FINAL REPORT

LUNAR ANTENNA MAST - ENGINEERING MODEL

Contract No. NAS9-10297

ARC-R-406

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ASTRO
RESEARCH
CORPORATION

SANTA BARBARA, CALIFORNIA

NASA CR 108532

SUMMARY AND INTRODUCTION

On December 22, 1969, Astro Research Corporation contracted to provide NASA Manned Spacecraft Center with one Lunar Antenna Mast - Engineering Model. The mast was to be 100 feet tall and automatically erectable and retractable, and capable of supporting itself, an RG-59 coaxial cable, plus a three-pound tip mass with only cantilever support at its base and tilted at an angle of five degrees from the vertical in lunar surface gravity. The mast and its deployment canister was to weigh less than 50 pounds and occupy less than 2.2 cubic feet. Twenty-eight volt direct current was to power its full-length deployment in less than 10 minutes. The useful life of the system was to be at least 20 deployment cycles subsequent to delivery to MSC, as demonstrated prior to delivery by at least three full-length erection cycles in earth-bound acceptance tests, to show it to be free of deficiencies.

A coilable Astromast* was designed, fabricated, successfully tested, and delivered to NASA in accordance with contract requirements. The coilable Astromast is a triangular lattice structure consisting of three fiberglass longerons, interconnected by evenly spaced triangular batten frames, and shear-torsion stiffened by pretensioned diagonal cables across all of its panels. A photograph of the mast configuration delivered to NASA is shown in Figure 1.

The engineering model weighs 54.5 pounds, including a remote-control unit and the installed coaxial cable with its TNC fittings. Its total volume is approximately 2.32 cubic feet.

Acceptance tests were performed at Vandenberg AFB in a deactivated Titan II launch silo June 8 and 9, 1970. On these two dates the mast was fully deployed a total of three times, essentially vertically, to determine its reliability and capability for full-length deployment in an environment in excess of lunar gravity. As part of the same test plan, the mast was twice deployed to a length of 50 feet while tilted at an angle which produced bending loads at its base slightly in excess of those calculated to be produced by the above-stated requirement for

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* Astro Research Corporation trademark; U.S. patent number 3,486,279.

lunar service. Full-length deployment and retraction were each achieved in less than the 10-minute limit. The mast successfully withstood the tilt test. The unit was accepted by Mr. H. A. Schultz, NASA Project Engineer, who witnessed the tests. It was delivered to NASA MSC June 16, 1970.

The text of this report gives a detailed description of the subject Lunar Antenna Mast, a summary of its structural analysis and its capability, as well as a summary of the acceptance tests.

Astro Research Corporation hereby expresses its appreciation for the opportunity to provide NASA with the Lunar Antenna Mast and is hopeful that it will be useful to NASA's space program.

MAST DESCRIPTION

The total mast unit is shown in a partially deployed configuration in Figure 1. The overall dimensions and parts of its stowage-deployment canister are designated by the drawing, Figure 2. Figure 3 is a close-up photograph into the top of the canister, which shows some details of the deployment mechanism and mast. The engineering model consists of three major components with their respective principal parts, as outlined below.

Mast

The mast is 1209 inches long and 10 inches in diameter. It consists of three continuous longerons, nominally 0.135-inch square, of uniaxial S-glass fibers in an epoxy matrix, and 212 bays formed by 211 triangular batten frames of S-glass fibers. Batten members have a rectangular cross section of 0.135 inch by 0.095 inch with doubly hinged aluminum joints at the corners of the frames which connect to the longerons at 5.7-inch spacings (see Fig. 3).

The upper end of the mast is terminated by an aluminum spider frame and a disk which serves as a dust cover. The lower end is terminated by an aluminum turntable.

Cables of 3 x 7 strand, 1/32-inch diameter stainless steel extend diagonally across each of the 636 panels of the mast to provide it with shear and torsional stiffness and strength (see Fig. 3). The diagonals are pretensioned to approximately 10 pounds, which the batten frames resist by buckling, thereby maintaining pretension in each diagonal. The diagonals are fixed at each joint by friction supplied by bolts as shown in Figure 3.

A single RG-59U cable is secured to one longeron by pressure-sensitive tape (Minnesota Mining & Manufacturing V-9133) two places in each 5.7-inch bay length as shown in Figure 3. The cable is terminated at the top by a TNC fitting. A Sage No. 345 coaxial rotary coupling conducts the cable through the turntable at the mast base, and the lower end of the cable is terminated by another TNC fitting.

The mast is painted with titanium oxide paint as a thermal control coating which is reported to have an effective solar

absorptivity of 0.2 and an IR emissivity of 0.9, which is calculated to maintain the temperature of the longerons at approximately 160°F in the most severe phase of the lunar thermal environment.

