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Final Report for

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SOLAR REFLECTING BEACON

Prepared for
NASA Manned Spacecraft Center
Houston, Texas 77058

[redacted]

Contract NAS9-4790

EOS Report 6976-Final 16 June 1966

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ABSTRACT

This final report covers the period 16 June 1965 through 16 April 1966 and is submitted in accordance with the requirements of Contract NAS9-4790. The goal of this program has been to develop conceptual and engineering designs for two types of Lunar Solar Reflecting Beacons to be emplaced during the early Apollo lunar landing missions. One beacon will be visible from the earth; the other will be visible from both the Apollo Command Module (CM) and the Lunar Excursion Module (LEM) vehicles.

Phase I of this two-phase program encompassed static and dynamic beacon design concepts including tracking beacons, photometric analysis of beacon detection, reliability as affected by the lunar environment, materials analysis, beacon location requirements, and preliminary weight and packaging determinations. These studies were summarized in the Phase I report dated 3 December 1965. A tracking, flat, specular earth beacon and an oscillating arch cislunar beacon were recommended to MSC. MSC concurred with the earth beacon recommendation but changed the field of view and range specifications for the cislunar beacon. These changes permitted the use of a static design to meet the revised MSC design specifications for the cislunar beacon. The second phase of the program covers specifications definition and engineering designs of the tracking flat earth beacon and the cislunar static beacon concepts recommended by NASA-MSC, Houston.

This report summarizes the results of Phases I and II. Phase II results include projected hardware schedules and specifications, including drawings and a recommended QC program. Two cislunar beacon alternates are given. Detailed recommendations and conclusions are included.

PREFACE

The Solar Reflecting Beacon Program is a study of reflecting instruments to be placed on the moon by astronauts during the early Apollo landing missions. The photometric requirements and conceptual designs of various lunar emplaced solar beacons have been described and discussed over the past decade. One study in 1965 investigated a beacon to be emplaced by early Surveyor missions which could be used as an aid for subsequent Apollo landings. This program has benefited much from these previous studies.

This final report has been written by Mr. Gordon Jelley, Dr. Bernard Kalensher, and Mr. Donald Stewart. The engineering design and the detail layouts were made by Mr. Victor Plotkin and Mr. William Wong, respectively. Mr. Jelley contributed to the overall design details and especially to the electronics and electromechanical details of the earth tracking beacon. Dr. Kalensher supervised the programming, computing, and analysis of the static beacon orientation and flash location, performed in the Phase I. Mr. Stewart, program manager, coordinated the technical efforts and performed miscellaneous design and analytical functions. Mr. Lloyd Popish improved the text readability. The program benefited greatly from the proximity to and the contacts with the Mt. Wilson and Mt. Palomar Observatories' offices, particularly with Mr. William Miller, staff photographer, and Dr. Bowen, retired director.

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1. INTRODUCTION

The subjects of this report are two Solar Reflecting Beacons, an earth beacon, and a cislunar beacon, to be emplaced upon the lunar surface during the early Apollo missions to provide reflected solar flashes to earth, i.e., the earth beacon, and the descending LEM vehicles which land at the beacon site on subsequent Apollo missions, i.e., the cislunar beacon. The technical problems involved in emplacing reliable beacons upon the lunar surface include reliability, weight, packaging volume, viewing range and field of view, detector type and size, and environmental and materials analysis.

The purpose of this contract has been to study various beacon concepts, recommend specific concepts to NASA/MSC, and use MSC's subsequent recommendations to establish specific beacon designs and specifications. The major technical problems have included meeting the weight and packaging specifications and the lack of space-qualified electronic and electromechanical hardware which can withstand the lunar environment. The beacons proposed could serve not only as navigational aids and selenodetic measurement reference points, but also as an emergency communications system and a national and international political advertisement.

Over the past decade several authors have dealt specifically or indirectly with the detection of signals from the lunar surface, astronomical detection problems, lunar lighting, and beacon configurations in limited detail. Studies on beacons were mainly broad investigations of various concepts. The work of Dole (Ref. 1), in 1957, was one of the first to discuss the specific problem of solar reflections from beacons on the lunar surface. In 1960 the problem received further attention in the Surveyor project studies (Ref. 2).

Subsequent investigations reported in 1965 become more specific and relate directly to the Apollo Program using either the Surveyor or an early Apollo vehicle to carry the beacon payload. (Ref. 3 through 6). The use of beacons as aids to selenodetic measurements was detailed in Contract NAS9-2803 by Geonautics (Ref. 6). This contract preceded and encouraged the investigations of this program. The NASA Working Group on Surveyor Landing Aids for Apollo met throughout 1965 (Ref. 4) and provided concurrent analytical and experimental data to crosscheck the preliminary detection studies presented in this program. Many more general analytical and empirical studies aided in the presentation and understanding of the detection problem including Blackwell (Refs. 7 and 8), Kopal (Refs. 25 and 26), Kuiper (Ref. 27), Russell (Refs. 35 and 39), and Tousy (Ref. 45), etc.

This program was a specific outgrowth of the beacon possibilities presented in the above references. Both the selenodetic and landing aid aspects of the study have been emphasized. The investigatory areas have been defined by detailed specifications for beacons which can be erected by the LEM astronauts. Specular reflectors have received major attention.

The Phase I studies were divided into four separate areas:

1. Beacon detection problems were studied systematically to include both visual and photographic detection using practical assumptions regarding detection instruments and visual conditions.
2. Beacon orientation and flash location programs were analyzed, developed, and run to better understand both the detection and beacon design problems.
3. Beacon conceptual designs were depicted and rated for recommendation to MSC.
4. Recommendations of several lunar and earth beacons were given to MSC in both verbal and written presentations.

MSC reviewed these recommendations together with the reduction of the Surveyor payload which virtually eliminated the possibility of erecting a Surveyor emplaced solar beacon. MSC then submitted a specific earth beacon design and revised cislunar specifications for further study. As Phase II started, the cislunar specifications were reviewed and subsequently the range was revised downward. The earth beacon design was studied in greater detail indicating possible difficulties in meeting the weight and packaging specification and in securing off-the-shelf or suitable state-of-the-art hardware. The recommendations were, therefore, reviewed and reaffirmed by MSC after careful consideration of the above problems and the detection probabilities and orientation requirements of alternate earth beacons.

Beacon designs were then started. Since much of the hardware proposed has not been extensively tested, analyzed, or exposed to the lunar or the lunar-simulated environment, the design philosophy has been to present prototype or model shop drawings using off-the-shelf components, where available, selected from experience or with minimal exploratory investigation. Therefore, definitions of the component functions and specifications have been made where state-of-the-art components could not meet the beacon requirements. Because the design process requires reiterative steps to approach and improve on the design specifications, prototype construction, followed by design revisions, will be required to produce additional design improvements. Instrument specifications and cost and schedule projections were also developed in Phase II.

2. SUMMARY

This final report summarizes both phases of the lunar beacon instrument development program. The first phase comprised the conceptual design and engineering feasibility design of two types of solar reflecting beacons to be emplaced by early Apollo lunar landing missions. Phase II encompassed the preparation of detailed design specifications and engineering drawings.

The earth viewed beacon weighs 20 pounds and has a one-cubic-foot volume design specification. The cislunar beacon viewed by the astronauts in the descending LEM over a 20 degree by 39 degree field of view has a 5-pound weight and a 0.25-cubic-foot volume design specification. Common design specifications include a one-year operating life, 0.90 reliability, and a maximum packaging dimension dictated by the LEM Scientific Containers Stowage Compartments (Ref. LID-360-2280).

The earth beacons will be detected both visually and photographically; the cislunar beacon will be sighted visually. Photographic detection is best accomplished with long flashes or a continuous signal. Any type of signal is appropriate for visual recognition, though flashes may be more readily detected.

2.1 Specular or Diffuse Beacons

Oriented specular flat beacons are 4.65×10^4 times more efficient per unit area than a diffuse flat. Diffuse spheres are 2.67 times more efficient than a specular sphere, on an illuminance-to-area ratio, when the reflecting and incident angles are normal to the surface. However, a specular sphere is more efficient than a diffuse sphere on an illuminance-to-weight ratio under all incident and reflected angle conditions. Extensive studies have been made by and for NASA on similar diffuse beacons. Therefore, for these reasons only specular beacon designs were studied on this program. The beacon designs considered are variations of flat or spherical surfaces in both static and dynamic modes.

2.2 Beacon Area, Viewing Time, Field of View, and Flash Frequency

Beacon areas were calculated by accepted photometric visual and photographic formulas using assumptions more realistic than used in earlier beacon area calculations. Calculations based upon the final specifications resulted in beacon flat areas and equivalent spherical diameters of 0.0017 ft^2 and 20 ft for the cislunar and 33 ft^2 and 2790 ft for the earth beacon. These represent a visual detection probability of 98 percent for the cislunar beacon and a photographic and visual factor of safety of over 10 for the earth beacon, based on the assumptions used. The cislunar beacon signal will have continuous signal since spherical segments can be used to reflect to the entire 20 degree by 39 degree field.

For a static earth beacon, it is impractical to fabricate spherical sections within the weight and packaging specifications which will cover the field of view required to produce a continuous beacon signal to the earth. Therefore, either an earth beacon is required that will track the continuous beacon signal or a flashing signal must be tolerated. The length and frequency of the flash will depend upon the beacon field of view (FOV), the motion of the beacon, and the position of the observer. Generally, the beacon field of view depends on the reflective area which, in turn, is proportional to the total package weight assigned to the reflective area.

2.3 Materials

The proposed beacon designs utilize space-qualified metals and plastics with high structural reliability, specific strength, specific rigidity, and environmental resistance. The proposed concepts rely heavily on aluminum and H Film.

2.4 Orientation

Orientation requirements have been defined and basic programs computed relative to beacon orientation accuracy, orientation angle calculations, and signal viewing time. Additional work is required to deliver a complete program package suitable for use by MSC's computers.

2.5 Reliability

Reliability, herein defined as the probability of the beacon meeting its design specifications after a one-year lunar operating life, is primarily dependent on the erectability, orientation, durability in the lunar environment, and the dust problem during LEM ascent. The prelaunch, launch, and translunar environmental phases should not adversely affect the reliability of the proposed beacon concepts.

2.6 Beacon Designs

Several beacon concepts were described for both the earth and cislunar beacons in the Phase I report. The flat tracking earth beacon design recommended by EOS was chosen by MSC primarily for its high percentage of viewing time, lack of orientation requirements, and ease in dust protection. The cislunar mosaic spherical and the inflatable alternate design were chosen on the basis of a continuous signal to the desired FOV, minimum orientation, high durability of either the metal or self-rigidizing plastic-aluminum foil concepts, and ease in dust protection.

A dynamic-tracking earth beacon was recommended and chosen for final design because, with its reorientation capabilities, the beacon signal could be detected throughout the lunar day for each lunar day. In Phase I, before more detailed state-of-the-art hardware investigations were made, it appeared that the very high probability of detection far outweighed the possible disadvantages. The broadness of the Phase I work, while touching on the problem areas, glossed over the magnitude of the weight-packaging and sophisticated hardware and tracking problems associated with such a dynamic beacon.

Early in the Phase II effort, a reexamination of the earth tracking beacon was made to consider the attributes of this concept in detail. Further guidance from MSC was requested after exploring such areas as:

1. Weight
2. Package volume
3. Sensor logic near 0-degree phase angles
4. State of the art of:
    a. Sensors
    b. Bearings and motors
5. Electrical requirements
6. Erectability

Despite the increased recognition of the magnitude of these problem areas, the original Phase I design recommendation was upheld since the probability of signal detection is much higher for a tracking beacon compared with either a static or a randomly programmed dynamic beacon. However, it was realized and reported at the time of this decision that the weight and volume specifications for this design would probably be exceeded. A maximum erection time of 10 to 15 minutes has been specified. Since the tracking beacon has a large number of components, minimum erection time requires a minimum of subassemblies. Subassemblies generally are more bulky, i.e., have lower weight per unit volume, than individual parts.

Due to the design schedule, funding level, and state of the art of some critical components, the choice was made to utilize existing hardware where possible, without extensive redesign. It was also decided that the prototype drawings would be made since the initial units would have to be made in a model or prototype shop. Many further refinements can logically be made on the basis of prototype assembly. The designs presented, therefore, can further be improved by the normal reiterative design and fabrication process.

The cislunar and earth beacon design drawings include:

Number	Title
1100201	Cislunar Reflecting Beacon Assembly
1100202	Tripod Assembly, Tracking Beacon
1100203	Mechanism Assembly Tracking Beacon
1100204	Tracking Beacon Assembly
1100205	Reflector Panels and Frame Assembly Tracking Beacon
1100206	Solar Panel Assembly Tracking Beacon
1100207	Inflatable Cislunar Reflecting Beacon Assembly (Alternate)
1100208	Configuration Cislunar Reflector Spec. Control (was D 614536)
1100209	Schematic Diagram Sun Acquisition and Longitudinal Control
1100210	Schematic Diagram Lateral Control System and Earth Sensing System
1100211	Schematic Diagram Lateral Control System and Earth Sensing System
1100212	Block Diagram Lateral Control System and Earth Sensing System
1100213	Block Diagram Sun Aquisition and Longitudinal Control System
1100214	Field Erection Procedure Cislunar Reflecting Beacon
1100215	Field Erection Procedure Tracking Beacon
1100216	Solar Panel Assembly Tracking Beacon (Alternate)

The inflatable cislunar reflecting beacon consists of the following components:

1. A commercial tripod with a pan head adapted for ease of beacon assembly by the astronauts on the lunar surface and a permanently attached plumb mounted at the base of the tripod center post.
2. A self-rigidizing aluminum foil-plastic inflatable reflector that will reflect to a field of view of ±10 degrees (20 degrees total) in a horizon and 39 degrees in elevation under

the LEM landing conditions, using a slightly curved inflatable camping mattress-type structure to produce the desired spherical approximation. This reflector assembly includes its own packing case and a circular preset bubble level built into the packing case. This design is based on a response from G. T. Schjeldahl in reply to an EOS inquiry.

An all metal mosaic spherical segment cislunar beacon utilizes a similar tripod assembly plus seven nestable electroformed nickel reflector panels which mount to a three-part frame which is readily erectable. The mosaic spherical segments mount to the frame using spring clips. While this design may have superior durability due to its metallic surfaces, the probability of reflector damage, due to the astronaut's limited dexterity and sense of feel, may be high. A slight increase in total beacon weight would improve this reliability appreciably.

The earth tracking beacon is basically an optical flat, instrumented to continuously track the earth and flash a continuous signal in the earth's direction.

Such a beacon requires a relatively sophisticated assembly compared with the simple static cislunar beacon. Component parts include:

1. Tripod assembly
2. Inner gimbal assembly
3. A tracking mechanism assembly
4. A reflector mounting frame
5. Hinged reflector panels (four)
6. Solar panel assembly
7. Reflector mounting frame
8. Packaging material and container

Four tracking axes are provided: Two for tracking the earth and two for tracking the sun. The earth and sun temperature sensors are mounted back to back so that the earth sensor points upward and the sun sensor downward. The earth and sun sensor are mounted on an arm attached to the earth tracking axes so that the sun sensor will always be co-axial with the earth. Therefore, if the sun's reflection strikes the sun sensor correctly, the reflection will be directed toward the earth. The other two axes are mounted on the same earth-sun sensor arm and align the reflector panels so that the solar reflection is always co-axial with the sun sensor. The earth's axes are designed to hunt over a ±8-degree field of view while the solar longitude tracking axis tracks over a ±45-degree field of view (i.e., half the sun's travel in a lunar day, since the mirror rotation need be only one-half the angular movement of the sun) and the solar latitudinal tracking axis which will track the ±2-degree solar selenographic latitude of ±2 degrees maximum.

This proposed tracking beacon presents many problems relative to the programs design specifications. The major problem areas include the following:

1. Weight. The design weight of 41 pounds is twice the 20-pound weight specification.
2. Package Volume. The total package volume of 7.125 ft^3 (including space for the 1/4 ft^3 cislunar beacon) is seven times the desired 1 ft^3 maximum.
3. Reliability. The tracking earth beacon reliability cannot be readily determined since the earth and sun sensor assemblies have not been designed in detail nor tested.

Minor earth tracking beacon design problems include questions of:

1. The optical accuracy and equivalent reflecting area of the 12 membrane, hinged panels: Panel stretching due to differential thermal expansion and localized rim and membrane reflector distortion should be studied using a prototype model.

2. Bearings and seals have been designed for vacuum environments similar to the lunar conditions; however, there is not complete agreement among investigators regarding suitable materials.
3. Differentiating between the sun and earth by the earth sensor will be a major problem at full moon. At this time, the earth sensor would tend to lock on the sun. Once locked on the sun, the earth sensor could not readily return to tracking the earth unless limit or cutoff switches are supplied to the earth tracking axes or signals. Depending upon the earth sensor field of view, the cutoff time could eliminate reflected signals from the earth beacon from up to 1 to 3 days around the lunar noon.

