# Design of an Astronaut-Operated, Lunar-Surface, Antenna-Aiming Mechanism

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## Theme

THE paper reviews materials, structural and lubrication problems of the mechanism used successfully by Apollo 12, 14, and 15 astronauts to aim the telemetry antenna for the Apollo Lunar Surface Experiment Package (ALSEP) toward the center of the Earth's libration range. The mechanism had to be: rugged enough to withstand ground tests, storage, and the trip to the moon; safely operable by a suited astronaut; noncontaminating to adjacent scientific experiments; complete with means for establishing a reference direction, aimable over ±90° azimuth and ±50° elevation from reference position with 2° total system error; capable of supporting the 1.25 lb tubular antenna rigidly for at least one year in the lunar environment (vacuum, sticky dust, and an expected temperature range of −250 to +250°F); and of 2 lb maximum weight. Thermal distortion, coatings, lubricants, metals (Al, Mg, and stainless steel), thermal stability, and qualification-/acceptance-testing are discussed.

## Content

The antenna system (Fig. 1) consists of a tubular metal mast, aiming mechanism (Fig. 2), and tubular fiberglass-reinforced epoxy antenna. Because the movement with time of the position of the Earth's center as seen from the moon falls within a rectangle of ±7° lat and ±8° long in lunar coordinates, this medium-gain fixed antenna was preferable to a continuously steerable higher gain because of its greater reliability and simplicity. An antenna beam width of 27° covers the entire predicted range of the Earth's movements as seen from the moon for a five-year period (with an allowance for aiming error). Early in the program a computer thermal analysis (described in the paper) indicated that thermal distortion due to radiant heat exchange between the sun, the antenna components, the lunar surface, and space would cause a maximum deviation in antenna aim of 0.1° (due primarily to mast deflection), well within the 0.2° allowable. This finding allowed approval of the basic concept.

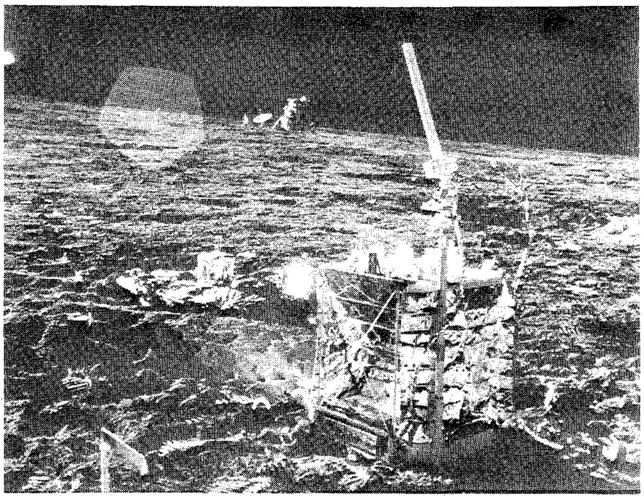

**Fig. 1 Antenna and aiming mechanism as deployed on the moon by the Apollo 12 astronauts.**

A sun shadow compass and a bubble level, especially qualified for thermal-vacuum exposure, were used to establish the reference position. The five degrees of freedom required of the mechanism to level (2 axes), orient (1 axis), and aim (2 axes) necessitated many moving parts—gears, bearings, and screw threads (Fig. 2). During deployment, the astronaut adjusts two knobs to center the bubble, rotates the mechanism through a worm-gear drive to align the sun compass in the east-west direction, and uses two additional sets of worm-gear drives to point the antenna.

To prevent cold welding, metal-to-metal contact was avoided by introducing compatible, dry surface films at all rubbing or sliding interfaces. Lightweight anodized magnesium gears operate against hard-coated aluminum worm screws with a thin film of molybdenum disulfide powder lubricant burnished into the surfaces by hardwood tools. Anodized aluminum leveling screws operate in strong polyimide plastic threaded blocks which are in turn supported by frictionless flexural pivots (Fig. 3), which allow ±6° motion without sliding. These pivots operate by the flexing of two intermediate metal strips which act as the hinge pins in the leveling plates. Ball bearings were lubricated with a low-vapor-pressure, wide-temperature-range, space-qualified, G-300 silicone grease and then sealed with rubbing elastomeric seals to keep out dust and to slow grease evaporation.

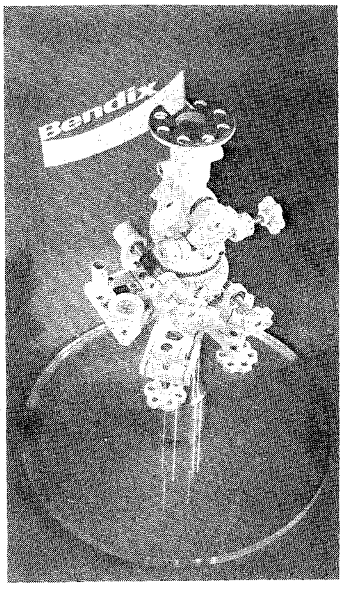


**Fig. 2 ALSEP antenna aiming mechanism.**

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Index categories: Optimal Structural Design; Manned Lunar and Interplanetary Systems; Thermal Modeling and Experimental Thermal Simulation.