Cylindrical aluminum rollers 0.335 inch in diameter extend radially from the apexes of each triangular batten frame. The rollers are engaged by the deployment "nut" to extend or retract the mast.

Stowage-Deployment Canister

The canister is 41-7/8 inches high and 10.98 inches in diameter over most of its length. It consists of the following parts:

1) The lower mast-stowage volume which stows the 20.5-inch height of coiled mast

The canister bottom is a plate to which the mast turntable and base-attachment lugs are mounted. The canister wall is 0.063-inch thick 6061-T6 aluminum, and the bottom plate is 0.125-inch thick 6061-T6 aluminum.

2) The intermediate transition section of the canister

The canister in this section supports three sets of transition rails to guide the coiled mast from its coiled to its erected configuration before entering the deployment mechanism part of the canister.

3) The deployment mechanism part of the canister

This mechanism consists of a rotatable three-thread aluminum nut and vertical guide rails. The nut is indicated as the top portion of the canister in Figure 2. In Figure 3 its threads are visible through a lightening hole in the interior vertical guide structure. The pitch of each of the three threads is one-half the mast lug pitch. The mast lugs are engaged in the threads and between the Teflon edging members of the vertical guide structure. Thus the erected portion of the mast is advanced, without rotating, when the deployment nut is rotated.

4) The ring gear about the base of the deployment nut

This gear is visible in Figure 3.

5) Two 28-volt, d.c. Globe motors (14.5:1 - 102A174-9) with 14.5:1 gear heads and one-inch diameter pinion gears

These motors can be seen in Figure 1 and are indicated on the drawing, Figure 2. The pinion gears engage the ring gear, which can be seen in Figure 3, to power its rotation and either deploy or retract the mast. A fiberglass guard covers the ring and pinion gears.

Electrical Controls

Figure 4 is a schematic of the electrical system for the 28-volt motors, limit switches, and control switch. The electrical controls outlet for the control switch and power supply is mounted on the side of the canister, as shown in Figure 2. The limit switch which stops mast retraction is visible in Figure 3 inside the top of the canister. A 25-foot long cable connects the hand-held control switch and power supply to the controls outlet on the side of the canister.

Weight Summary

Following is a weight summary for the complete Lunar Antenna Mast.

Canister	26 lb 13.5 oz
Mast (including 2-lb 10-oz coaxial cable)	24 lb 8.0 oz
Antenna mount & dust cover	0 lb 7.5 oz
Electrical control box and cable	2 lb 8.0 oz
TNC cable terminals and rotatable cable coupling	0 lb 3.0 oz
Total	54 lb 8.0 oz

The volume of the canister is calculated to be approximately 2.32 cubic feet.

RESULTS OF STRUCTURAL ANALYSIS

A structural analysis of the Lunar Antenna Mast was formulated, based on the Stodola method involving successive approximations to determine the mast equilibrium shape when it is tilted and loaded by its own weight and a concentrated tip mass. The analysis accounts for elastic deflections of the mast, including beam-column effects as well as the flexibility of the base constraint. This latter consideration is due to the eccentricity with which the threads of the deployment nut, bearing on the roller lugs of the mast, reacts the axial loads in the longerons. The analysis was programmed for automatic digital computer solutions which produced the following results.

Results for Lunar Environment

For the total mast weight (earth) of 23.75 lb (1170 in. length) extending above the canister support level, with the canister base tilted at 5 degrees from vertical, and a tip weight (earth) of 3.469 lb (3-lb antenna + 0.469-lb dust plate and antenna mount), it was determined that the maximum bending moment on the mast is 313.8 in.-lb. The corresponding tip displacement from the vertical was found to be 127.9 in., including 27.8 in. of elastic deflection.

Another set of calculations was performed to determine the maximum tilt angle the 1170-in. length of mast with the same tip mass could withstand in the lunar environment. The resulting limit was a 6.8-degree base tilt angle which produced a maximum bending moment of 439 in.-lb with 179 in. tip deflection. Thus, the present mast provides a safety margin of 0.36 relative to the specified requirement for a 5-degree tilt angle.

Results for Earth Environment

As a guide for earth-bound testing, the same type of analysis was performed to determine the capability of the mast in earth gravity. In this analysis it was assumed that the 3-lb antenna would not be present; only the 0.469-lb tip mass of the dust cover plus the antenna mount. The results are plotted in Figure 5 as extended mast height versus tilt angle. These results represent tilt angles which are 1/1.36 of the tilt angle which

will cause failure of the mast. They thus represent the same safety margin as exists for the lunar case.

The test points indicated on Figure 5 are those to which the mast was exposed in the acceptance tests, which are discussed in the next section of this report.