2.7 Specifications

In addition to the drawing package, specifications are included covering the desired characteristics of a sun and earth sensor. The QC specification details the general steps to be taken in inspecting the prototype beacon assemblies.

2.8 Cost and Schedules

A 3-year program to produce a flight unit earth tracking beacon would cost $560,000. A 2-year program to produce an inflatable cislunar beacon would cost $140,000; an all-metal reflector cislunar beacon would cost $170,000 for the same time period.

3. CONCLUSIONS AND RECOMMENDATIONS

As a result of the Phase I studies and the Phase II engineering design, specific conclusions and recommendations can be made relative to a lunar emplaced earth and cislunar solar reflecting beacon.

3.1 Conclusions

3.1.1 Beacon Feasibility

Specular reflectors, whether they are spherical, flat, or combinations thereof, are superior to diffuse beacons on an illuminance-to-weight ratio due to the higher reflectance, specific strength, and specific rigidity of a specular surface.

3.1.2 Computer Programs

The computer programs formulated during the Phase I program can determine the orientation requirements for static beacons and can predict the location and duration of a beacon signal from a static beacon at any point in space or on the earth's surface. Minor refinements are still required before NASA can usefully employ these programs. With these modifications, the program could be used when knowledge of the pointing direction of a communication link or camera is required.

3.1.3 Cislunar Beacon

A cislunar beacon can be built within the original weight and packaging specifications and to the revised photometric, range, and FOV requirements. The probability of achieving the 90-percent reliability specification is high. Also, there are no serious remaining design problems to be solved before producing the prototype cislunar beacon.

The electroformed reflector design alternate has one major area of uncertainty: The rigidity of the thin shell reflector panels and the possibility of damage to these during the unpacking and beacon erection operations.

The inflatable self-rigidizing reflector design alternate requires less assembly time than the electroformed reflector design and involves less possibility of damage during assembly.

3.1.4 Earth Tracking Beacon

The state of the art of sun and earth sensors operating in the lunar environment, particularly an earth sensor near full moon, is not sufficiently advanced in the areas of high temperatures, materials, minimum packaging, minimum field of view, and detection logic to permit the use of an off-the-shelf sensor design or hardware package for an earth tracking beacon. Such a sun and earth sensor assembly would be valuable for any lunar emplaced project requiring the transmission of electromagnetic signals from the moon to an earth receiver, having a known relationship with respect to the sun, earth, and radiation source on the lunar surface.

The low specific weight of the reflector panels can be achieved by a stretched membrane and rigidized rim design using hinged rectangular panels which must be carefully oriented with respect to each other to obtain the desired reflected energy to a particular field of view. While the assumptions made have been based on similar stretched membrane work performed at EOS, the accuracy of the flatness and alignment assumptions cannot be readily determined analytically.

Tradeoffs must be made between a wide field of view sensor, which reduces the complexity of the electromechanical tracking system but increases the realignment and hunting time at the lunar dusk and dawn, respectively, and sun lock-on time during dusk and full moon periods, and a narrow field of view sensor which yields greater net reflection time to the earth and requires a more sophisticated tracking system.

The weight limitation on the earth tracking beacon has been exceeded by a factor of two. Volume specifications have been exceeded by a factor of seven. While subsequent iterations should reduce both the weight and packaging figures, it is unlikely that the original specifications can ultimately be met for this beacon design.

The proposed tracking design could easily be converted to a static reflector beacon by the elimination of the tracking sensors and drive system and substituting an accurate alignment system. Such a static reflector would weigh about 20 pounds and occupy a volume of 2 ft^3, thereby approaching the desired weight and volumetric goals.

3.2 Recommendations

The computer programs developed for the orientation programs should be completed in a follow-on program if there is a high probability that:

1. A static lunar-emplaced earth reflector will be built.
2. Lunar photographic missions require specific sun-moon-camera phase angles which cannot be conveniently calculated by other programs.
3. A highly collimated communication system requires accurate positioning when the selenographic coordinates of the receiver (transmitter) are known with respect to the transmitter (receiver) position on the lunar surface.

Scale models of the cislunar and earth tracking beacons should be built to demonstrate the major features of the proposed designs.

3.2.1 Cislunar Beacon

A cislunar beacon prototype program should be initiated as soon as possible, utilizing the inflatable reflector concept. An ROM cost for delivering a flight unit two years after receipt of the order would be $140,000 assuming that any solar simulation test facilities required would be provided by MSC.

If the all-metal design shows promise as an alternate approach, a backup reflector study should be initiated at an ROM cost of $60,000 for a one-year period.

3.2.2 Earth Tracking Beacon

If the earth tracking beacon has a high priority, a prototype development program should be funded immediately to improve and produce a working design. Such a program would require 16 months at an ROM cost of $320,000.

If the earth tracking beacon design at present is of doubtful value due to the state-of-the-art sensor and motor problems and if the priority for such a beacon is not high, a 16-month, $200,000 program should be initiated to develop the sensors, motors, and bearing requirements for the earth beacon.

Any reflector concept using a stretched-membrane, rim-supported design should be studied analytically and empirically in greater depth.

Because of the weight and packing volumes actually achieved and the uncertainty of the component reliability of an earth beacon, serious consideration should be given to either shelving the concept of a small solar reflecting specular beacon or to studying alternate beacons such as a sun-powered flash tube, laser, etc., which would have higher weight and packaging specifications than those specified.

4. TECHNICAL DISCUSSION

The Phase I report provided NASA/MSC with parametric data relative to tradeoff considerations used in establishing beacon signal detection, reflector lifetime and reliability in the lunar environment, cost, weight, volume, and overall feasibility. The Phase II portion of the program details the engineering specifications and designs for the cislunar and earth beacons recommended by NASA/MSC following the presentation and analysis of the Phase I results. The following design constraints were originally placed on the beacon study.

Constraint	Earth Beacon	Lunar Beacon
Weight	20 earth pounds	5 earth pounds
Package volume	1 cubic foot	0.25 cubic foot
Maximum packaging dimension	23 inches	23 inches
External power source	Only solar energy	Only solar energy
Minimum operating lifetime	One year (self-contained)	One year (self-contained)
Reliability*	0.90	0.90
Environmental criteria	Environment specifications for Apollo scientific equipment	Environment specifications for Apollo scientific equipment

The beacons will be emplaced within a corridor ±5 degrees latitude by ±45 degrees longitude and will be considered to be viewed under full moon background brightness.

At the end of Phase I the maximum packaging dimensions were revised to reflect volumetric dimensions shown for the LEM Descent Stage

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*Reliability refers to the probability of receiving a detectable signal from the beacon within the design field of view after 1 year of operation.

Scientific Container Storage referenced in LID-360-22810. Also, the field of view of the cislunar beacon was confined to the angle contained by a $\pm 10^{\circ}$ horizontal angle and a 5 to 45° elevation angle, assuming that the subsolar point is east of the landing site, and with a range of 20 nautical miles as seen by the naked eye through the LEM window. Subsequent analysis and discussion indicated that the maximum range should be reduced to 10 nautical miles. The maximum range was also defined as a function of the elevation angle for the highest LEM landing trajectory.

This section discusses the details of the conceptual and engineering designs and the specifications developed for both types of solar beacons including the following areas:

1. Specular versus diffuse beacon comparison
2. Beacon photometry
3. Orientation
4. Beacon recommendations
5. Cislunar and earth beacon designs
6. Earth beacon design schedule, quality control, and miscellaneous

Various detector-detection instrument combinations for the earth and cislunar beacons are listed in Table 4-I. Note that the most recent MSC recommendations have emphasized combination 3 for the cislunar beacon — the naked eye. Photographic detection represents a more difficult design problem than visual detection, particularly with the cislunar beacon.

The optimum beacon flash times will vary with the detection instrument and use of the reflected signal. For photographic detection, the flash time should be long compared to the shutter speed to insure that sufficient protons strike the photographic emulsion. The percentage of flash time within the camera field of view should be high to increase the detection probability. If necessary, the percentage of flash time within the maximum camera field of view, i.e., an earth-based

TABLE 4-I

VARIOUS DETECTOR-INSTRUMENT COMBINATIONS

Combination	Detector	Instrument	Comments
EARTH BEACON			
1	Photograph	Camera with 10 to 60-inch aperture telescope	Long flash time desirable over specific field of view on earth.
2	Eye	10 to 60-inch aperture telescope	Either long or short flash time acceptable over specific field of view.
CISLUNAR			
1	Eye	1.58-inch aperture 28X sextant	High- or low-frequency flashing over wide field of view desirable.
2	Photograph	Camera	Long flash time over field of view within $\pm 47^{\circ}$ of local vertical to improve probability of photographic detection.
3	Eye	Eye	High- or low-frequency flashing over wide field of view desirable; short flash time acceptable.
4	Eye	Sighting telescope	High- or low-frequency flashing over wide field of view desirable; short flash time acceptable.

telescope, can be increased by any of the following methods:

1. Increase the beacon instantaneous field of view by:
   a. Decreasing the area factor of safety for a fixed total weight or area
   b. Increasing the beacon area
   c. Decreasing the detection range
   d. Designing the beacon for detection at less than the maximum background illumination
2. Increase the percentage of beacon flash time within the camera field of view by programming the motion of a dynamic beacon.
3. Limit the beacon total dynamic random field of view to increase the percentage of time within the camera field of view.

For visual landing recognition from the LEM vehicle, the beacon flashes can be short in duration (0.1 second or less) if the photon intensity from the flash is above the minimum detectable illuminance. The flashes should be frequent enough, however, to permit multiple beacon sightings within the landing time span and thereby improve the detection probability. The revised specifications permit a continuous beacon signal.

4.1 Comparison between Specular and Diffuse Reflectors

Reflectors are characterized by two different surface characteristics: specular and diffuse reflectance. The photometric analysis of lunar-emplaced solar specular or diffuse reflecting beacons is discussed in Appendixes A and B, respectively. Table 4-II summarizes the comparison of various optical and physical characteristics for specular and diffuse reflectors.

The illuminance from a flat specular reflector is 4.65×10^4 times more intense than a diffuse flat of equivalent area and reflectance when the phase, incident, and reflected angles are all zero degrees.

TABLE 4-II

COMPARISON OF SPECULAR AND DIFFUSE REFLECTORS

Comparison Characteristic	Units	Specular Reflector	Diffuse Reflector	Comments
1. Basic Physical Law		angle of incidence ψ = angle of reflection ϕ	$E = E_o \cos\phi$ Lamberts Law	1. Diffuse elemental area omni-directional; specular elemental area unidirectional
2. Illuminance from Flat Reflector, F		$E = \frac{a_s r_b E_s}{\Omega_s R^2} \cos\psi$	$E_d = \frac{a_d a_b E_s}{R^2} \cos\psi \cos\phi$	2. $E_s/E_d = \frac{a\ r_b}{a_d a_b\ \Omega_s} \frac{\cos\frac{\theta}{2}}{\cos\psi \cos\phi}$ $= 4.65 \times 10^4$ at $a = a_d$; $r = a_b$; θ, ψ, and $\phi = 0^o$
3. Intensity of signal from spherical reflector (collimated incident radiation)		$I_{bs} = r_b \left(\frac{d_b^2}{16}\right) E_s$	$I_{bd} = a_b \left(\frac{d_b^2}{6\pi}\right) [\sin\theta + (\pi-\theta) \cos\theta] E_s$	3. $I_{bd} = 2.67\ I_{bs}$ at $\theta = 0^o$; $I_{bd} = I_{bs}$ at $\theta = \pm 83^o$
4. Reflectance		r_b; 0.80-0.93	a_b; 0.70-0.90	4. Specular reflectance generally greater than diffuse reflectance
5. Mirror Material				
5.1 Thickness	inches	$2\text{-}4 \times 10^{-6}$ to 0.18×10^{-3}	$0.5\text{-}2 \times 10^{-3}$	5.1 Specular thickness much less than diffuse
5.2 Roughness	inches, rms	$\sim 1\text{-}2 \times 10^{-6}$	$8\text{-}32 \times 10^{-6}$	5.2 Specular surface much smoother
5.3 Strength	psi	$2\text{-}4 \times 10^5$ to 4×10^4	$0.5\text{-}10 \times 10^3$	5.3 Specular layer strength higher than diffuse
5.4 Weight of Reflectance Material	$lb/in.^2$	$\sim 1 \times 10^{-6}$	$\sim 1 \times 10^{-4}$	5.4 Diffuse layer much heavier than specular and almost equal to substrate weight in many cases
5.5 Application of Reflective Mat'l.		vacuum coated — foil	spray-coated, fired, or embossed foil	5.5 Specular application easier to control
5.6 Reflective Material		homogeneous layers of metals or inorganic dielectrics	Heterogeneous or homogeneous nonmetallic pigments; organic carriers or carriers	
5.7 Environmental Resistance		not susceptible to low energy uv, high energy uv, or protons	organic carriers darken under vacuum uv	5.7 Organic diffuse reflectors highly susceptible to uv

Nomenclature

- a = area, albedo
- d = diameter
- E = illuminance
- I = intensity
- r = reflance
- R = range
- θ = phase angle
- ϕ = angle of reflection
- φ = angle of incidence
- Ω = solid angle

Subscripts

- b = beacon
- d = diffuse
- s = specular, sun

However, for spherical reflectors the diffuse reflector has a reflectance advantage for phase angles less than or equal to $|83|$ degrees of arc. The attractiveness of the diffuse sphere over this range of phase angles has been a major factor in the design considerations for a lunar landing aid to be emplaced by the Surveyor vehicle. However, the attractiveness of a diffuse reflector decreases rapidly when one considers the strength, weight, and environmental resistance penalties which must be applied to diffuse surfaces. The weight of the diffuse layers is almost equal to the substrate weight for balloon (or balloon-erected) designs. Also, diffuse coatings have a specific strength almost an order of magnitude less than specular reflecting layers. In addition, diffuse coatings made with organic binders probably will exhibit much greater losses in reflectance than specular metallic surfaces.

Only specular beacons have been studied in detail during this program because:

1. A cislunar spherical diffuse beacon would weigh almost 10 times the cislunar design weight limit.
2. Diffuse beacons have been studied in depth by NASA as a lunar landing aid to be emplaced by the Surveyor.
3. The illuminance from a small diffuse spherical segment is much less than from a specular spherical segment of equal area.

4.2 Beacon Photometry

The variables affecting beacon area, viewing time, observation frequency, and field of view factors are listed in Table 4-III. These factors will be discussed in the subsections below.

4.2.1 Beacon Area Analysis

Beacon area analyses for specular and diffuse reflectors are listed in Appendixes A and B, respectively. Due to the weight and area penalties for diffuse beacons, as discussed above, the Phase I effort concentrated entirely on specular beacon design concepts.

TABLE 4-III

VARIABLES AFFECTING BEACON AREA, VIEWING TIME, OBSERVATION FREQUENCY, AND FIELD OF VIEW

	Variable	Area	Viewing Time	Observation Frequency	Field of View
1.	Background brightness, B_f	X			
2.	Beacon reflectance, r_b, a_b	X			
3.	Sun-moon-instrument phase angle, θ	X			
4.	Instrument beacon range, R	X			
5.	Integrated instrument optical transmittance, T_t	X			
6.	Integrated instrument angular resolution as a function of aperture, instrument errors, atmospheric seeing (and for photographic records of the detector errors), β	X			
7.	Atmospheric transmittance, T_e	X			
8.	Contrasts required for a given detector and probability of detection, C_v — visual, C_p — photographic	X			
9.	Lunar beacon location	X			
10.	Beacon surface geometry	X	X		X
11.	Beacon alignment to the sun, static or tracking		X	X	
12.	Beacon motion, static, rotary, oscillatory		X	X	X
13.	Beacon earth-sun orientation, static or tracking		X	X	

Table 4-IV summarizes the minimum beacon areas calculated for the earth and cislunar beacons. The minimum design areas were calculated using correction multiplication factors for the Tiffany data which represents contrasts for 50 percent probability of detection.

Recommended design areas for the beacons for zero-degree phase angle detection are presented based on arbitrary safety factors of 2 for the earth-photographed beacon, 7.2 for the earth-visually-detected beacon (using 10- to 60-inch telescopes) and 1.0 cislunar photograph and visual beacons. Earth factors of safety will increase by almost a factor of 10 as the phase angles approach $\pm 90^{\circ}$. Correspondingly, if the phase angles approach $\pm 90^{\circ}$, the telescopic seeing conditions could be poorer by a factor of $\sqrt{10}$, or the beacon design areas could be decreased by a factor of 10 and still be detectable. Multiexposure and electronic image enhancement techniques are available to improve the detection probabilities of photographic techniques.