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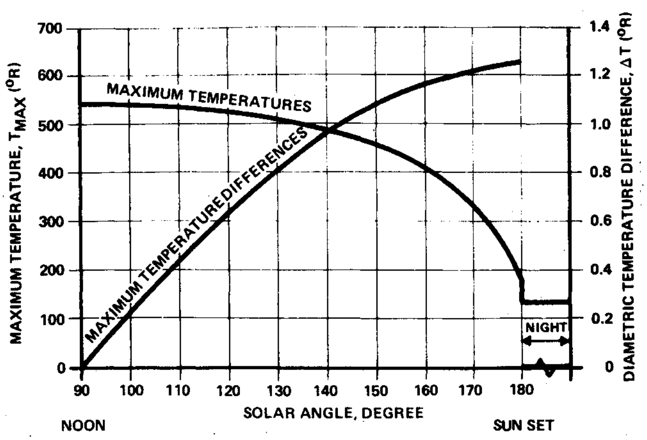


Fig. 3 Frictionless flexural pivot.

Only materials (Table 1) with a high degree of structural stability in the temperature range of interest were considered. The weight restraint was met through use of AZ31B magnesium (rather than LA141 magnesium or aluminum) for larger components. Lightening holes were used where appropriate. Much lighter construction would have been sufficient to support the antenna's weight but not rugged enough for astronaut handling. For thermal control, inorganic white coatings would be resistant to the thermal-vacuum, solar-ultraviolet lunar environment, but they are brittle and adhere poorly. We selected an acrylic lacquer which can better withstand handling. It gradually discolors, but thermal analysis and testing showed that the discoloration would not significantly degrade system performance. The White Velvet lacquer is applied as a nominal 2-mil film over an alkyl enamel primer.

**Table 1 Principal materials and coatings used**

| | |
|---|---|
| Base, inner and outer gimbals, ground plane, knobs, and worm gears | AZ31B magnesium |
| Fasteners | 416 stainless steel |
| Adjusting screws and worm screws | 6061-T6 aluminum |
| Worm screw and gear bearings | 440C balls and races, phenolic separator, G-300 grease |
| Leveling blocks | Polyimide plastic |
| Flexural pivots | 420 stainless steel |
| Thermal control coating (acrylic) | 3M-202A10 White Velvet |
| Magnesium anodize | Dow 17 to MIL-M-45202 Class I, Type C |
| Aluminum-hardcoat (1 mil) | Alumilite 226 to MIL-A-8625, Type 3 |
| Aluminum corrosion protection anodize | Iridite to MIL-C-5541 |
| Sealants | Silicone rubber (RTV) |
| Dry lubricant powder | Molybdenum disulfide |

**Table 2 Equipment qualification for lunar environment**

Design verification tests on production prototype:
- Temperature: −320° to +350°F, 3 cycles of 8 hr each
- Vibration: sinusoidal 50 to 2000 Hz, at 1 *g*
- Vacuum: $10^{-4}$ torr for 110 hr
- Thermal-vacuum: $10^{-4}$ torr for 90 hr at +250°F

Acceptance tests on flight models:
- Temperature: −300° to +250°F, 1 cycle of 2 hr
- Vibration: sinusoidal, 10 to 250 Hz at 2 *g*

Verification tests on critical components:
- Temperature cycling: flex pivots, polyimide plastic, ball bearings, silicone rubber sealant, bubble level, all coatings and paints
- Vibration: bubble level
- Acceleration: worm gear set, 22 *g*
- Thermal vacuum: bubble level, ball bearing, all paints

A thermal stabilization procedure has employed for all structural components because residual manufacturing stresses in magnesium and aluminum might be relieved during thermal cycling, and retained austenite in stainless steel AISI 440C ball bearings could transform to martensite. Small dimensional changes could lead to a malfunction or antenna misalignment. Therefore, in a simulation of the lunar day/night cycle, all parts were repeatedly heated and cooled until no further dimensional changes occurred.

Design verification and acceptance tests included human factors evaluation and the environmental tests in Table 2. Each completed unit was tested in both the stowed and erected configuration before acceptance.

On Nov. 19, 1969, the Apollo 12 astronauts erected an ALSEP antenna on the moon (Fig. 1) and aimed it accurately; this accomplishment was repeated by the Apollo 14 and 15 astronauts. All three antennas were still operating properly in September 1971.