ACCEPTANCE TESTS

Two pre-delivery acceptance tests of the mast were planned to demonstrate compliance with performance specifications of the contract and that it was free of construction deficiencies. The tests were planned as follows:

- Test No. 1 - three cycles of deploying the mast vertically to full height, then retracting it.

- Test No. 2 - two cycles of deploying the mast at an angle of 4.25 degrees, to a height of 600 inches, then retracting it.

In each test the mast was, of course, to be acted upon by the gravity environment of the earth. The tip load in each test was 0.647 lb, the weight of the mast's top spider frame and dust cover plus an eye bolt, weighing an additional 0.178 lb, to which a safety tether line was attached.

The purpose of Test No. 1 was to demonstrate that the mast could be reliably deployed to its full length within the designated time limit of 10 minutes. Test No. 2 was to demonstrate that the strength of the mast was sufficient to withstand the bending moment calculated to result from the specified lunar condition of full-length deployment, with the base tilted at 5 degrees and a tip mass of 3 lb (earth weight). It was calculated that a maximum bending moment of 345.2 in.-lb would result from the conditions of Test No. 2. That bending moment is approximately 10 percent greater than that calculated to result from the specified lunar condition and was accordingly considered to be a sufficient test to demonstrate the structural capability of the mast to meet the lunar requirement.

The tests were performed June 8 and 9, 1970 in a deactivated Titan II launch cell at Vandenberg AFB, California. The launch cell was selected so as to conduct the tests in a wind-free environment. The mast, mounted on a level in the cell at approximately 115 feet below ground, is shown in Figure 6. A lightweight tether line attached to the top of the mast and passed over a pulley at ground level was kept slightly taut during deployment and retraction of the mast. This was a safety measure to prevent damage to the mast in the event of its collapse. The mast is

shown in Figure 7 in its partially extended configuration during Test No. 2.

The results of the tests were as follows:

Test No. 1 - The mast was successfully deployed to full height and retracted three times. A slight tilt angle was present, as indicated by the test point plotted on the graph in Figure 5. The time required for deployment was 9 minutes 51 seconds, and that required for retraction was 9 minutes 36 seconds. Some oscillatory motions of the mast were induced by the deployment mechanism during deployment and retraction. Slight tension was held on the tether line during some phases of this test; however, the tension was released periodically to establish that oscillations were not sufficiently severe to produce failure of the mast. Tension was also released each time the mast was fully extended, to demonstrate its free-standing capability at that height.

Test No. 2 - The mast was twice deployed and retracted with its base tilted at approximately 4.25 degrees (see test point on Figure 5).

During one of these two tests deflection of the mast was measured as 27.15 in. at a height of 296 in. above the canister while the mast tip was at 600 in. The moment and deflection calculations tabulated on the following page for the test condition of 4.25-degree tilt and 600-in. extension show that deflection at the 296-in. level should have been about 24 in. Therefore the mast was actually tilted slightly more than 4.25 degrees, and the base moment was greater than the listed value of 345.2 in.-lb.

Calculated Mast Deflections and Bending Moment for Test No. 2

Length = 600 in. Tilt angle = 4.25°

Height	Y	M	Y Elastic
0.00	0.00	345.9474	0.00
40.00	3.1235	306.4065	.1565
80.00	6.3428	269.1685	.4036
120.00	9.6461	233.5442	.7449
160.00	13.0223	199.8708	1.1541
200.00	16.4611	168.363	1.6258
240.00	19.9525	139.2043	2.1581
280.00	23.4874	112.5437	2.718
320.00	27.0575	88.5227	3.321
360.00	30.6553	67.2281	3.9518
400.00	34.2742	48.7436	4.6837
440.00	37.9085	33.1283	5.2703
480.00	41.5531	20.4241	5.9434
520.00	45.2042	10.6536	6.6325
560.00	48.8538	3.8479	7.32
600.00	52.5147	0.00	8.0088

CONCLUSION

It is concluded that the engineering model of the Lunar Antenna Mast has essentially met all the specified conditions and is suitably reliable for evaluation testing by NASA within the bounds identified in Figure 5.