The beacon design areas cited above and in Table 4-IV are much larger than earlier area calculations found in the literature. Depending on the FS and contrast values used, the areas are equal to or less than some related current beacon calculations. The variations in the values cited herein and other past and current computed sizes are due to such factors as:

1. Lunar background assumptions
2. Limitations of seeing conditions on resolution angle and the choice of resolution angle for computational purposes
3. Telescope magnification factor and its interrelationship with seeing conditions
4. Range
5. Telescope transmission
6. Atmospheric transmission
7. Choice of beacon reflectance

The effect of these is explained in Appendix A.

TABLE 4-IV

VIEWING TIME, FIELD OF VIEW AND OBSERVATION FREQUENCY FOR VARIOUS BASIC BEACON CONCEPTS

Beacon Type			Viewing Time - Fraction of Calendar Year Beacon Visible from Random			
Name	Classification Number (see Fig. 3-2)	Field of View FOV = Field of Reflection	Earth Observation (single point)	Cislunar Observation from 2π steradian FOV	Observation Frequency within FOV	Orientation Requirements
Sphere	1.1.1	4π steradians	1.0	1.0	continuous	none
Hemisphere	1.1.2	2π steradians	1.0	1.0	continuous	Axis of symmetry in line with local vertical
Lune	1.1.3	$2\theta^{*}$ steradians max	1.0 if $\theta \geq 8^{o}$	$\frac{\theta}{94^{o}}$	continuous	Longitudinal axis of lune parallel with lunar latitude; axis of symmetry of lune oriented to mean solar selenographic latitude
Cap	1.1.4	$\frac{8\theta^2}{\pi}$ steradians max	1.0 if $\theta \geq \frac{\pi}{2}$	$\frac{2\theta}{\pi}$ max	continuous	Attain maximum field of view by pointing axis of symmetry at the bisector of the angle defined by local vertical and moon-sun axes
Arch	1.1.5					
$\pm 4^{o}$ latitude		$\pm 8^{o}$ selenographic latitude	1.0	-	continuous	a. Longitudinal axis of arch parallel with lunar latitude axis of symmetry pointed to mean solar selenographic latitude
$\pm 45^{o}$ longitude		$\pm 90^{o}$ selenographic longitude				
$\pm 47^{o}$ latitude		2π steradians	-	1.0	continuous	b. Same as above
$\pm 90^{o}$ longitude						
$\pm 47^{o}$ latitude		4θ steradians	-	$\frac{2\theta}{\pi}$ max	continuous	c. Same as above
$\pm \theta^{o}$ longitude						
N facets	1.2.3	$N \times 7.13 \times 10^{5}$ steradians	$N \times 1.1 \times 10^{-4} \sim$ $N \times 29$ min/yr max	$N \times 1.135 \times 10^{-5}$ max		Accurate orientation required for specific earth detection point
Rotating 90^{o} cylindrical segment	2.1.3	2π steradians	$\frac{a_b}{a_{earth\ hemisphere}}$	$\frac{a_b}{a_{cislunar\ hemisphere}}$	$1 \leq 0.1$ sec flash in 1/rps seconds*	90^{o} cylindrical segment rotated to form an hemispherical approximation; axis of rotation parallel with the local vertical
Oscillating $\pm 47^{o}$ cylindrical segment $\pm\ \theta$ oscillation		4θ steradians	$\frac{a_b}{a_{earth\ arch}}$	$\frac{a_b}{a_{cislunar\ arch}}$	$2 \leq 0.1$ sec flashes in** 1/cps sec	Axis of oscillation is perpendicular to the axis of symmetry and parallel to local latitude for earth detection; parallel to local meridian for cislunar case
N-flats rotating about 2 axes	2.2.3	4π steradians	$\frac{a_b}{a_{earth\ sphere}}$	$\frac{a_b}{a_{cislunar\ sphere}}$	$N \leq 0.1$ sec flashes in $1/(rpm_1 \times rps_2)$** sec	

* θ = angular measurement; lune width; cone half angle; arch length from arch centerline; oscillation angle

** rps or cps = rotations or cycles per second = $0.1 \times 360^{o} \div$ instantaneous field of view

Of the above seven variables, all but the range and telescope transmission vary with time. The lunar background varies cyclically; the beacon reflectance is a decaying function with time, and the resolution angle, telescope magnification, and atmospheric transmission are interrelated factors which vary statistically from hour to hour and night to night in a general yearly cycle basis. Instead of arbitrarily choosing a given value for each of these time-dependent variables, a time function could be applied to the cyclical and decaying functions and a probability function to the other variables. These could all then be integrated to yield a time-dependent probability of detection. Such an expression would be complex and expensive to develop. However, the resultant calculations would give a more realistic concept of beacon detectability than when using arbitrarily chosen values such as have been listed in this report. Despite the arbitrary choice of values, the beacon areas calculated herein appear conservative.

4.2.2 Beacon Area, Viewing Time, Observation Frequency, and Field of View

The variables affecting beacon area, observation frequency, and field of view are shown in Table 4-V. It is desirable to obtain a maximum field of view for a given beacon area. Either a sphere or hemisphere will give the desired large field of view. However, each of the structures is inefficient in its use of reflective area. If one is willing to increase the orientation specifications for a given beacon, the beacon field of view can be maintained while decreasing beacon area up to a certain point.

The accuracy of the beacon surface will affect both the beacon field of view and the required area to produce a given signal intensity. In many flat designs it may be more advantageous, from a weight standpoint, to accept the optical sag due to gravitational effects than to provide the rigidity necessary to minimize distortion. Using a paraboloidal sag approximation where the sag, $S = r^2/2R$, r is the mirror radius and R the mirror radius of curvature; the edge slope

TABLE 4-V

BEACON AREA SUMMARY

Beacon	Detection	C_p or C_{50} [1]	Design Area/Radius	Range (nm)	Detection Resolution (β)
Earth	Photograph	0.08	33 ft^2	207,000	0.5 sec
Earth	Visual	0.016	4.6 ft^2	207,000	1.0 sec
Cislunar	Visual	1.0	10 ft	10	60 sec

[1] C_p = Photographic contrast

C_{50} = Tiffany 50 percent detection contrast

[2] Miscellaneous

T_t = 0.7 for earth beacon
0.1 for cislunar beacon

T_e = 0.7 for earth beacon
1.0 for cislunar beacon

K_θ = phase angle reflectance factor = 1.0

Γ_b = beacon reflectance = 0.80

M/Do = diametrical magnification factor = 25.4 for earth-visual

Do = instrument aperture ≈ 10 to 60 inches for earth detector
≈ 0.16 inches for cislunar detector

correspondingly is $dS/dr = r/R$; therefore, the allowable mirror sag is

$$S = \frac{r}{2}\left(\frac{dS}{dr}\right)$$

For a maximum error in mirror flatness of ±1 minute of arc, then the flatness tolerance would be ±0.000147 inch/radial inch.

A rim error of 1 second in flatness would require an area increase of 0.29 percent to insure the required beacon intensity. Correspondingly, the area increase for any other rim angular error would be

$$\left(1 + \frac{2.67|\theta|}{0.00928}\right)^2 - 1$$

where θ is the edge error in radians.

Since a rim rigidized flat is attractive from a weight standpoint, the tension, T, the film thickness, t, and lunar density, ρ, the flat edge length, ℓ, and the edge error, θ, are related by the term

$$\theta = \frac{t\rho\ell}{2T}$$

where $T = \frac{\sigma y}{t}$, where σy = yield stress of the material.

From this, the yield stress required to keep a 3-square-foot earth beacon optical flat accurate to within ±1 second of arc would be 115,000 pounds, which can be attained by controlled electroforming.

4.3 Reflector Orientation Studies

4.3.1 Purpose of Study

The purpose of the reflector orientation study is sevenfold:

1. Determine the orientation angles (γ_o, σ_o) of the reflector, relative to the moon's surface, which enable the reflected light to strike a given point on the earth's surface at a specified time.

2. Determine the path $[\Theta(t'), \Phi(t')]$ of the reflected light across the earth's surface, for a given orientation of the mirror.
3. Determine if the reflected light from the fixed mirror intercepts the earth in succeeding months.
4. Determine the times (t_{mi}) that an observer on earth enters and leaves the cone of reflected light, or merely enters or leaves the light.
5. Develop a method (i.e., mechanical device) for orienting the reflector on the moon's surface.
6. Determine the perturbed path of the reflected light on the earth's surface due to errors in the orientation of the reflector by the astronaut.
7. Determine the orientation of the mirror which allows the reflected light to intercept the Apollo vehicle orbiting the moon.

4.3.2 Completed Tasks

Item 1

The computation of the reflector orientation angles γ_o, σ_o requires the use of Programs I and II (refer to "Schematic of Computer Program," Fig. 4-1) plus the values of $i(t)$, $\Lambda(t)$, $\Omega'(t)$ (orientation angles of moon relative to earth), and X_{em}, Y_{em}, Z_{em}; X_{se}, Y_{se}, Z_{se} (position coordinates of moon relative to earth, and earth relative to sun) at one or one-half day intervals. The latter six coordinates will eventually be obtained from the JPL ephemeris tapes. For the purpose of early machine computation, these six coordinates have been obtained (at one-day intervals) from the 1962 edition of the American Ephemeris and Nautical Almanac. Programs I and II, along with $i(t)$, $\Lambda(t)$, $\Omega'(t)$, have been programmed on the EOS IBM 1620 digital computer (refer to Appendix C) and values of γ_o σ_o have been obtained. The results of a sample calculation are shown on pages 15 and 17 of the September monthly report.

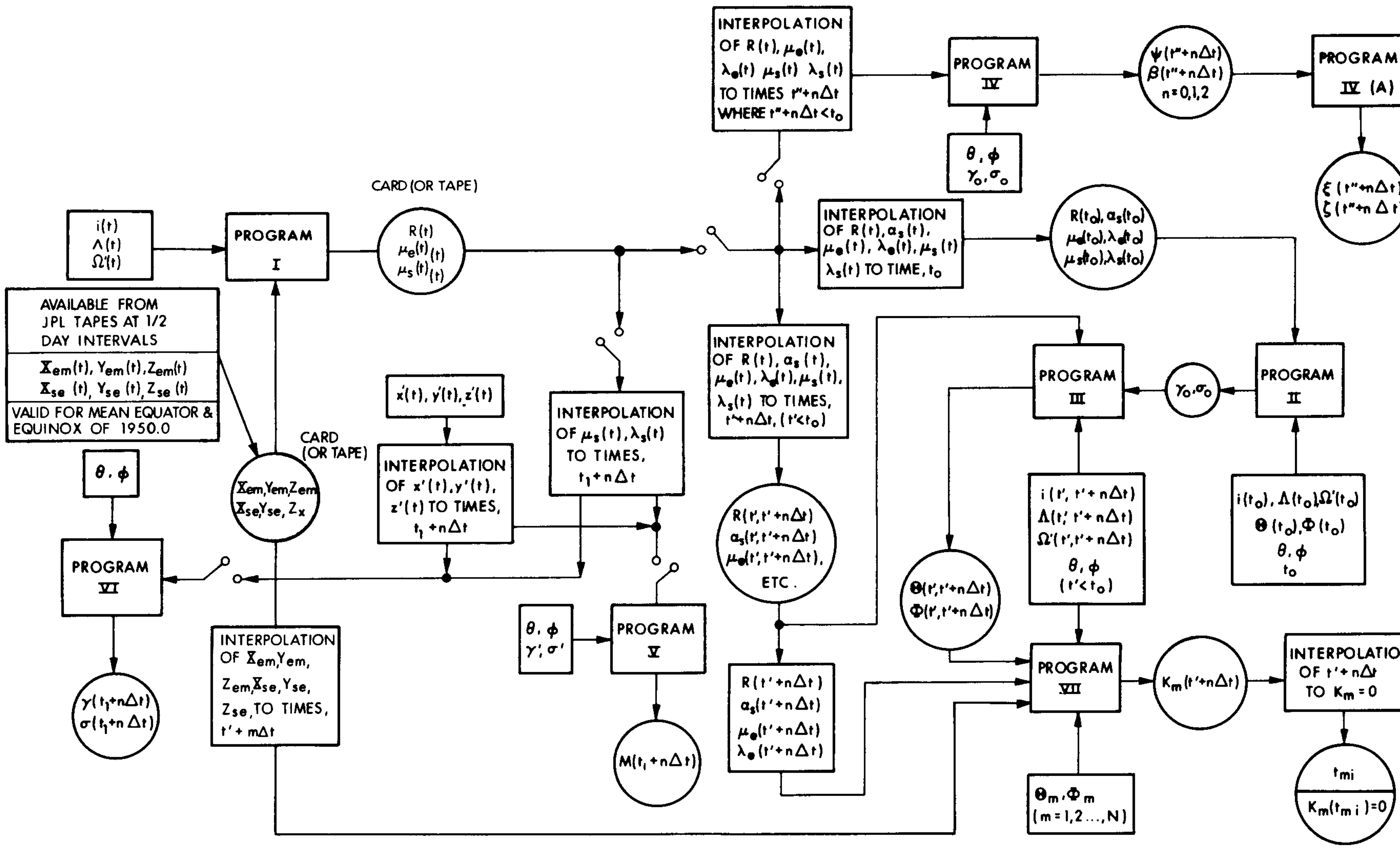


FIG. 4-1 SCHEMATIC OF COMPUTER PROGRAM

JPL has promised to provide EOS with the earth's and sun's selenographic coordinates (μ_e, λ_e and μ_s, λ_s, respectively) at one-day intervals for the years 1965-1980. If we make use of their results, then that part of Program I which calculates these coordinates can be eliminated.

Item 2

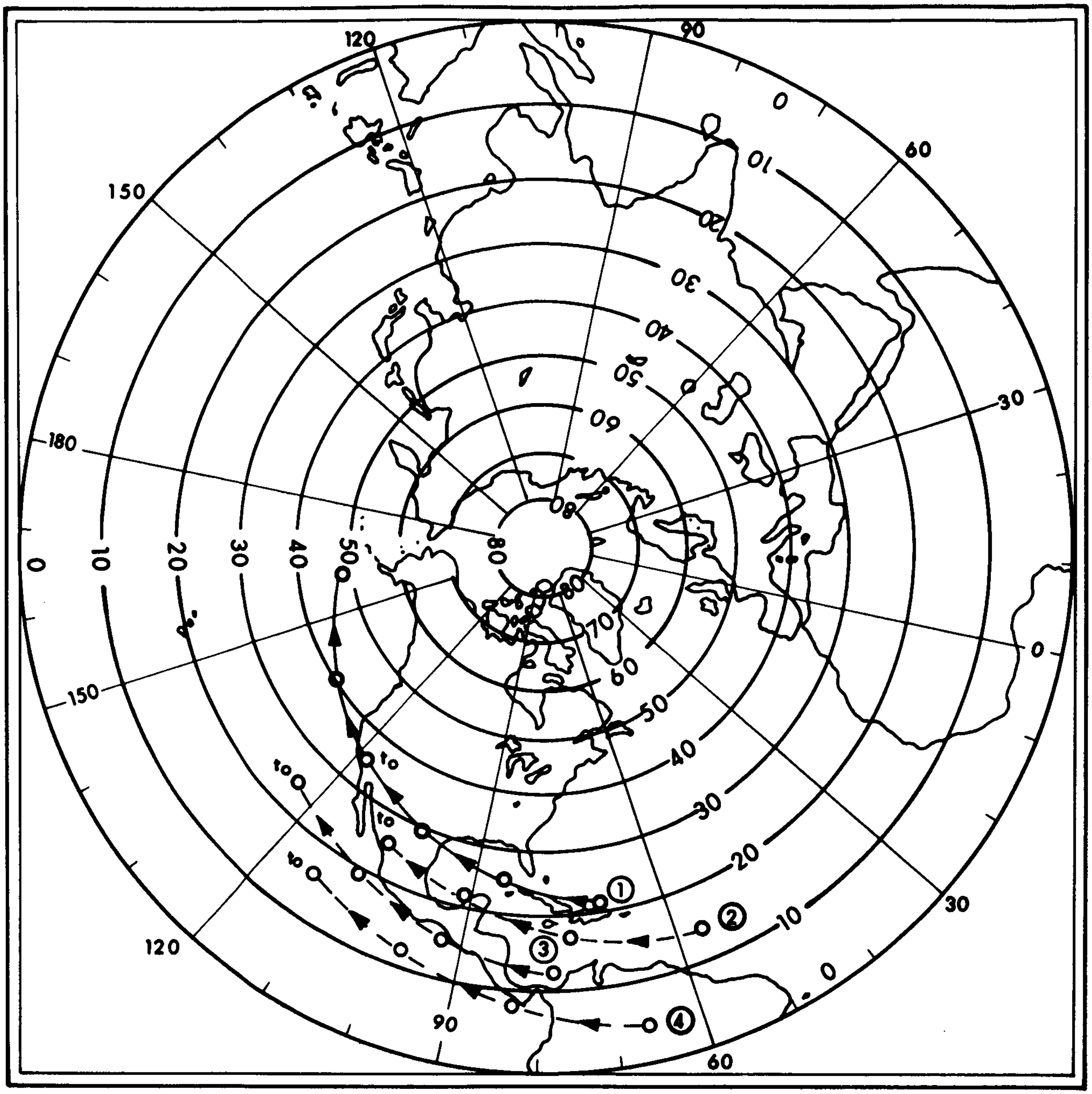
The computation of the path $\Theta(t')$, $\Phi(t')$ (= longitude and latitude, respectively, of the axis of the reflected light cone) of the reflected light across the earth's surface requires the use of Programs I and III, and the values γ_o, σ_o. Program III (refer to Appendix C) has been put on the digital computer and values of $\Theta(t')$, $\Phi(t')$ have been obtained. The results of a sample calculation are shown on page 17 of the September monthly report.

