Concern over magnetic interference disallowed electrically powered adjusting mechanisms at the platform end. Consequently, tilt adjustments could only be achieved by gimbaling the boom at its base, which would cause the platform to translate. This side effect, coupled with the narrow field of view of the ATS, severely limited the tilt adjusting capability. For this reason considerable engineering analysis and testing were necessary to demonstrate that the Scout launch environment, uncaging, deployment, thermal distortions, and attitude control disturbances would not compromise the ability to achieve the precise alignments that were required.

The following three major areas of concern received considerable attention.

Control of Thermal Distortion

The requirement was to limit initial boom thermal distortions caused by broadside solar illumination sufficiently to permit acquisition of the ATS remote mirrors by gimbaling the boom at its base. Although the gimbals were adjustable $\pm 2^\circ$ in pitch and yaw and $\pm 5^\circ$ in roll, any tilting of the boom at its base would translate as well as rotate the remote mirrors. Since the target zone was ± 1.91 cm square, any mirror tilting that was necessary for acquisition had to be achieved within 0.33° once the mirrors entered the target zone. This made the initial tilt angle of the mirrors and direction of tilt extremely important. If, for instance, the mirrors were perfectly centered within the target zone initially, acquisition would have to be achieved within 0.16° or 9.6 arc-min of angular displacement.

The ± 3 arc-min requirement on mirror angle limited the permissible transverse offset of boom tip position to ± 0.51 cm for simple mechanical misalignment and ± 0.25 cm for misalignments caused by thermal distortion. It was important for the system to be free of play and for the boom elements to be made of some material that is virtually immune to thermal distortion. (Active temperature control was ruled out because of the complexity required for implementation and lack of sufficient electrical power.) Graphite fiber-reinforced plastic (graphite epoxy) with a coefficient of thermal expansion of very nearly zero ($+0.34 \times 10^{-6}/^\circ\text{C}$) was chosen to cope with the thermal distortion problem.

To control boom-link temperatures and temperature gradients in the presence of the solar and earth infrared environments, each link was taped with aluminized Kapton coated with aluminum oxide. This thermal covering was selected to give link equilibrium temperatures close to 25°C where all mechanical alignments would be checked.

Thermal distortion tests conducted in the Goddard Space Flight Center simulator on a four-link version of the flight boom yielded favorable results and indicated that the transverse and angular displacements of the platform caused by boom thermal distortion would be well within the allowable range.

Uncaging, Separation, and Extension

Two independent caging systems were provided to contain the boom during launch and to prevent the 7 kg sensor platform from transmitting damaging loads into the relatively delicate boom structure. Both were actuated by pyrotechnic piston-type actuators. Because the boom system was stowed in an unheated external compartment, boom-link and cable temperatures as low as -70°C were expected. Resistive heaters attached to the boom drive base

were to provide 16 W of power to warm the boom cable and drive just prior to platform separation and boom extension. Torsion springs located at each boom-link pivot were designed to overcome cold-cable stiffness as well as hinge frictional resistance. The existence of many single-point failure mechanisms in this area of concern resulted in a considerable amount of cold temperature testing to demonstrate and guarantee system integrity.

Pre-Launch Mechanical Alignments

To bring the remote mirrors mounted on the sensor platform into the fields of view of the ATS pitch/yaw and roll optical heads and then into linear range by fine adjustment, a terrestrial test that negated the 1 g bias had to be contrived. The best proposal utilized a pair of 6.1 m long water troughs (Fig. 2). Specially designed floats with gimbaled pulleys were attached to each of the boom-link pivots. The idea was to simulate a zero-g condition in a plane parallel to the plane of the water. Remote mirror transverse or angular offsets could then be corrected by gimbaling the boom at its base or introducing shims at the platform interface. The boom system was installed in a special fixture that was attached to a rotary table, the purpose of



Fig. 2—The Magsat magnetometer boom float system. The magnetometer boom is suspended from floats in 6.1 m long flotation tanks that provided zero-g simulation in the horizontal plane. The boom was rotated about its longitudinal axis into four positions 90° apart. Measurements of inclinations of sensor platform-mounted mirrors provided data that were used to align the mirrors by operating the gimbal at the base of the boom or by shimming the vector magnetometer base at the sensor platform end. Final measurements, adjustments, and checks were made by the attitude transfer system with the instrument module mounted on the rotary fixture.

which was to rotate the boom into its pitch and yaw planes for orthogonal plane, zero-g measurements, and adjustments. With the aid of an autoreflecting telescope, a theodolite, and numerous mirrors to measure the transverse and angular offsets of the plane remote mirror, sufficient data were obtained to guarantee remote mirror acquisition in orbit.

OPERATIONAL PERFORMANCE

On November 1, 1979, following a successful launch a few days earlier, the spacecraft attitude was stabilized. At 6:27:53 PM EDT, after successful uncaging, the magnetometer boom was extended. Telemetry indicated that the extension was proper and complete (see Fig. 3 of the Mobley article in this issue). Surprisingly, telemetry indicated that the remote mirrors were within the field of view of the ATS optical heads. This obviated the need for extensive gimbaling for ATS acquisition. On the following day slight gimbaling adjustments were made to bring the remote mirrors into the ATS linear range. Subsequent gimbaling adjustments were unnecessary.

Figure 3 — data from one orbit 92 days into mission life — shows roll, pitch, and yaw angles relative to orbital time and boom-link temperatures as measured by thermistors attached directly opposite one another on a boom link. Oscillations are evident, with periods approximately equal to the orbital period and amplitudes well within the ± 180 arc-s pitch and yaw and ± 300 arc-s roll limitations of the ATS. The boom-link temperatures exhibit

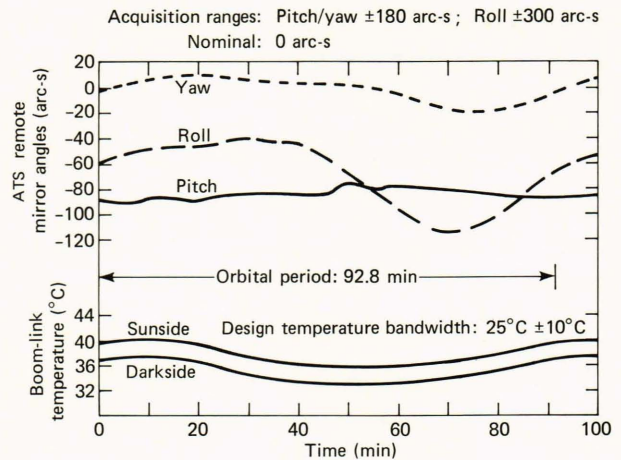


Fig. 3—Magsat ATS remote mirror angles and magnetometer boom-link temperatures, 029:22:40:15 (January 29, 1980, orbit 1410).

this same cyclical characteristic. This coincidence leads to the inference that the boom is being thermally excited at the orbital frequency. The continually varying temperatures are caused by the once-per-orbit coning of the solar vector. Their magnitudes are functions of the boom-link angle relative to the sun, which is set by the link angle relative to the boom axis and the seasonal variation in the solar vector.

The landmark performance of the boom system in orbit is an endorsement of the concept and of the special precautions that were exercised to guarantee its successful use.