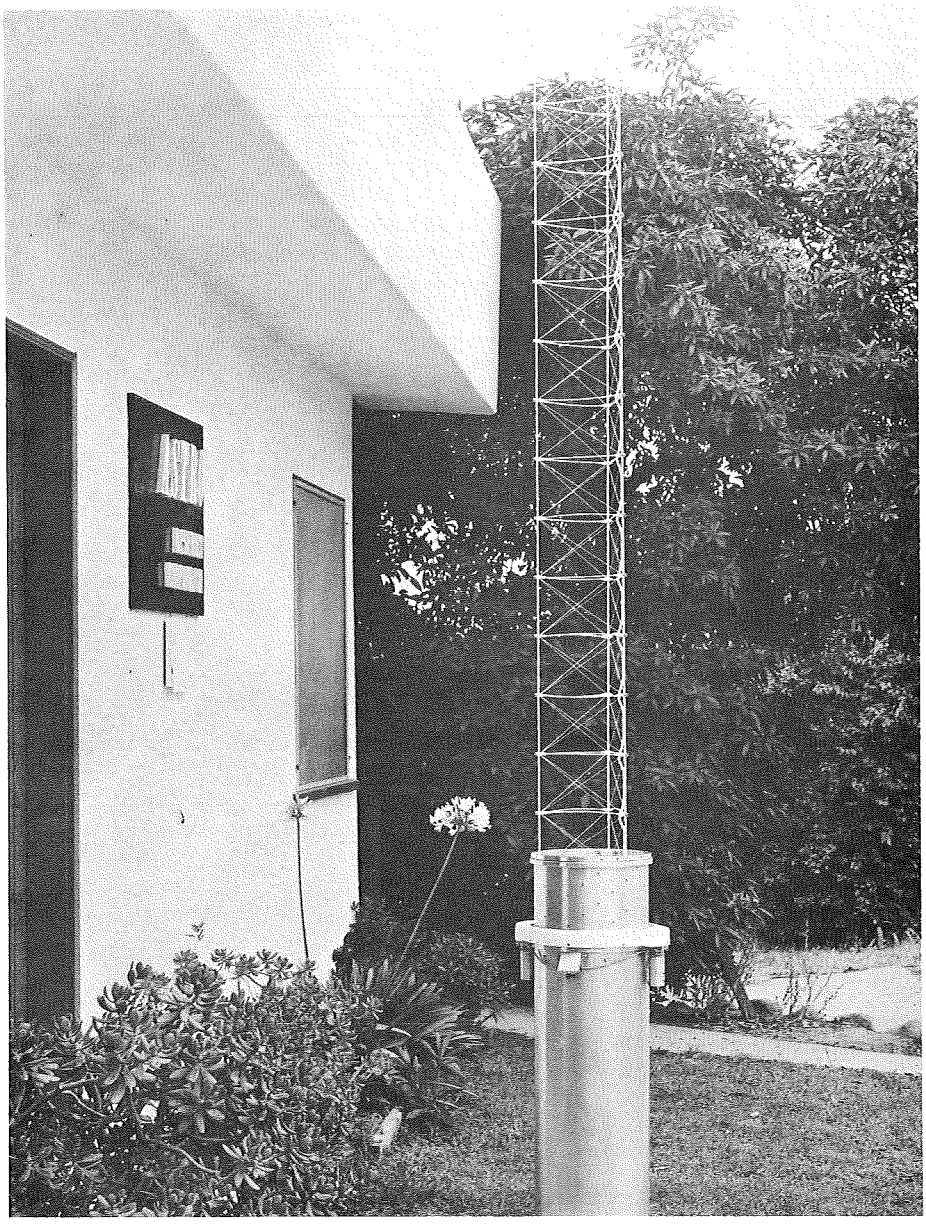


Figure 1. Lunar Antenna Mast - Engineering Model