Item 3

In order to learn if the reflected light from the fixed (i.e., γ_o, σ_o are fixed) mirror intercepts the earth in succeeding months, the computation of Θ, Φ would have to be initiated each month, at a time when the relative positions of the earth, moon, and sun would seem favorable for such an interception. The computation would continue until the reflected light no longer shone on the earth, or until it was clear that this light would not intercept the earth. Figure 4-2 graphs the paths resulting from various orientation angle errors.

Item 4

The computation of the entrance and exit times t_{mi} (m identifies the observation station; i = 1 signifies entrance, i = 2 signifies exit) of an earth-bound observation station into and out of the reflected light cone, requires the use of Programs I and VII, the values of $\Theta(t')$, $\Phi(t')$, and the coordinates of the station(s) Θ_m, Φ_m. Program VII was put on the digital computer and an initial attempt to generate the t_{mi} was unsuccessful, due to the use of $\cos H_1$, instead of



REFLECTOR ORIENTATION FOR PERTURBED PATH: $\gamma_o + \Delta\gamma_o, \sigma_o + \Delta\sigma_o$

PATH	$\Delta\gamma_o$	$\Delta\sigma_\theta$
1	0	0
2	+0°.10	0
3	0	+0°.10
4	+0°.10	+0°.10

FIG. 4-2 REFLECTOR ORIENTATION FOR PERTURBED PATH: $\gamma_o + \Delta\gamma_o$, $\sigma_o + \Delta\sigma_o$

$\sin H_1$ (refer to Appendix C). The desired Program VII is given in the appendix, but it has not yet been programmed on the digital computer.

Item 5

According to the scheme devised by B. E. Kalensher for orienting the reflector on the moon's surface (refer to pages 14 through 15 and pages 20 through 23 of the September and October monthly reports, respectively), a knowledge of the four angles ψ, β, ζ, ξ is required. The computation of ψ, β requires the use of Programs I and IV and the values of γ_o, σ_o, θ, φ (θ, φ = longitude and latitude, respectively, of reflector on moon), and the computation of ζ, ξ requires Program IV(A) and the values of ψ, β. Program IV (refer to Appendix C) has been put on the digital computer and values of ψ, β have been obtained. The results of a sample calculation are given on page 15 of the September monthly report. Program IV(A) is given in the appendix, but it is not yet programmed on the digital computer.

Item 6

The perturbed path, $\Theta(t') + \Delta\Theta$, $\Phi(t') + \Delta\Phi$, of the reflected light on the earth's surface can easily be determined by introducing perturbed values $\gamma_o + \Delta\gamma_o$, $\sigma_o + \Delta\sigma_o$ into Program III. Since the reflected light will move a distance of approximately 7200 n.mi. across the earth's disc per degree change in γ_o or σ_o, we see that $\Delta\gamma_o$ and $\Delta\sigma_o$ must be less than 3440/7200 deg = 0.48 degrees. A calculation of the perturbed path has not yet been made.

Item 7

The computation of the mirror orientation angles γ, σ which enable the reflected light to intercept the module orbiting the moon, requires the use of Programs I and VI and the position coordinates of the module, $x'(t)$, $y'(t)$, $z'(t)$, measured in the orthogonal coordinate system x', y', z' fixed in the moon. The computation of the angle, M, between the reflected ray and the radius vector from the reflector to the module requires the use of Programs I and V and the instantaneous orientation angles, γ', σ'. Programs V and VI (refer to Appendix C) have been programmed on the digital computer, but values of γ, σ, M have not yet been computed.

4.4 Beacon Recommendations

4.4.1 Materials

Beacon materials can be chosen from a wide range of ceramics, metals, and plastics. However, the environmental and design constraints limit the logical material choices to plastics, metals, and metal-plastic composite structures. Due to the severe design weight constraints, and therefore the necessity for lightweight beacon designs, the materials chosen should have high specific strength and specific rigidity in the thin foil thicknesses and lightweight sections. Table 4-VI summarizes many of the materials which can be chosen for beacon construction.

Of the plastic materials, DuPont's Kapton type H film has superior temperature and structural properties. Of the metal foils, aluminum is the most desirable. However, electroformed nickel can achieve slightly higher specularity and will resist micrometeoroid attack better than aluminum.

Micrometeoroid mirror attack has been correlated with the density of the mirror material, the specific heat of the mirror material, the temperature difference between the mirror melting point and ambient mirror temperature, and the latent heat of fusion of the mirror material. These physio-thermal properties favor a nickel reflector surface for minimum micrometeorite damage. However, aluminum reflector surfaces will yield greater net reflective area per unit weight even after micrometeorite damage.

4.4.2 Power Systems, Drives, and Seals

Any motion imparted to the beacon will have to be initiated by energy, either external or internal to the beacon system. Various sources of power are given in Table 4-VII along with ratings

TABLE 4-VI BEACON MATERIAL COMPARISON

CODE	MATERIAL	DENSITY (LBS/IN³)	WT/1000 FT² AT 1-MIL THICK (LBS)	ROOM TEMP. ULT. TENSILE STRENGTH (PSI)	TENSILE MOD. OF ELASTICITY (PSI)	SOLAR RADIATION RESISTANCE	MAX. CONTINUOUS TEMP. (°F)	MIN. CONTINUOUS TEMP. (°F)	COMMENTS
1	TITANIUM (6AL-4V)	.164		130,000	15.5/16.0 $\times 10^6$	EXCELLENT	A	A	
1	MAGNESIUM	.064		30,-40,000	6.5×10^6	EXCELLENT	A	A	
1	ALUMINUM ALLOY	.098		18,-80,000	10.0/10.6 $\times 10^6$	EXCELLENT	A	A	
1	STAINLESS STEEL	.286		75,-185,000	28.0/29.0 $\times 10^6$	EXCELLENT	A	A	
1	BERYLLIUM COPPER	.297		60,-195,000	17.0/19.0 $\times 10^6$	EXCELLENT	A	A	
1	BERYLLIUM	.066		30,000	40×10^6	EXCELLENT	A	A	
1	TEFLON	.08		2,-4,500	$.058\times10^6$	GOOD	550	-425	DYNAMIC & STATIC COEF. OF FRICTION = .04
2	ALUMINUM FOIL	.10	14.4	13,000	10.0×10^6	EXCELLENT	A	A	
2	ETCHED ALUMINUM FOIL		4.3	13,000	10.0×10^6	EXCELLENT	A	A	USED FOR INNER SURFACE OF EXPANDABLE REFLECTORS. 70% OF ALUMINUM IS REMOVED BY CHEMICAL ETCHING.
2	NICKEL FOIL	.32	46.0	45,000	30.0×10^6	EXCELLENT	A	A	VALUES GIVEN ARE FOR ELECTROLYTIC NICKEL
3	"KAPTON" TYPE H	.051	7.4	25,000	$.43\times10^6$	GOOD	752	-452	
3	TEDLAR (PVF)	.050	7.17	19,000	$.28\times10^6$	GOOD	225	-100	
3	POLYPROPYLENE	.033	4.7	26,000	$.32\times10^6$	POOR	330	-80	VALUES GIVEN ARE FOR UNION CARBIDES' ORIENTED FILM
3	TEFLON FEP	.077	11.4	3,000	$.07\times10^6$	GOOD	400	-425	TYPE "C" CAN BE BONDED WITH CONVENTIONAL ADHESIVES.
3	MYLAR	.050	7.25	25,000	$.55\times10^6$	POOR	300	-75	
4	THERMAL COATING (WHITE PAINT)	.087	12.5	—	—	GOOD	B	B	APPLIED .001" THICK. COATING # S-13 DEVELOPED BY ILLINOIS INSTITUTE OF TECHNOLOGY RESEARCH INSTITUTE
4	PRIMER-THERMAL COATING	.056	8.0	—	—	GOOD	B	B	APPLIED .0005" THICK
4	ADHESIVE-FILM & FOIL LAMINATES	.069	10.0	—	—	GOOD	300	-328	APPLIED .00003" THICK. VALUES GIVEN ARE APPROX. MFG. BY SCHJELDAHL - # GT-301

CODE:
1 = STRUCTURAL & BEARING MAT'L
2 = METAL FOILS
3 = PLASTIC FILMS
4 = THERMAL COATINGS & ADHESIVES
5 = SELF RIGIDIZING LAMINATES

NOTES:
* .18 MIL AL FOIL ON BOTH SIDES
** .18 MIL AL FOIL ON OUTSIDE & .18 MIL ETCHED AL FOIL ON INSIDE

A WILL WITHSTAND LUNAR TEMP. RANGE INDEFINITELY
B MAT'L WAS NOT AFFECTED AFTER BEING TESTED IN SIMULATED SPACE ENVIRONMENT FOR 6 MONTHS.

CODE	LAMINATE	FILM THICKNESS (MILS)	METAL FOIL THICKNESS (MILS)	ADHESIVE THICKNESS (MILS)	TOTAL THICKNESS (MILS)	WT/1000 FT² * (LBS)	WT/1000 FT² ** (LBS)	COMMENTS
5	AL-KAPTON-AL	.5	2x.18	2x.03	.92	9.5	7.7	
5	AL-TEDLAR-AL	.5	2x.18	2x.03	.92	9.4	7.6	
5	AL-POLYPROPYLENE-AL	.5	2x.18	2x.03	.92	8.1	6.3	
5	AL-FEP-AL	.5	2x.18	2x.03	.92	11.5	9.7	
5	AL-MYLAR-AL	.5	2x.18	2x.03	.92	9.4	7.6	

TABLE 4-VII

COMPARISON OF POWER GENERATING SYSTEMS

Generating Source	Power Generation System	Power Output	Advantages	Disadvantages	*Relative Rating
SOLAR RADIATION	Solar Cells	Electrical	Lightweight, compact, no moving parts. Prior experience with solar cells.	Solar cells are degraded due to solar radiation, meteorites, dust, etc. Power output is not constant, depends on sun-cell orientation and temperature of cells. Solar cell efficiency reduced about 60% on the moon	1
SOLAR RADIATION	Thermionic Converter	Electrical	Capable of large power output, high power-to-weight ratio.	State of the art not sufficiently developed yet. Requires continuous, accurate alignment of solar concentrator with respect to converter.	5
SOLAR RADIATION	Thermal Expansion Drive	Mechanical	Simple construction, lightweight, large forces can be produced but output movement is small. Not degraded by environment.	Limited motion, must radiate heat away before output cycle can be repeated, long cycle time.	3
SOLAR RADIATION	Bimetallic Drive	Mechanical	Simple construction, lightweight, can be used for limited motion, low force applications. Prior experience with bimetals. Not degraded by environment.	Limited motion, low force output, must radiate heat away before output cycle can be repeated.	4
SOLAR RADIATION	Solar Pressure	Mechanical	Utilizes environment	Forces produced are too small (solar pressure = 1.3×10^{-9} psi), necessitating extremely large reaction areas to obtain usable output force.	9
CHEMICAL REACTION	Battery	Electrical	Self-contained power source. Space experience.	Limited operational life. May need further development to meet temperature and vacuum environment. Excessive weight for required life.	8
CHEMICAL REACTION	Hydrogen-Oxygen Fuel Cell	Electrical	Self-contained unit, three or four times the output per pound as compared to a battery.	Requires fuel supply, plumbing, etc. Excessive weight for required life.	7
NUCLEAR RADIATION	Radioisotope Thermoelectric Generator	Electrical	Self-contained, extremely long life (many years). Output independent of environment. Fairly compact (approx. size = 4" x 4" x 4"). Larger units have been successfully tested in space.	Cost of plutonium fuel element is high. Weight is about 2 to 4 pounds.	2
ASTRONAUT	Spring or Weight System	Mechanical	Astronaut can either wind a spring or use lunar objects to drive pendulum system.	Decaying force output; limited storage life; storable energy limited by spring weight or structural strength to bear pendulum weight.	6

*1 = Highest Rating

for each system. Despite the complexities of a photovoltaic system, the successes of photovoltaic power systems in space still rate this as the leading space power system today. Though photovoltaic systems have been described for many dynamic beacon concepts, thermal-mechanical drives can be readily substituted for the photovoltaic system in some design concepts.

Table 4-VIII describes various drives that can be used with dynamic beacons. Though the ac motor drive is listed with the highest rating, recent developments with brushless sealed dc motors indicate that a dc drive is almost as reliable as an ac drive. Figures 4-3 and 4-4 show various proven methods for sealing bearings from the high-vacuum environment including the harmonic drive, labyrinth seal, and hermetically sealed bellows approaches. Sealing bearings by any of these methods should present no design or reliability problems.

4.4.3 Reliability

The reliability of the lunar-emplaced solar reflecting beacon will depend upon the following factors:

1. Erectability
2. Orientation
3. Durability in the lunar environment
4. LEM ascent dust protection

4.4.3.1 Erectability

Beacon erectability is primarily dependent upon the mobility of the space-suited astronaut. Stooping and bending movements will be difficult because these operations reduce the volume of the pressure suit. These movements will require a definite exertion to counteract the changes in the pressure suit, particularly since the low lunar gravity reduces the effective weight of the astronaut in the bending process. The manual dexterity of the suited astronaut will be equivalent to when one wears heavy mittens over rubber gloves. Though the space suit gloves are designed to curve naturally, gripping small-diameter objects for extended periods will require effort, since the

TABLE 4-VIII

COMPARISON OF DRIVES

Power Input Required	Drive	Power Output	Advantages	Disadvantages	*Relative Rating
Electrical	Brushless dc Motor	Continuous Rotation	Long operating life, direct utilization of dc power, no inverter required.	Relatively new development.	2
Electrical	Ac Motor	Continuous Rotation	Long operating life, conventional motor construction.	Requires an inverter to convert dc to ac.	1
Electrical	Dc Motor	Continuous Rotation	Conventional motor construction, direct utilization of dc power, no inverter required.	Short operating life due to excessive brush wear in vacuum environment.	3
Mechanical	Clock-Motor	Continuous Rotation	No electronics involved.	Requires a "self-winding" mechanism such as a thermal or bimetallic expansion drive.	4
Thermal	Thermal Expansion Drive	Limited Motion	Simple, lightweight, not degraded by environment.	Limited motion, long cycle time.	5
Thermal	Bimetallic Drive	Limited Motion	Simple, lightweight, not degraded by environment.	Limited motion, long cycle time.	6

*1 = Highest Rating

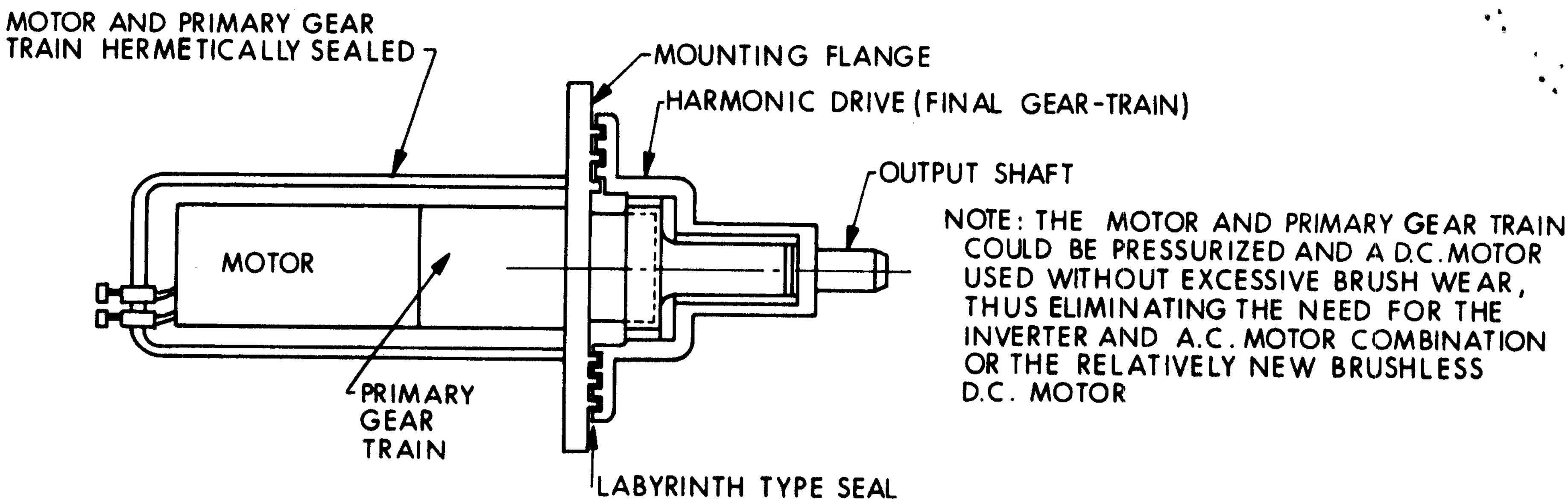


FIG. 4-3 HARMONIC DRIVE (primary stage hermetically sealed)

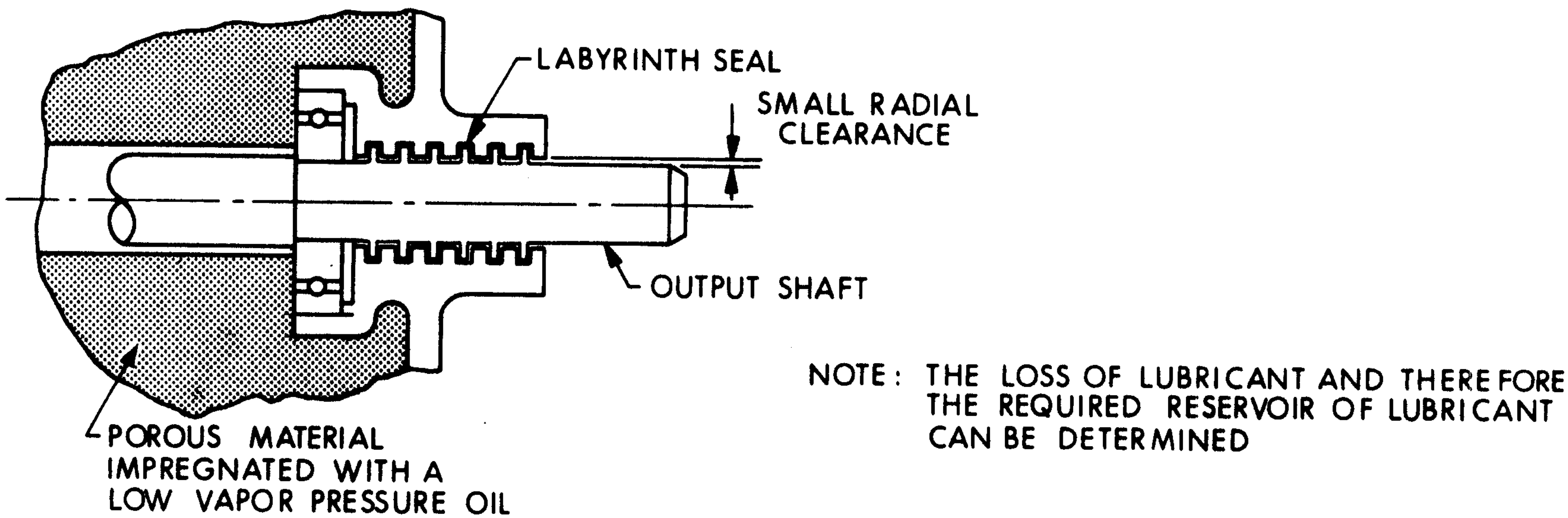


FIG. 4-4 LABYRINTH SEAL

pressure within the suit tends to restore the fingers to the normal position. The reduced sensitivity of the gloved fingers will present problems in handling fragile thin foils or beacon sections. It will be difficult to lift the arms higher than the head or to hold any object in front of the helmet face plate.

Erectability is also dependent upon the number of component assemblies required for the final beacon assembly. Each assembly operation will require additional time which will vary with the movements and forces required. High assembly forces may tax the astronaut and increase the total assembly time. Orientation requirements to maximize beacon effectiveness also affect erectability.

Erectability relates to reliability in that a beacon which can be readily assembled within the schedule without difficulty will have a high probability of success, and therefore reliability. Those beacons which are difficult to erect may be left unassembled if the astronaut encounters difficulties, thus reducing the reliability of the beacon concept.

4.4.3.2 Orientation

Primary consideration in the orientation of the solar beacons is the accuracy of the alignment sighting and adjustments. The sighting accuracy depends upon the instrument accuracy, the astronaut's precision, and the coupling between the alignment instrument and the beacon structure. The alignment instrument accuracy is dependent upon its optical and mechanical design. The precision with which the astronaut takes the alignment sightings will depend upon the astronaut's training, the relationship between the helmet face plate and the alignment instrument, the dexterity required for instrument alignment and manipulation, and the coupling of the alignment instrument upon the beacon. If the beacon does not have sufficient rigidity to withstand the vibration and shocks attendant with the attachment and detachment of the alignment instrument from the beacon, the alignment and adjustment of the beacon orientation may be adversely affected. Beacon orientation will also be dependent upon the number and accuracy of the beacon adjustments.

The load-bearing strength of the lunar surface may be insufficient to hold the aligned beacon within the orientation accuracy tolerances even after using large pads to reduce the penetration within the lunar surface. The present penetration predictions should be verified as soon as possible to increase the reliability of the beacon design and orientation.

If the orientation problem is difficult, time-consuming, and inaccurate, the reliability of the beacon will be adversely affected.

4.4.3.3 Durability in the Lunar Environment

Table 4-IX summarizes characteristics of the lunar environment. The major potential problem areas in the lunar environment are the lunar and beacon surface temperatures, the meteoroid and micrometeoroid impact, ultraviolet and x-ray radiation, the nozzle dust from the LEM ascent, and the lunar surface bearing strength, as discussed above.

The lunar temperature range will not adversely affect the structural materials proposed for the various beacon concepts. However, the temperature extremes will affect electronic components and storage batteries. High lunar temperatures will reduce the efficiency of photovoltaic cells as much as 60 percent and may affect electronic components such as photomultiplier tubes. Specific regulation of the thermal characteristics of the components or component packaging will be necessary to maintain operating temperatures within desired limits.

Micrometeoroid impact is still being studied in space probes and ground experiments. Such a wide variation in empirical and analytical reflectance degradation tests exists, that the estimation of degradation characteristics of any reflective surfaces

TABLE 4-IX

LUNAR ENVIRONMENT SUMMARY

Characteristic	Subheading	Quantity	Remarks
Temperature	Maximum lunar Minimum lunar Maximum reflector* Minimum reflector*	$400 \pm 25^{o}K$ - $261^{o}F$ $120 \pm 5^{o}K$ - $-243^{o}F$ $470^{o}K$ - $+387^{o}F$ $100^{o}K$ - $-280^{o}F$	Kapton plastic film solves plastics durability problems. High temperatures reduce solar cell efficiency and accuracy of electronic components
Atmosphere	Pressure Composition	10^{-10} mm Hg 50-70% CO_2 45-27% H_2O 4-2% H_2	Presents no design difficulties No chemical corrosion problems
Meteoroids		1/2 earth impact rate indicated	NASA, Lewis FY'64 ground experimental tests indicate up to 50% reflectance loss, more data required; 1/2% reflectance loss/year estimated on basis of analytical data
Gravitational Field		$0.16\ g \approx 162.2\ cm/sec^2$	Presents no design difficulties
Electromagnetic Radiation	Solar Constant > 3000Å	$2.0 \pm 0.04\ cal/cm^2/min$ $15.2 \pm 0.6\ lumens/cm^2$	Can accentuate thermal control problem of power system, plastics; depends on absorptivity and emissivity NASA, Langley FY'66 ground experimental program; plastic and dielectric overcoatings may be affected significantly; helps rigidize some plastics.
	Solar UV x-rays < 3000Å	$0.0028\ cal/cm^2/min$	
	Planetary albedo radiation Planetary thermal emission Moon albedo radiation	0.073 average	Effect on beacon varies with phase angle, local terrain and composition and beacon altitude
Charged Particles	Galactic Cosmic Rays Solar Cosmic Rays	2×10^8/cm/sec 0.5 to 5 keV higher flux and energies in periods of high solar flare activity	~ 1Å/year erosion ≤ 1% reflectance loss/year. NASA, Langley FY'66 ground experimental program; 10-23%/year reflectance rates possible during high solar activity

*$\alpha/\epsilon >> 1$; reflectance coatings with an α/ϵ lower than 1 can be applied.

TABLE 4-IX (contd)

LUNAR ENVIRONMENT SUMMARY

Characteristic	Subheading	Quantity	Remarks
Surface Dust and Crust Thickness	Charged Particle Levitation Meteoroid Ricochet LEM Nozzle Dust Sprays Bearing Strength	10 cm penetration/ 1 psi static load 30 cm penetration/ 12 psi dynamic load	Thickness of dust layer and bearing strength determine design of beacon supports; surface charges should be minimized, shielding desirable where optically practical; low bearing strength may accentuate orientation problem
Magnetic Field		10^{-3} gauss	No design problems

is difficult to predict. Prediction of the durability of inflated balloons and toruses and thin-shell, self-rigidized structures is also difficult. Based on earlier analytical and empirical investigations at EOS, it appears that a reflectance loss of as much as 50 percent per year should be a conservative figure. The uncertainty in this figure accounts for the large beacon area factor of safety.

High-energy ultraviolet and proton radiation will also reduce the surface reflectance. A present ground experiment funded by NASA/Langley is investigating this phenomenon for electroformed nickel and vacuum overcoated plastic-coated aluminum panels.

4.4.3.4 LEM Ascent Dust Protection

Methods of protecting the beacon reflective surfaces from the dust created by the LEM ascent include:

1. Reflector Orientation. If the reflector is oriented such that the reflective surface does not see the LEM vehicle, then the reflective surface will not receive direct impingement of dust particles other than those whose trajectory lobs the particle onto the reflective surface. If the beacon is oriented upside down during the LEM ascent, then no particles will directly strike the reflective surface. However, this upside-down orientation is not practical for all beacon concepts.
2. Coated Reflector. The reflector surface can be overcoated with a subliming material which will boil off or evaporate under the effects of ultraviolet and solar radiation. This coating will reduce the degradation caused by direct dust impact and can serve as a gas bearing for the removal of dust particles on surfaces which oscillate or are steeply inclined. Such a coating may have little or no value in the removal of dust from surfaces which are horizontal.

3. Shields. Smaller beacons can utilize a plastic or foil shield placed on the blast-off side of the reflector which can be swung out of the way after the LEM vehicle has departed. Such a shield could consist of a lean-to foil or plastic sheet which utilizes a camphor plug, mousetrap-type mechanism as a timing and removal device. The camphor plug will eventually evaporate. When evaporated, it will activate the release mechanism.
4. Physical Location. Depending on the mobility of the astronaut, it may be possible to carry the beacon package to a site away from the immediate vicinity of the LEM vehicle. This preferred site would also improve beacon reliability.

4.4.4 Recommended Beacon Concepts

A wide variety of beacon concepts were studied in Phase I resulting in a limited investigation of the problem areas of each beacon type. The conclusions derived from these conceptual studies were overly optimistic and minimized the difficulties in meeting the weight and packaging specifications. Phase II design studies pointed out these difficulties. A 33 ft^2 flat reflector tracking earth beacon and a dynamic cislunar beacon with a virtual image of 0.01 ft^2 were recommended. See the Phase I summary report for additional details. Since the weight, and packaging and hardware problem areas were not realized or emphasized at the Phase I presentation, and since a relatively continuous signal is very desirable for detection, MSC concurred with the earth tracking beacon recommendation. About this time NASA decided that the Surveyor did not have sufficient payload to carry a self-inflating spherical beacon to be used as a lunar landing aid. This gave greater emphasis to the cislunar beacon designed for this program for its use as a lunar landing aid.

4.5 Beacon Designs

Revised cislunar beacon specifications were submitted to EOS by MSC to start the Phase II design effort. These included:

Range:	20 nautical miles (later revised to 10)
Altitude:	Reference "Final Phase LEM Landing Trajectories"
Maximum Packaging Dimensions:	Reference "LEM Descent Stage Scientific Equipment Containers Storage", Ref. LID-360-22810
LEM Elevation Angles:	5 to 45°
LEM Horizontal Angle:	$\pm 10^{\circ}$
Solar Elevation:	7 to 45°
Erection Time:	10 minutes

Note that the maximum packaging dimensions and erection time apply also to the earth tracking beacon.