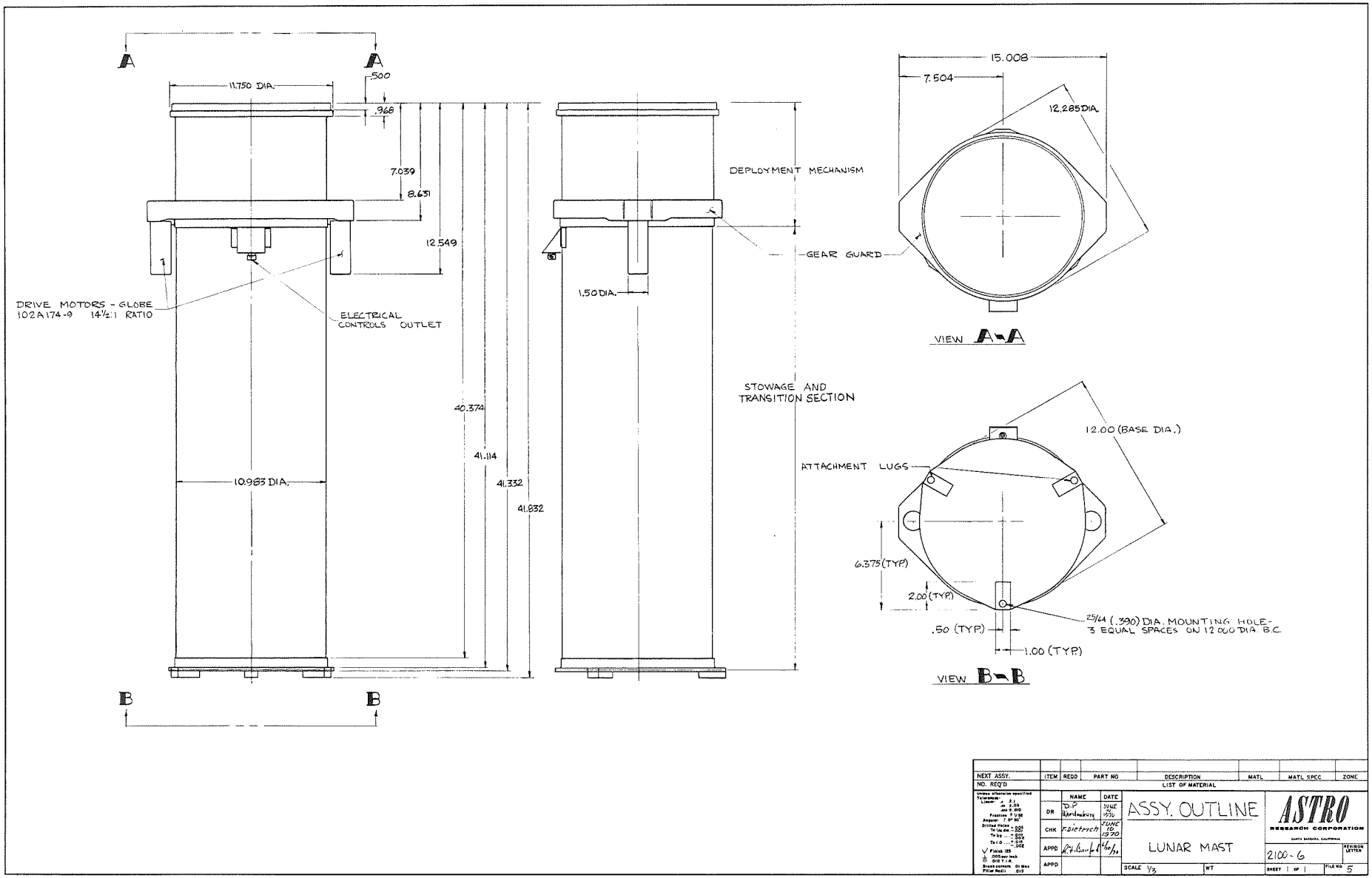


Figure 2. Outline Drawing of Canister