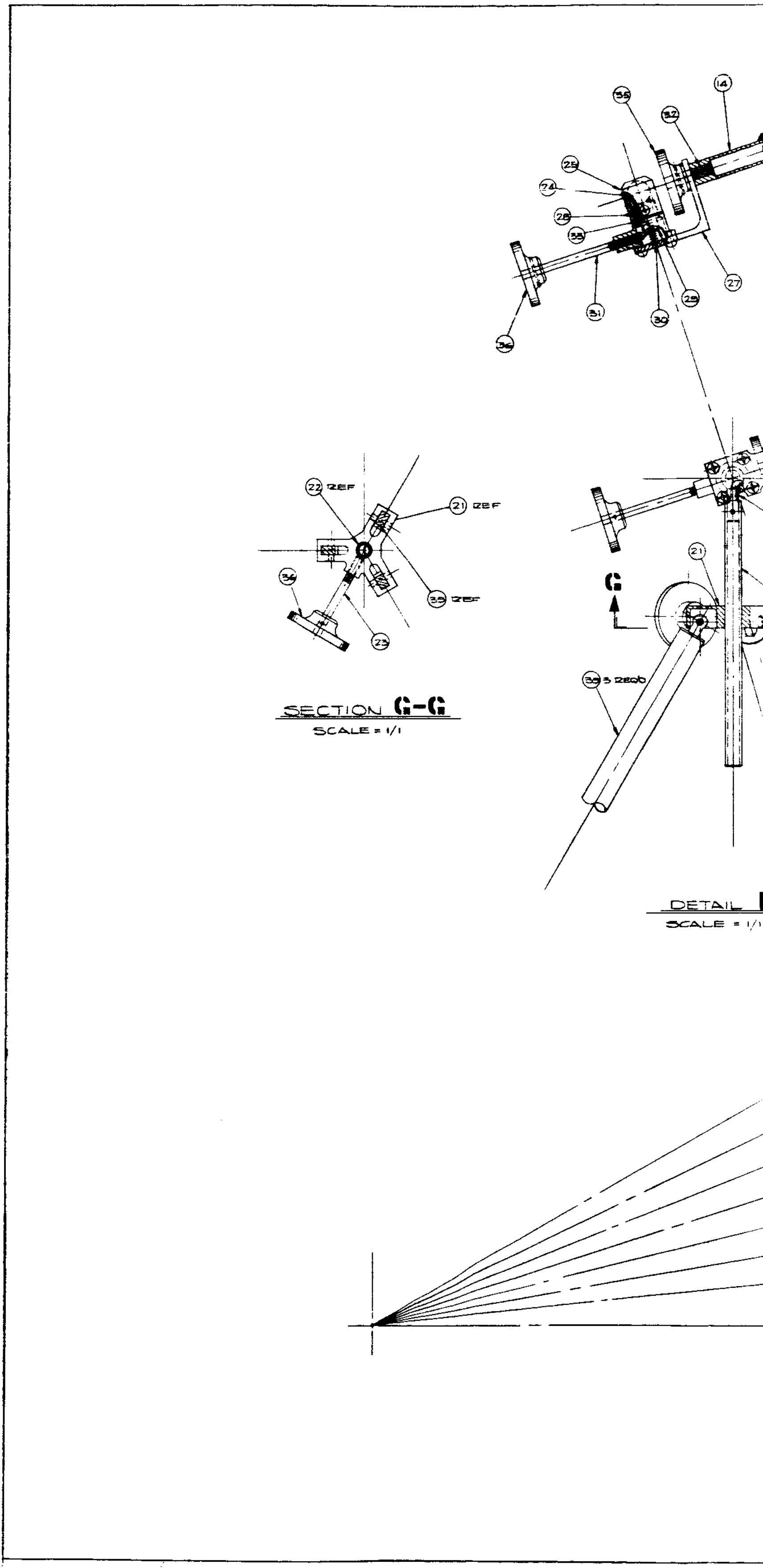
4.5.1 Cislunar Beacon

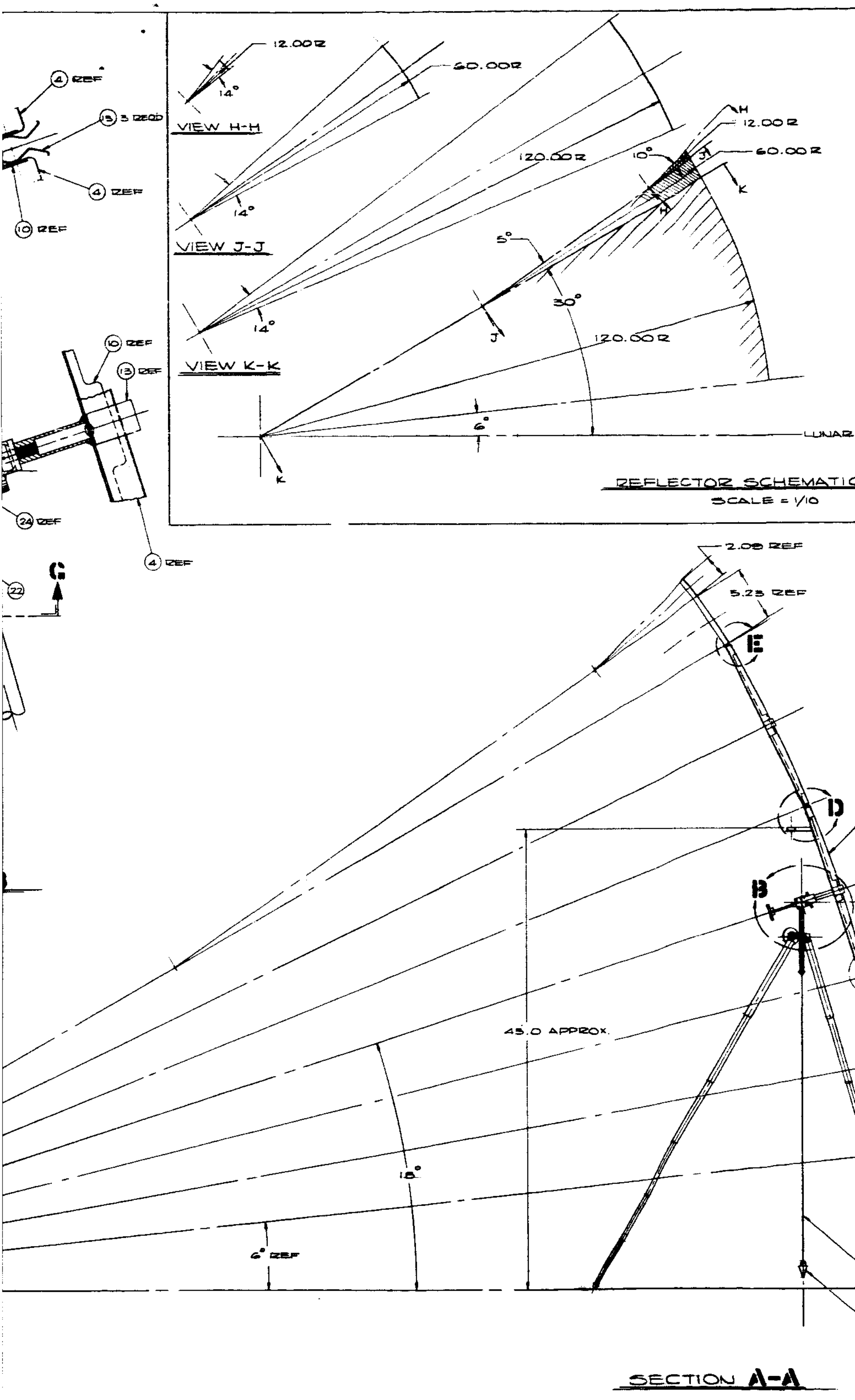
The revised cislunar beacon specifications reduced the required field of view to a solid angle 20° in horizon by 40° in elevation. Therefore, allowing for a maximum selenographic solar latitude change of $\pm 2^{\circ}$, the beacon need only subtend a total angle of 14° by 39° in elevation. By revising the visual range requirements from 20 nautical miles to 10 nautical miles, a practical beacon weight of 5 pounds can be achieved. Two designs are proposed for the cislunar beacon, both of which have different advantages relative to the reliability and erectability.

The cislunar beacon designs are shown in Figs. 4-5, 4-6, 4-7, and 4-8.

4.5.1.1 All Metal Cislunar Reflecting Assembly

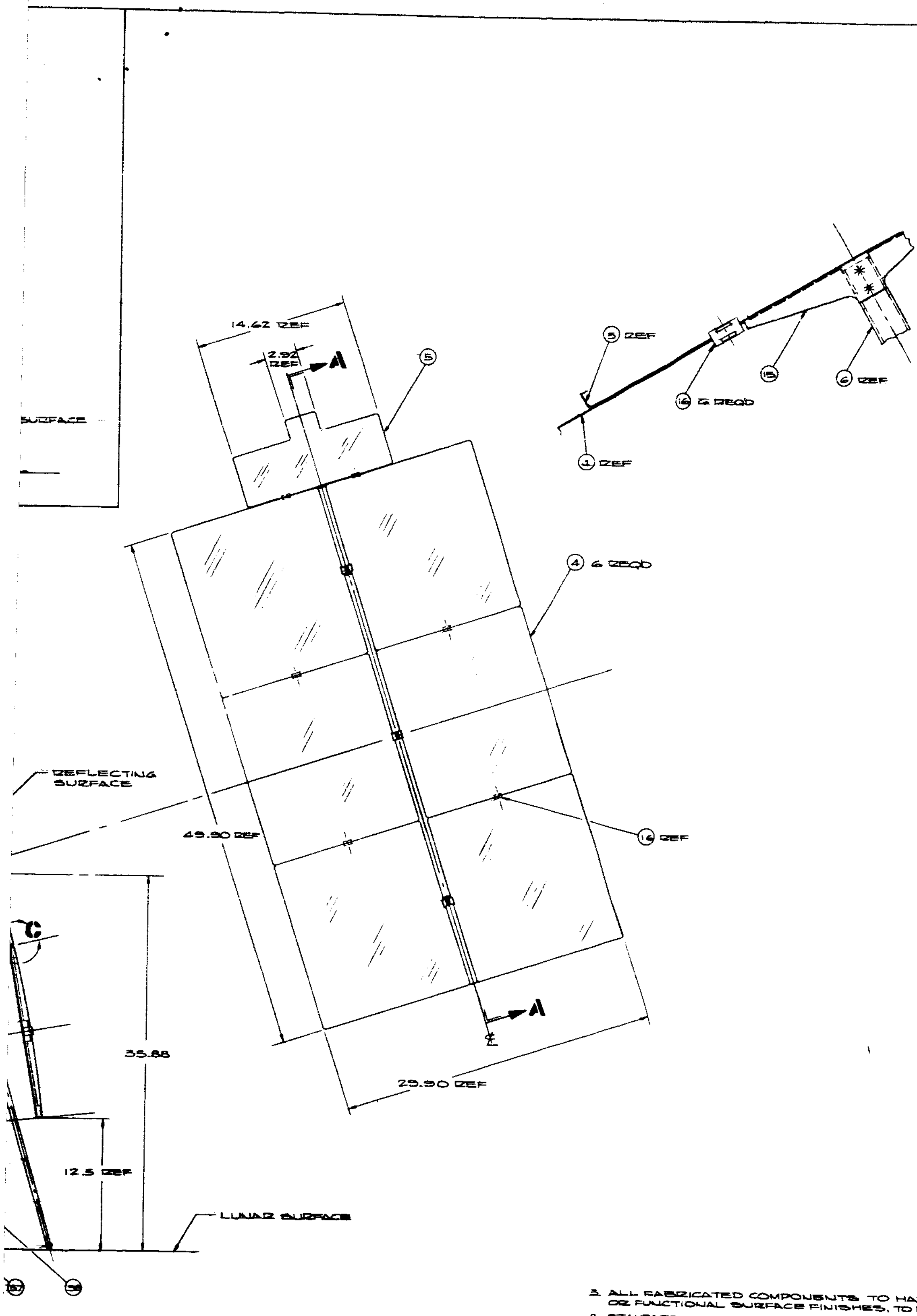
Figure 4-5 is a complete assembly of the metal mosaic reflector utilizing vacuum overcoated electroformed nickel spherical segments rigidized by the rims of the reflector. This design


SECTION G-G
SCALE = 1/1
DETAIL
SCALE = 1/1



4 REF
13 3 REQD
4 REF
10 REF
VIEW H-H
12.00 R
14°
60.00 R
VIEW J-J
14°
VIEW K-K
14°
120.00 R
10°
H
12.00 R
J
60.00 R
K
H
5°
30°
J
120.00 R
6°
K
LUNAR
REFLECTOR SCHEMATIC
SCALE = 1/10
10 REF
13 REF
24 REF
4 REF
22
G
2.08 REF
5.25 REF
E
D
B
45.0 APPROX.
18°
6° REF
SECTION A-A

47-2



3. ALL FABRICATED COMPONENTS TO HA
OR FUNCTIONAL SURFACE FINISHES, TO
2. STANDARD MISCELLANEOUS FASTENING
SUCH AS SCREWS, WASHERS, NUTS, P
NOT CALLED OUT IN THE BILL OF MAT
ARE TO BE OF SUITABLE STAINLESS
SELECTED AND ITEMIZED IN ACCORDA
PRACTICE AT TIME OF DETAIL DESIG
1. WEIGHT (CALC.): REFLECTOR & FRAME
TRIPOD
SHIPPING CONTAINER
TOTAL

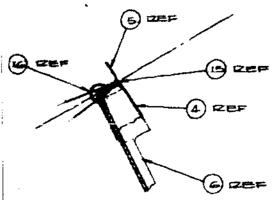
NOTES:

3
2

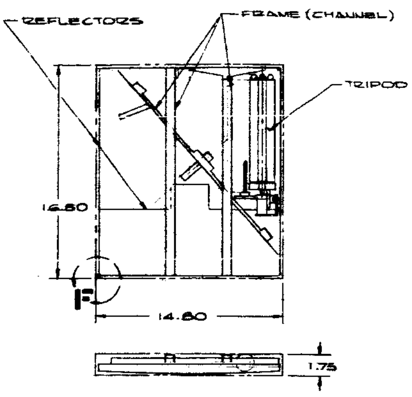
FIG. 4-5

48-1

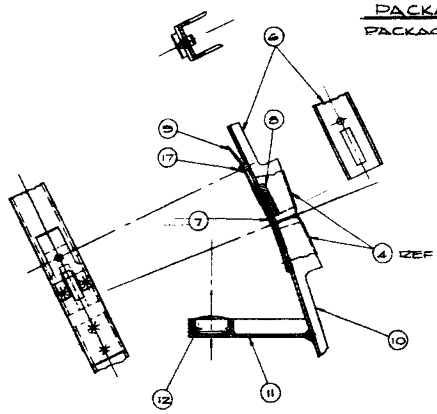
REVISIONS



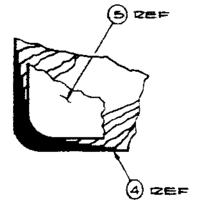
DETAIL E
SCALE = 1/1



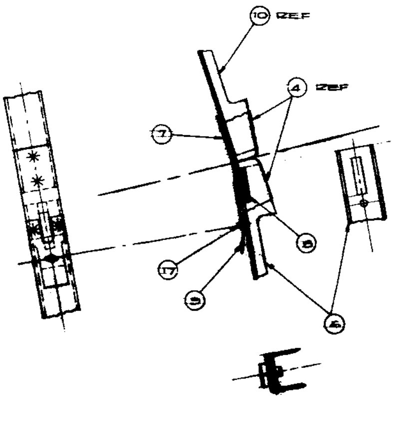
PACKAGING CONFIGURATION
PACKAGE VOLUME = 1/4 CUBIC FOOT



DETAIL D
SCALE = 1/1



DETAIL F SCALE = 4/1
REFLECTORS NESTLED IN STOWAGE POSITION



DETAIL C
SCALE = 1/1

...VE SUITABLE PROTECTIVE
...E SPECIFIED BY ENGINEERING.
...HARDWARE,
...NS ETC.,
...ERIALS
... STEEL MATERIALS.
...NCE WITH GOOD ENGINEERING
...
2.0 LBS
1.5
2.0
5.5 LBS

3		39		TRIPOD LEG	3 SECTIONS STOWED = 5/8 DIA x 8 5/8 LONG EXTENDED = 41 1/4 LONG		COML
1		38		PLUMBLINE	1/32 DIA	NYLON	
1		37		PLUMB	APPROX 3 OZ.	BRASS	COML
2		36		KNOB	1 1/2 DIA	NYLON	
1		35		KNOB	1 1/2 DIA	NYLON	
		34					
1		33		SPACER	3/4 DIA	NYLON	
1		32		SHAFT	1/4 DIA	2024-T4 AL ALY	
1		31		SHAFT	3/16 DIA	2024-T4 AL ALY	
1		30		SPRING	5/32 ID DIA	CRES	COML
1		29		CYLINDER	3/8 DIA	2024-T4 AL ALY	
1		28		RETAINER	5/8 DIA	2024-T4 AL ALY	
1		27		ANGLE	.125 x 1.75 x 1.75	2024-T4 AL ALY	
1		26		ADAPTER	1.00 THK	2024-T4 AL ALY	
1		25		HOUSING	3/4 DIA	2024-T4 AL ALY	
1		24		POST	1/2 DIA	6061-T6 AL ALY	
1		23		SHAFT	3/16 DIA	2024-T4 AL ALY	
1		22		TUBE	3/8 O.D. x.058 W	6061-T6 AL ALY	
1		21		HEAD PLATE	1/2 THK	2024-T4 AL ALY	
		20					
		19					
		18					
	2	17		PIN	1/8 DIA	2024-T4 AL ALY	
	6	16		CLIP			COML
	1	15		ANGLE	.032 THK	6061-T6 AL ALY	
	1	14		ROD	1/2 DIA	6061-T6 AL ALY	
	3	13		SPRING CLIP	.025 THK	304 CRES	
	1	12		CIRCULAR BUBBLE LEVEL	3/4 O.D. BODY	ROLYN CO, ARCADIA, CALIF OR EQUIV.	
	1	11		BRACKET	3/8 THK	6061-T6 AL ALY	
	1	10		CHANNEL	.050 x .625 x .750	6061-T6 AL ALY	
	2	9		LATCH SPRING	.025 THK	304 CRES	
	2	8		LATCH	3/16 THK	6061-T6 AL ALY	
	2	7		STRIP	.063 THK	6061-T6 AL ALY	
	2	6		CHANNEL	.050 x .625 x .750	6061-T6 AL ALY	
	1	5		REFLECTOR	.002 THK TOP .005 THK SIDE	ELECTROFORMED NICKEL	
	6	4		REFLECTOR	.002 THK TOP .005 THK SIDE	ELECTROFORMED NICKEL	
		3					
X		2	-2	TRIPOD ASSY			
	X	1	-1	REFLECTOR ASSY			

LIST OF MATERIALS

UNLESS OTHERWISE NOTED:

ELECTRO-OPTICAL SYSTEMS, INC.,
Pasadena, California - A Subsidiary of Xerox Corp.

CISLUNAR
REFLECTING BEACON
ASSEMBLY

J | 1100 201

12705

AS NOTED | 1 OF 1

4

48-2

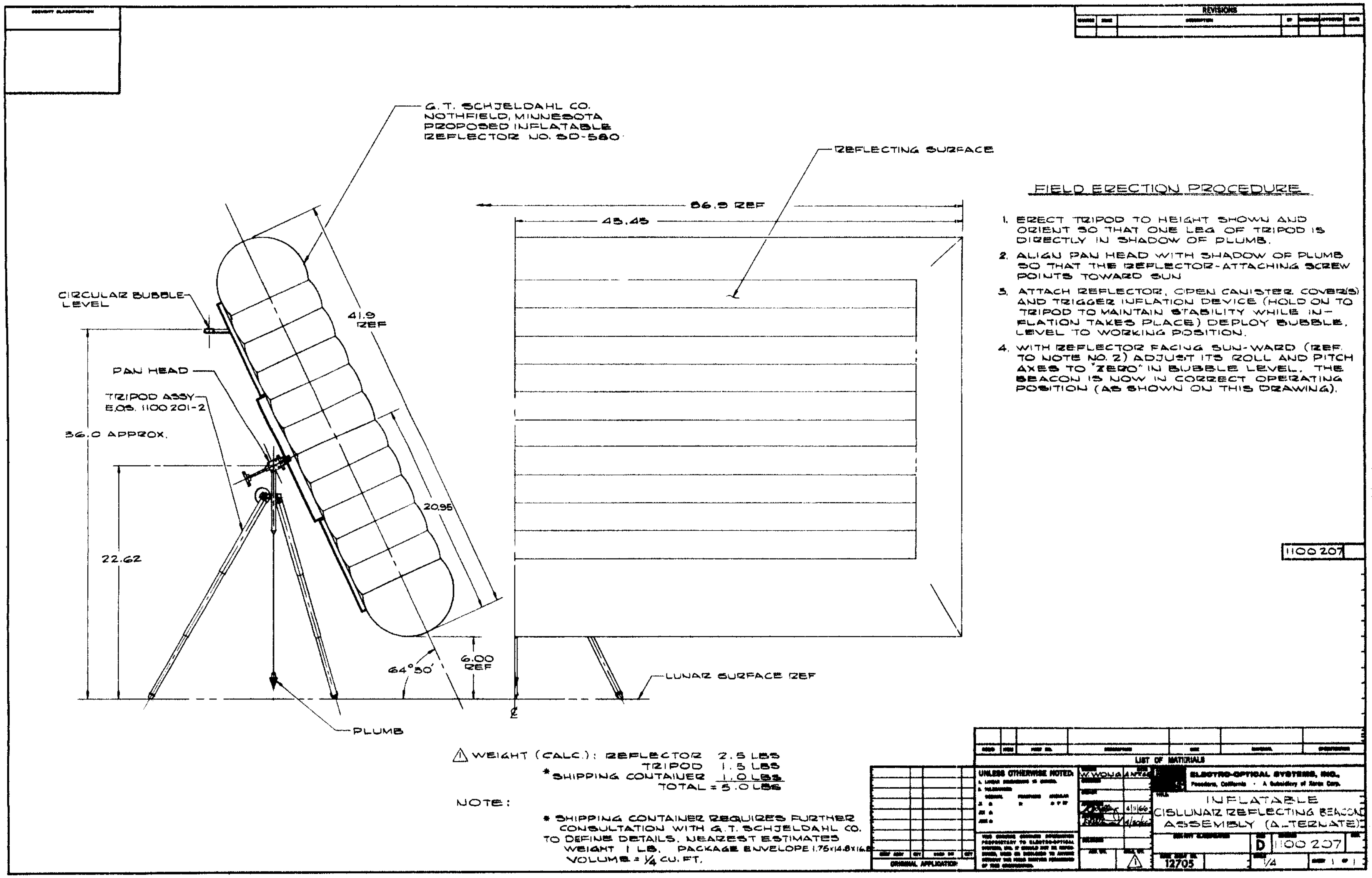

G.T. SCHJELDAHL CO.
NOTHFIELD, MINNESOTA
PROPOSED INFLATABLE
REFLECTOR NO. SD-580
REFLECTING SURFACE
86.9 REF
45.45
41.9 REF
20.95
CIRCULAR BUBBLE LEVEL
PAN HEAD
TRIPOD ASSY E.O.S. 1100201-2
36.0 APPROX.
22.62
64°30'
6.00 REF
LUNAR SURFACE REF
PLUMB
FIELD ERECTION PROCEDURE
1. ERECT TRIPOD TO HEIGHT SHOWN AND ORIENT SO THAT ONE LEG OF TRIPOD IS DIRECTLY IN SHADOW OF PLUMB.
2. ALIGN PAN HEAD WITH SHADOW OF PLUMB SO THAT THE REFLECTOR-ATTACHING SCREW POINTS TOWARD SUN
3. ATTACH REFLECTOR, OPEN CANISTER COVER(S) AND TRIGGER INFLATION DEVICE (HOLD ON TO TRIPOD TO MAINTAIN STABILITY WHILE INFLATION TAKES PLACE) DEPLOY BUBBLE, LEVEL TO WORKING POSITION.
4. WITH REFLECTOR FACING SUN-WARD (REF. TO NOTE NO. 2) ADJUST ITS ROLL AND PITCH AXES TO "ZERO" IN BUBBLE LEVEL. THE BEACON IS NOW IN CORRECT OPERATING POSITION (AS SHOWN ON THIS DRAWING).
WEIGHT (CALC.): REFLECTOR 2.5 LBS
TRIPOD 1.5 LBS
*SHIPPING CONTAINER 1.0 LBS
TOTAL = 5.0 LBS
NOTE:
* SHIPPING CONTAINER REQUIRES FURTHER CONSULTATION WITH G.T. SCHJELDAHL CO. TO DEFINE DETAILS. NEAREST ESTIMATES WEIGHT 1 LB. PACKAGE ENVELOPE 1.75x14.8x16.8 VOLUME = 1/4 CU. FT.
1100207
REVISIONS
LIST OF MATERIALS
UNLESS OTHERWISE NOTED
ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.
INFLATABLE
CISLUNAR REFLECTING BEACON
ASSEMBLY (ALTERNATE)
D 1100207
12705
1/4
ORIGINAL APPLICATION

FIG. 4-6

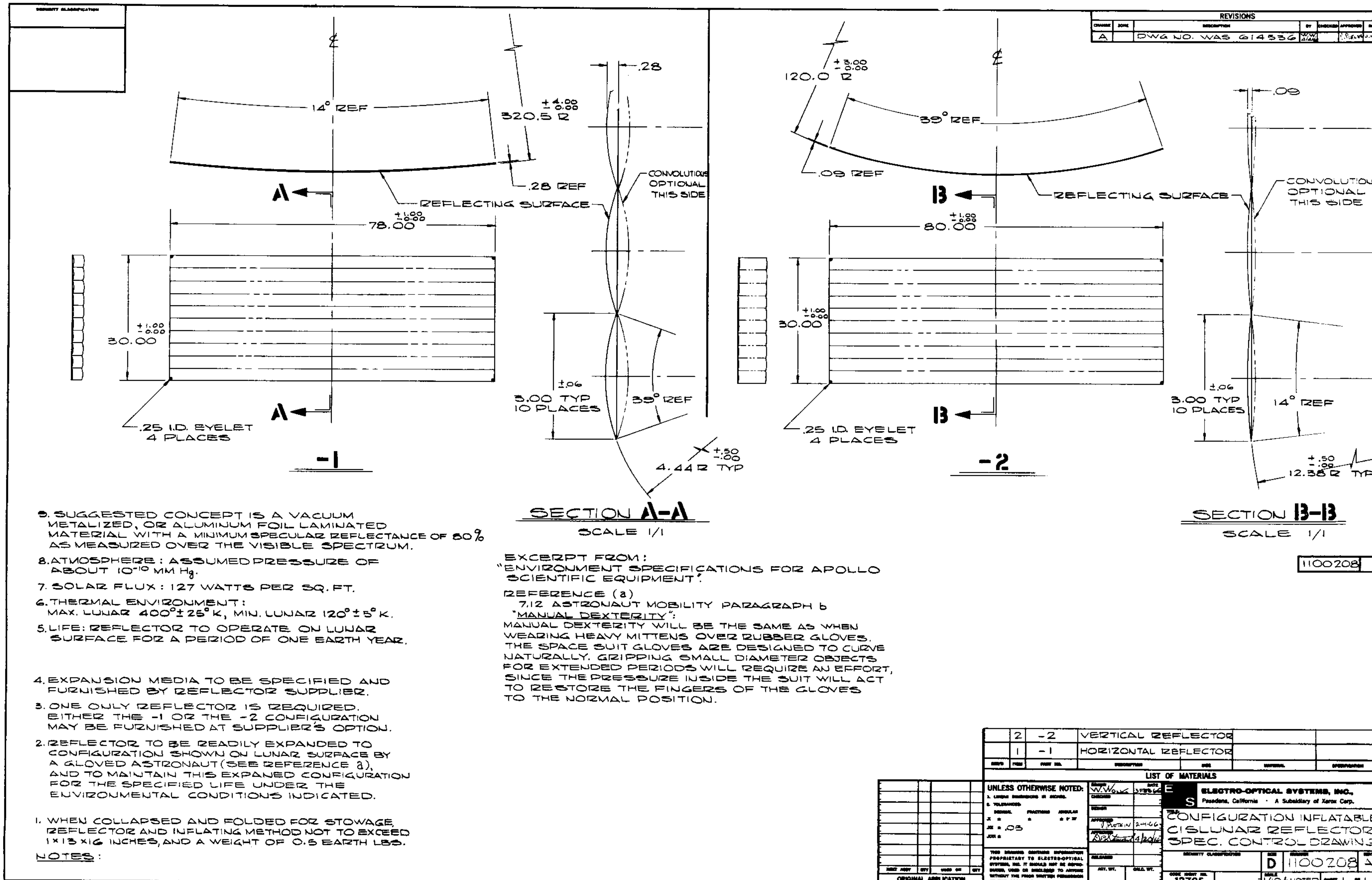

REVISIONS
A DWG NO. WAS 614536
14° REF
320.5 R +4.00 -0.00
.28
.28 REF
REFLECTING SURFACE
CONVOLUTIONS OPTIONAL THIS SIDE
78.00 +1.00 -0.00
30.00 +1.00 -0.00
3.00 TYP ±.06 10 PLACES
35° REF
4.44 R TYP +.50 -.00
.25 I.D. EYELET 4 PLACES
-1
SECTION A-A
SCALE 1/1
120.0 R +3.00 -0.00
35° REF
.09 REF
.09
80.00 +1.00 -0.00
30.00 +1.00 -0.00
14° REF
12.38 R TYP +.50 -.00
-2
SECTION B-B
SCALE 1/1
1100208
NOTES:
1. WHEN COLLAPSED AND FOLDED FOR STOWAGE, REFLECTOR AND INFLATING METHOD NOT TO EXCEED 1 X 13 X 16 INCHES, AND A WEIGHT OF 0.5 EARTH LBS.
2. REFLECTOR TO BE READILY EXPANDED TO CONFIGURATION SHOWN ON LUNAR SURFACE BY A GLOVED ASTRONAUT (SEE REFERENCE a), AND TO MAINTAIN THIS EXPANDED CONFIGURATION FOR THE SPECIFIED LIFE UNDER THE ENVIRONMENTAL CONDITIONS INDICATED.
3. ONE ONLY REFLECTOR IS REQUIRED. EITHER THE -1 OR THE -2 CONFIGURATION MAY BE FURNISHED AT SUPPLIER'S OPTION.
4. EXPANSION MEDIA TO BE SPECIFIED AND FURNISHED BY REFLECTOR SUPPLIER.
5. LIFE: REFLECTOR TO OPERATE ON LUNAR SURFACE FOR A PERIOD OF ONE EARTH YEAR.
6. THERMAL ENVIRONMENT: MAX. LUNAR 400° ± 25° K, MIN. LUNAR 120° ± 5° K.
7. SOLAR FLUX: 127 WATTS PER SQ. FT.
8. ATMOSPHERE: ASSUMED PRESSURE OF ABOUT 10^{-10} MM Hg.
9. SUGGESTED CONCEPT IS A VACUUM METALIZED, OR ALUMINUM FOIL LAMINATED MATERIAL WITH A MINIMUM SPECULAR REFLECTANCE OF 80% AS MEASURED OVER THE VISIBLE SPECTRUM.
EXCERPT FROM:
"ENVIRONMENT SPECIFICATIONS FOR APOLLO SCIENTIFIC EQUIPMENT".
REFERENCE (a)
7.12 ASTRONAUT MOBILITY PARAGRAPH b
"MANUAL DEXTERITY":
MANUAL DEXTERITY WILL BE THE SAME AS WHEN WEARING HEAVY MITTENS OVER RUBBER GLOVES. THE SPACE SUIT GLOVES ARE DESIGNED TO CURVE NATURALLY. GRIPPING SMALL DIAMETER OBJECTS FOR EXTENDED PERIODS WILL REQUIRE AN EFFORT, SINCE THE PRESSURE INSIDE THE SUIT WILL ACT TO RESTORE THE FINGERS OF THE GLOVES TO THE NORMAL POSITION.
2 -2 VERTICAL REFLECTOR
1 -1 HORIZONTAL REFLECTOR
LIST OF MATERIALS
UNLESS OTHERWISE NOTED:
ORIGINAL APPLICATION
ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.
CONFIGURATION INFLATABLE CISLUNAR REFLECTOR SPEC. CONTROL DRAWING
D 1100208 A
12705
1/10 & NOTED

FIG. 4-7

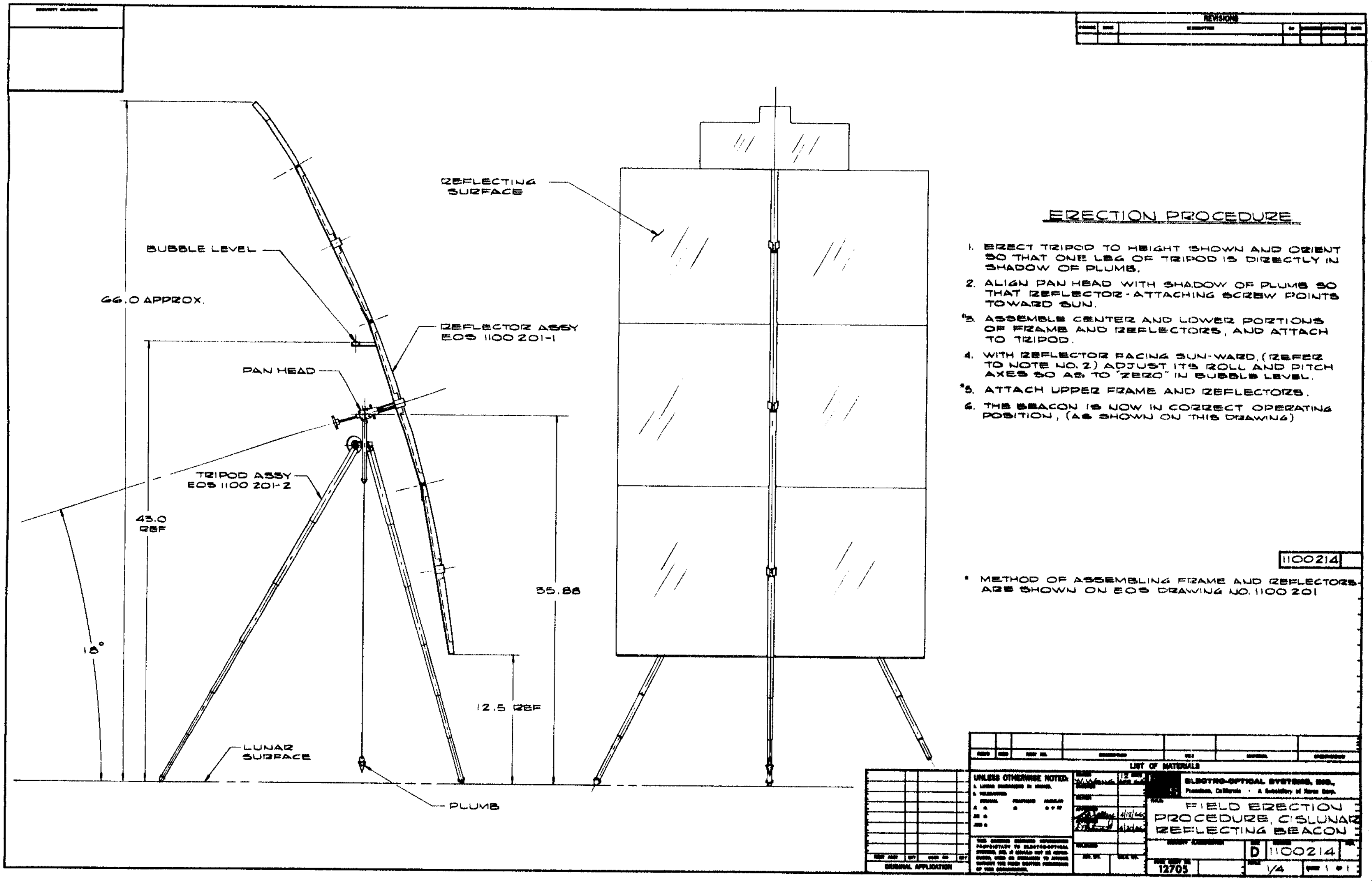

REVISIONS
REFLECTING SURFACE
BUBBLE LEVEL
66.0 APPROX.
REFLECTOR ASSY EOS 1100 201-1
PAN HEAD
TRIPOD ASSY EOS 1100 201-2
45.0 REF
18°
35.88
12.5 REF
LUNAR SURFACE
PLUMB
ERECTION PROCEDURE
1. ERECT TRIPOD TO HEIGHT SHOWN AND ORIENT SO THAT ONE LEG OF TRIPOD IS DIRECTLY IN SHADOW OF PLUMB.
2. ALIGN PAN HEAD WITH SHADOW OF PLUMB SO THAT REFLECTOR-ATTACHING SCREW POINTS TOWARD SUN.
*3. ASSEMBLE CENTER AND LOWER PORTIONS OF FRAME AND REFLECTORS, AND ATTACH TO TRIPOD.
4. WITH REFLECTOR FACING SUN-WARD, (REFER TO NOTE NO. 2) ADJUST IT'S ROLL AND PITCH AXES SO AS TO "ZERO" IN BUBBLE LEVEL.
*5. ATTACH UPPER FRAME AND REFLECTORS.
6. THE BEACON IS NOW IN CORRECT OPERATING POSITION, (AS SHOWN ON THIS DRAWING)
1100214
* METHOD OF ASSEMBLING FRAME AND REFLECTORS ARE SHOWN ON EOS DRAWING NO. 1100 201
LIST OF MATERIALS
UNLESS OTHERWISE NOTED:
ORIGINAL APPLICATION
ELECTRO-OPTICAL SYSTEMS, INC.
FIELD ERECTION PROCEDURE, CISLUNAR REFLECTING BEACON
D 1100214
12705
1/4

FIG. 4-8

achieves the desired packaging specification but exceeds the weight limitation by 0.5 or 10 percent. The beacon consists of 11 separate assemblies plus clips:

1. Six electroformed nickel spherical reflectors overcoated with a silicon monoxide protective layer and an aluminum reflective layer.
2. One compound curvature electroformed nickel reflector overcoated with a silicon monoxide protective coating and an aluminum reflective coating
3. One tripod assembly
4. Three interlocking channel frames
5. Six rear mounting mirror clips
6. Three spring clips

The techniques of electroforming these reflectors and the subsequent vacuum overcoating steps are detailed in Appendix D. If the state of the art of aluminum electroforming advances, aluminum electroformed reflector panels could become more rigid for the same weight than the nickel panels whose rigidity to weight ratio is about 0.1 that of aluminum. The major disadvantages of this design are (1) the number of clips and reflectors which must be separately assembled, and (2) the possibility of reflector damage during assembly due to the thinness of the segments and the limited dexterity of the astronauts when using space suits. Optical accuracy may be a function of the reflector thickness and assembly characteristics also. The full extent of these possible disadvantages could be readily determined during prototype construction and assembly tests. The all metal reflector design exhibits excellent environmental resistance. Doubling the reflector weight, by adding 1.5 pounds, would rigidize the panels sufficiently to eliminate the assembly problems.