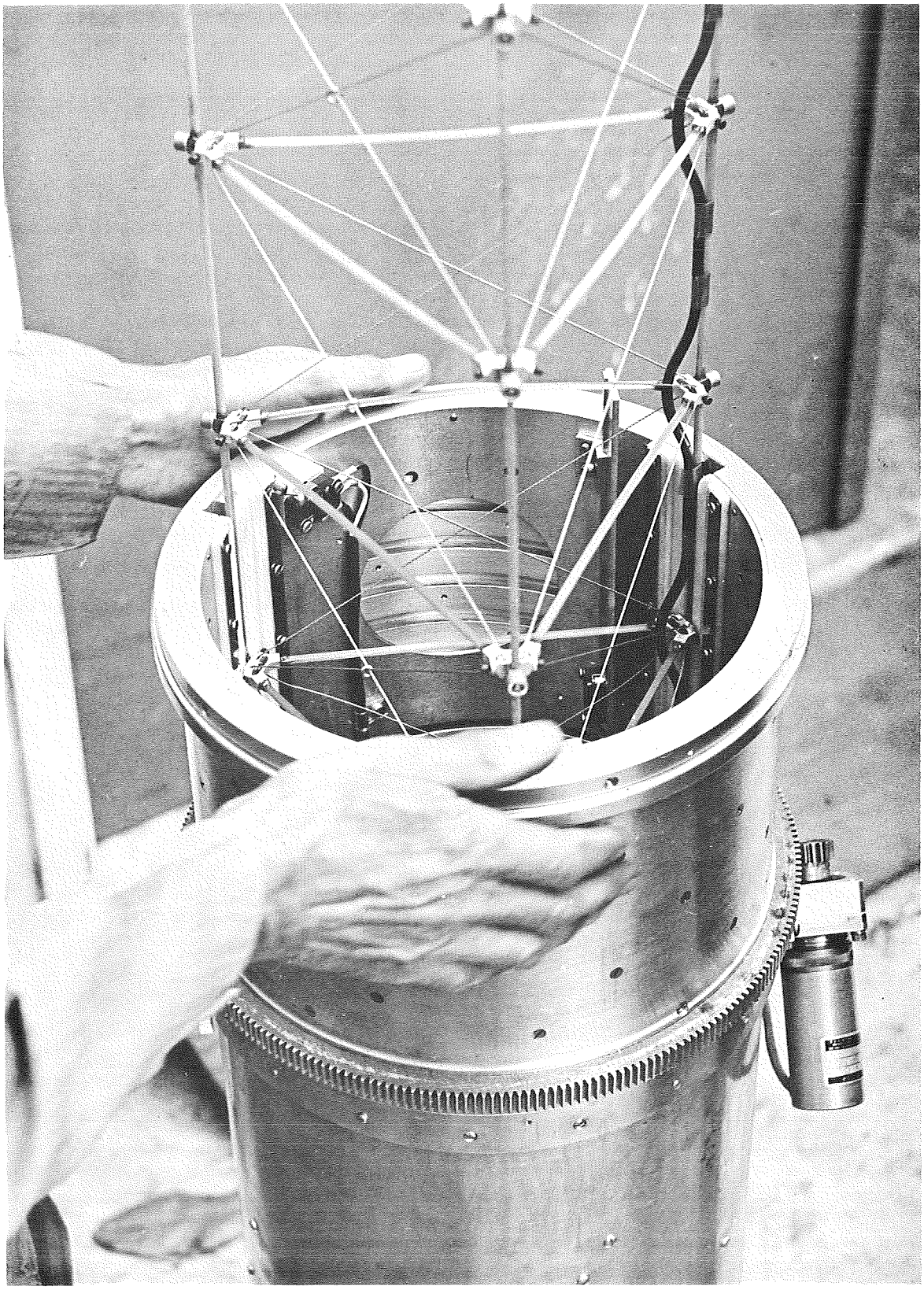
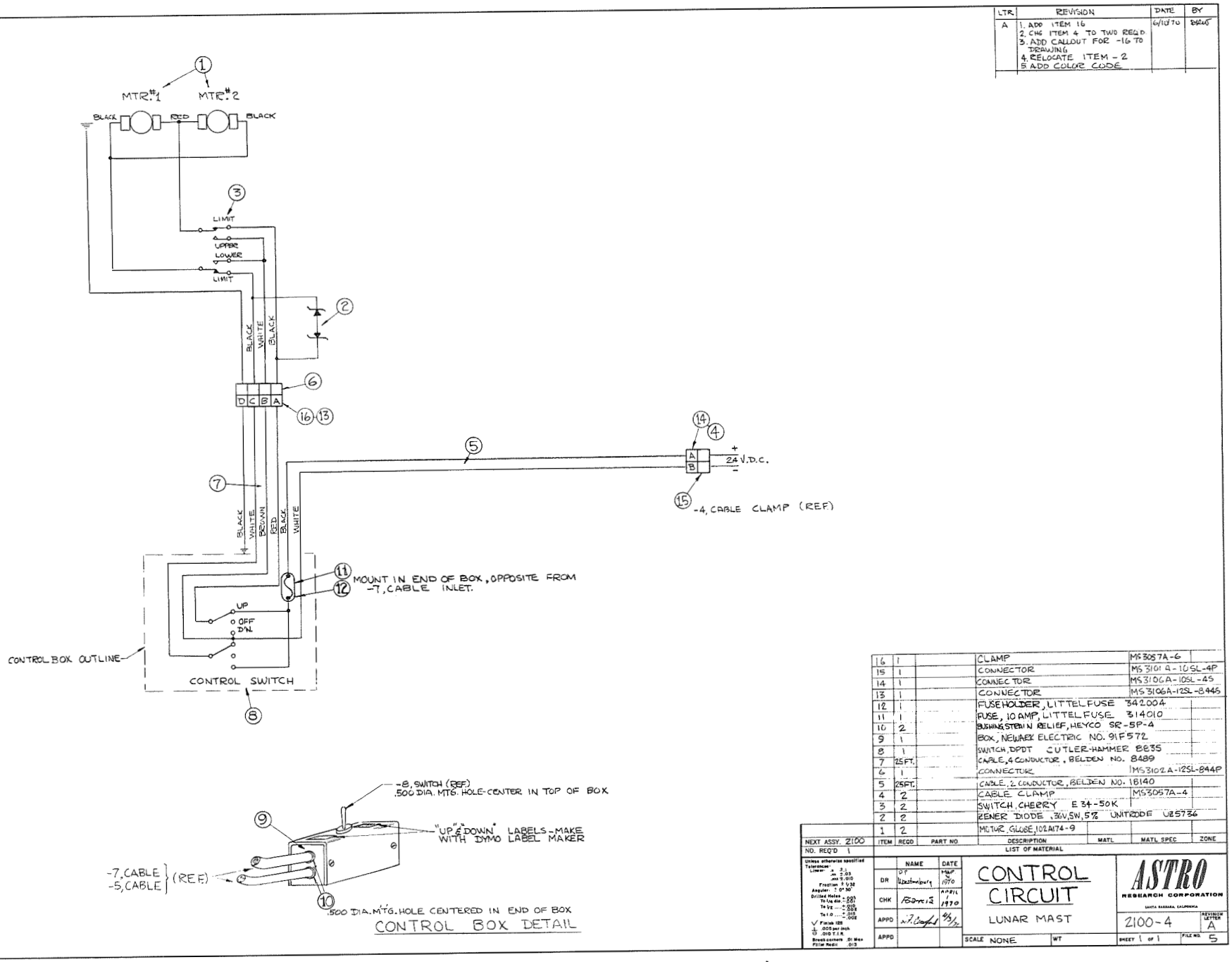


Figure 3. Close-up of Top of Canister and Mast



LTR	REVISION	DATE	BY
A	1. ADD ITEM 16 2. CHG ITEM 4 TO TWO REQ'D 3. ADD CALLOUT FOR -16 TO DRAWING 4. RELOCATE ITEM - 2 5 ADD COLOR CODE	6/10/70	[illegible]

ITEM	REQD	PART NO	DESCRIPTION	MATL	MATL SPEC	ZONE
16	1		CLAMP		MS3057A-6	
15	1		CONNECTOR		MS3101A-10SL-4P	
14	1		CONNECTOR		MS3106A-10SL-4S	
13	1		CONNECTOR		MS3106A-12SL-8S4S	
12	1		FUSEHOLDER, LITTELFUSE 342004			
11	1		FUSE, 10 AMP, LITTELFUSE 314010			
10	2		BUSHING STRAIN RELIEF, HEYCO SR-5P-4			
9	1		BOX, NEWARK ELECTRIC NO. 91F572			
8	1		SWITCH, DPDT CUTLER-HAMMER 8835			
7	25FT.		CABLE, 4 CONDUCTOR, BELDEN NO. 8489			
6	1		CONNECTOR		MS3102A-12SL-8P4P	
5	25FT.		CABLE, 2 CONDUCTOR, BELDEN NO. 18140			
4	2		CABLE CLAMP		MS3057A-4	
3	2		SWITCH, CHERRY E34-50K			
2	2		ZENER DIODE .36V, 5W, 5% UNITRODE UZ5736			
1	2		MOTOR, GLOBE, 102A174-9			

NEXT ASSY. 2100 — NO. REQ'D 1 — LIST OF MATERIAL

Unless otherwise specified Tolerances: Linear: .x ±.1, .xx ±.03, .xxx ±.010; Fractions ± 1/32; Angular: ± 0° 30'; Drilled Holes: To 1/4 dia. +.003 -.001, To 1/2 +.005 -.002, To 1.0 +.010 -.002; √ Finish 125; .005 per inch; .010 T.I.R.; Break corners .01 Max; Fillet Radii .015

	NAME	DATE
DR	D.P. Montgomery	MAY 7 1970
CHK	[illegible]	APRIL 1 1970
APPD	[illegible]	5/5/70
APPD		

CONTROL CIRCUIT
LUNAR MAST
SCALE NONE — WT

ASTRO RESEARCH CORPORATION
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2100-4 — REVISION LETTER A
SHEET 1 OF 1 — FILE NO. 5

Figure 4. Electrical Schematic

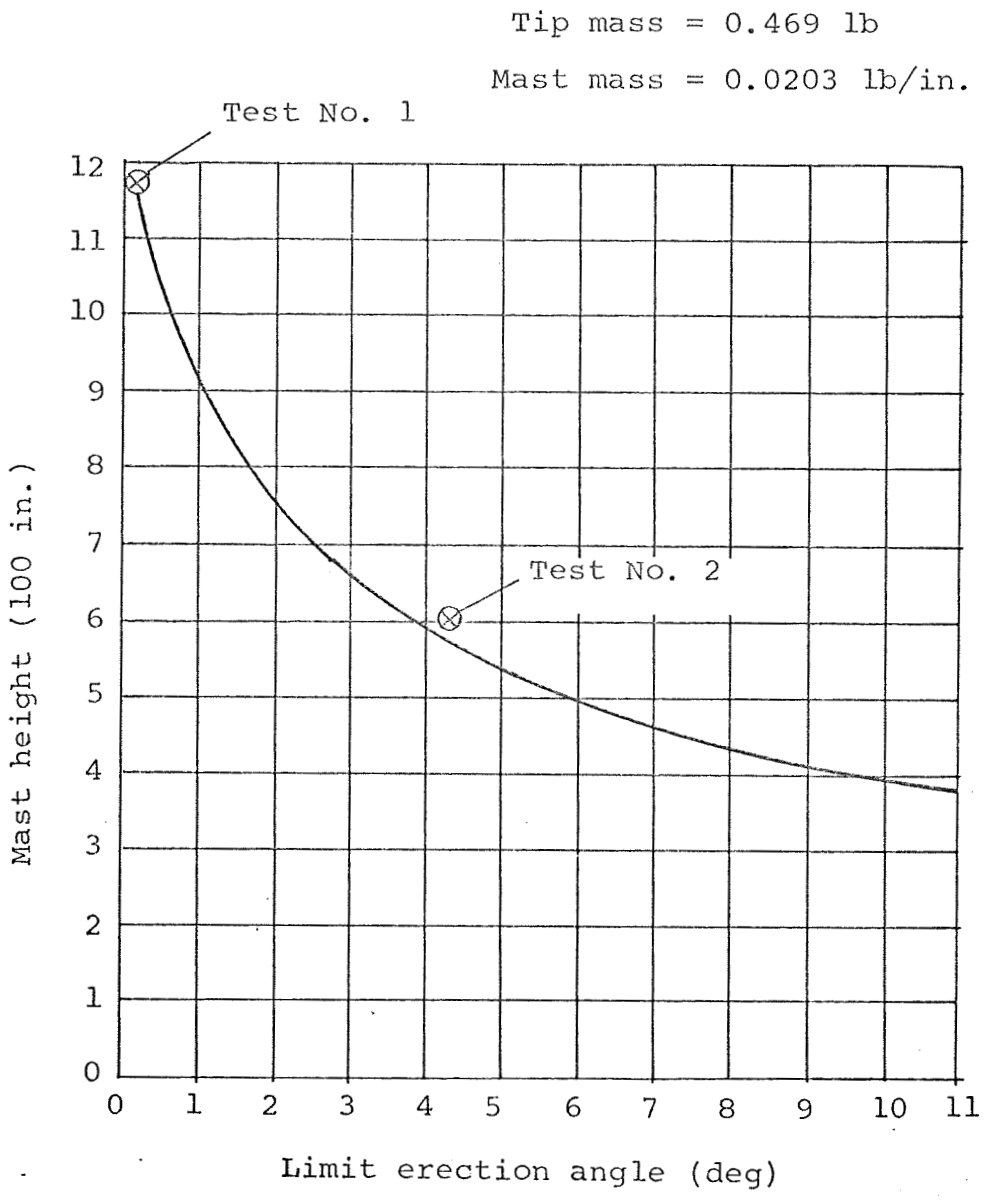

Figure 5. Capability of Lunar Antenna Mast in Earth Gravity

Figure 6. Lunar Antenna Mast - Ready for Test

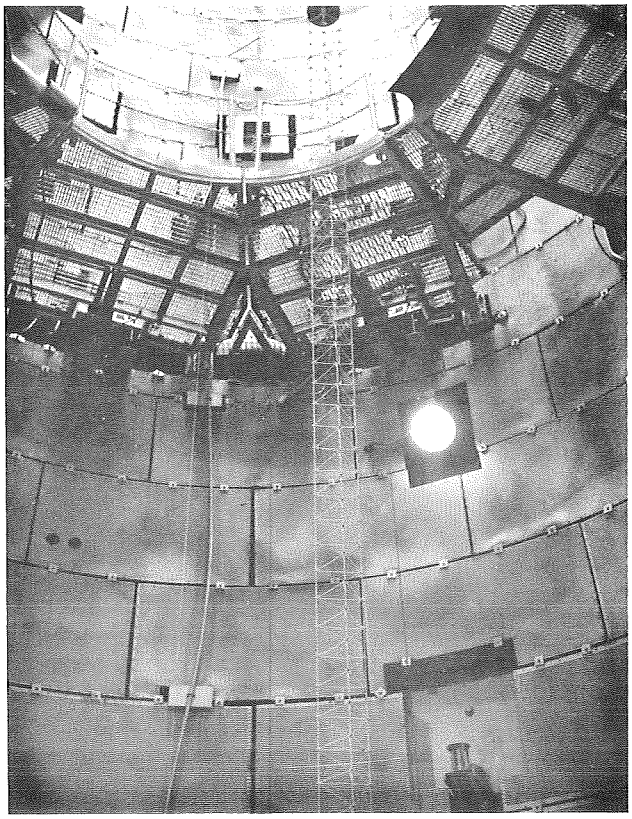

Figure 7. Partially Deployed Lunar Antenna Mast During Pre-delivery Test