The philosophy and calculations upon which the mirror dimensions are based are given in Appendix E. Erection instructions are given in Fig. 4-8. The elevation angle adjustment is accomplished by leveling a bubble level preset for the landing site location and local vertical anomalies. The alignment of the rear leg with the plumb bob establishes the proper azimuthal angle by lining up the tripod head within the desired east-west direction. A more precise sight such as a two-post sight, which would yield more accurate azimuthal orientation, may be required.

To minimize the effects of lunar dust impingement, the reflector should be mounted eastward of the LEM vehicle so that any particles produced during LEM ascent will strike the rear surface or will lob onto the reflector surface at a glancing incident angle as the particles descend. Even descending particles will have an eastward horizontal velocity component; therefore there should be no problem of falling dust. Also, those particles which would tend to fall on the reflective surfaces would, if the reflector surfaces are clean, probably ricochet off to the ground.

4.5.1.2 Inflatable Cislunar Beacon

Figure 4-7, the cislunar reflector specification control drawing, lists the basic reflector configuration submitted to G. T. Schjeldahl for quotation. The 14° reference horizontal angle and the 39° elevation angular subtend satisfied the desired field of view requirements of 20° x 40° when one considers the selenographic longitudinal and latitudinal coordinants of the sun and the azimuth and elevation position of the LEM vehicle during the projected landing phases. The inflatable cislunar reflecting beacon assembly alternate, Fig. 4-6, exceeds the dimensions of the cislunar reflector specification control drawing, Fig. 4-7, because the rims of the inflatable reflector do not reflect entirely to the desired field of view. While inflation is initially required, once inflated the reflector is self-rigidized in the lunar environment. Similar structures have already been space tested. The weight and packaging details listed for this configuration are believed to be quite conservative compared with

Fig. 4-5, the all-metal cislunar reflecting beacon lunar assembly. The inflatable reflector material would be aluminum foil and Mylar with either an aluminized coating only or a vacuum deposited thermal control coating over the aluminum coating. Alternatively, the high temperature H film material might be used.

4.5.2 Earth Tracking Beacon

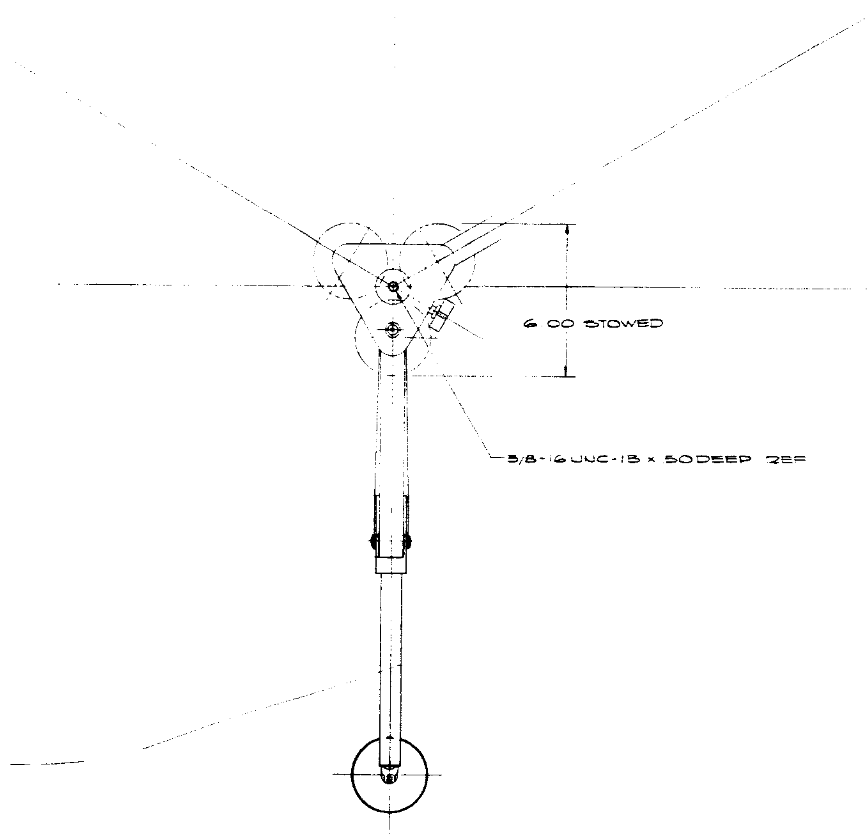
The earth tracking beacon is a sophisticated instrument composed of four major subassemblies:

Assembly	Figure
Tripod Assembly	4-9
Mechanism Assembly	4-10
Solar Panel Assembly	4-11 and 4-12
Reflector Panels and Frame Assembly	4-13

These are shown combined in Fig. 4-14, Tracking Beacon Assembly. The beacon assembly, combined with foam packing and simple banding, since the storage space serves as the packing liner, weighs 42 pounds, over twice the design weight. The packaging volume of over 7 cubic feet, including the cislunar beacon, exceeds the design specification by a factor of 7. The low bulk density of 6 pounds per cubic foot is primarily due to the bulky, lightweight subassemblies. Bulkiness has resulted from efforts to minimize the erection time.

4.5.2.1 Tripod Assembly, Fig. 4-9

The tripod shown is an adaptation of a Linhof tripod made of anodized aluminum. It has high specific rigidity and would be readily assembled on the moon using the modified latch-arm leg-locking devices. Other modifications include the pointed, disc tripod leg pads which are presently designed to accommodate a porous lunar surface. However, if subsequent lunar data indicate that the surface is relatively rocky, the disc area would not be necessary to support the tracking beacon assembly. Without any structural modifications, lightening ribs, or holes, this tripod weighs 4 1/2 pounds



6.00 STOWED
3/8-16 UNC-1B x .50 DEEP REF

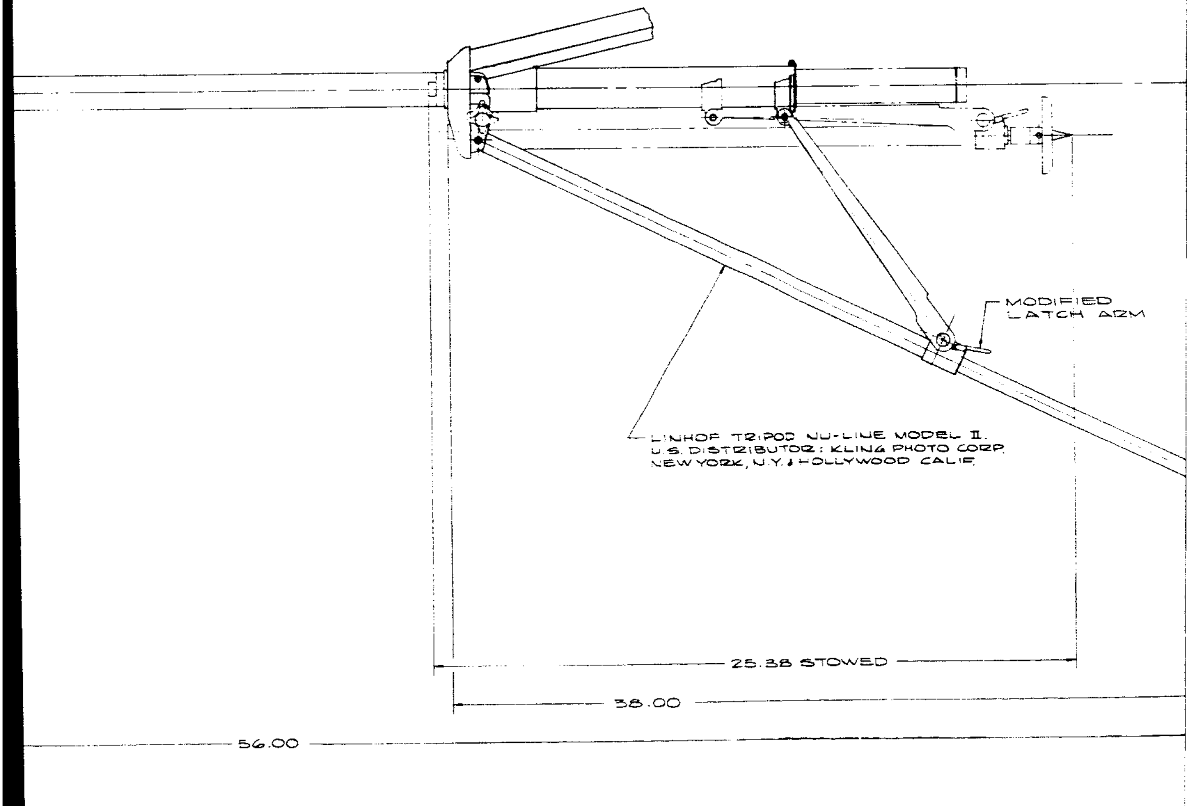
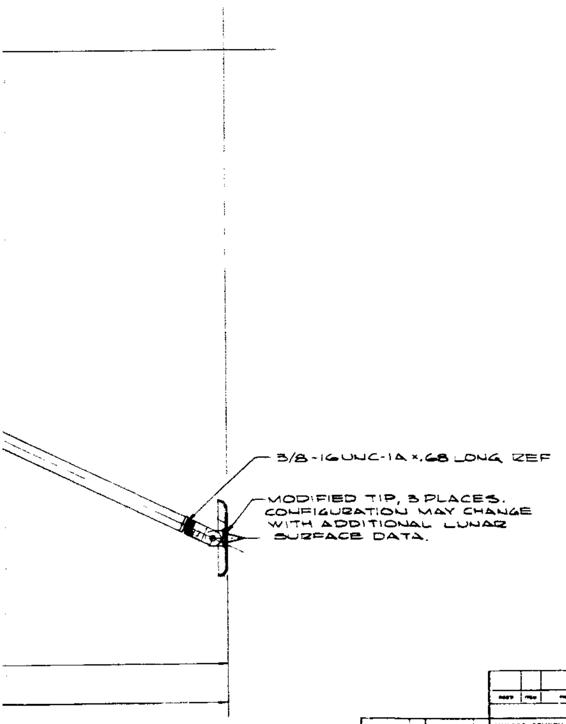

MODIFIED
LATCH ARM
LINHOF TRIPOD NU-LINE MODEL II.
U.S. DISTRIBUTOR: KLING PHOTO CORP.
NEW YORK, N.Y. & HOLLYWOOD CALIF.
25.38 STOWED
38.00
56.00

FIG. 4-9

55.2



LIST OF MATERIALS

UNLESS OTHERWISE NOTED:

ELECTRO-OPTICAL SYSTEMS, INC.

TRIPOD ASSEMBLY
TRACKING BEACON

SIZE	NUMBER	REV
J	1100 202	

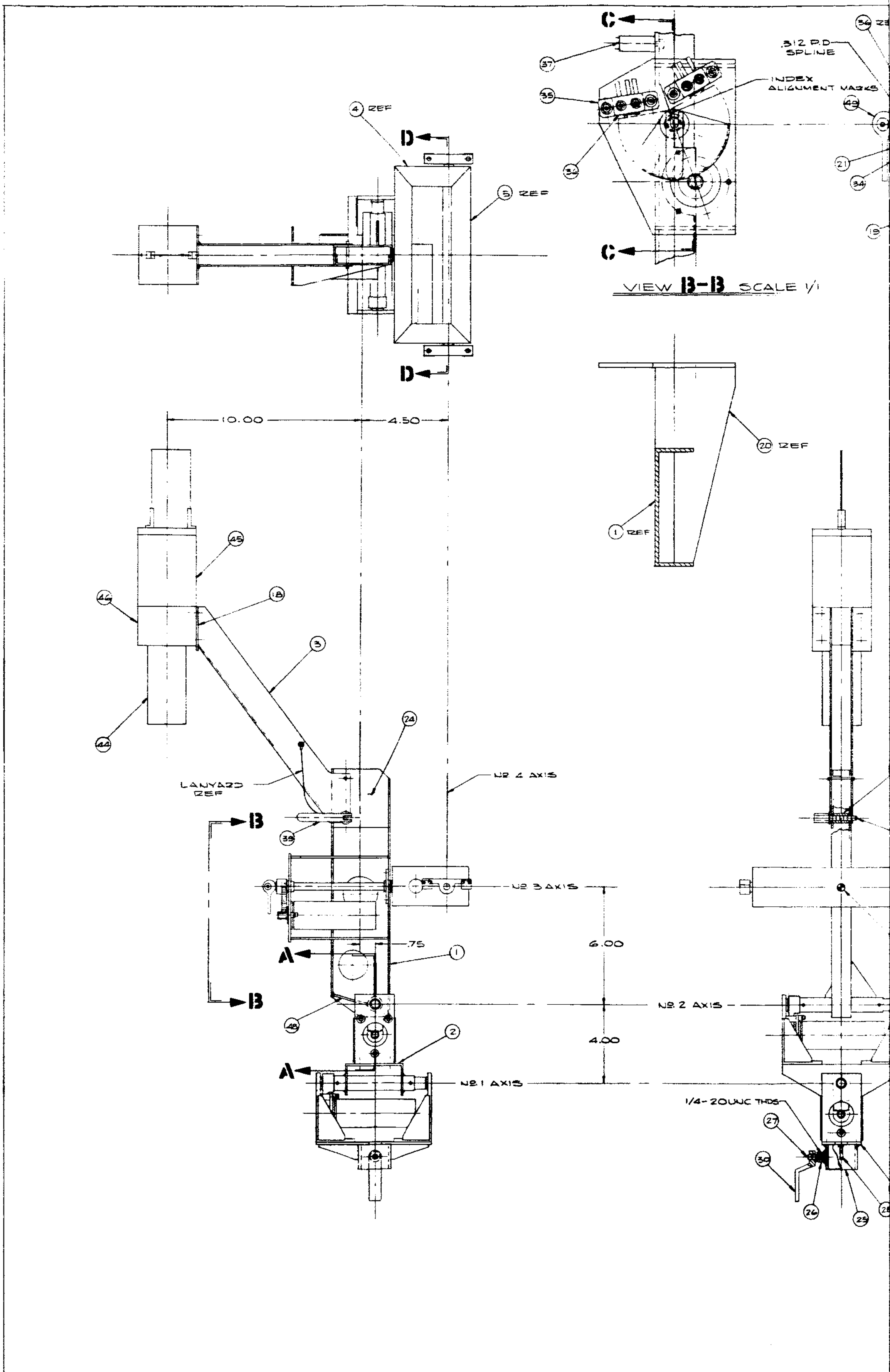
CODE IDENT NO.	SCALE	SHEET
12705	1/2	1 OF 1

CALC WT. 4½ LBS

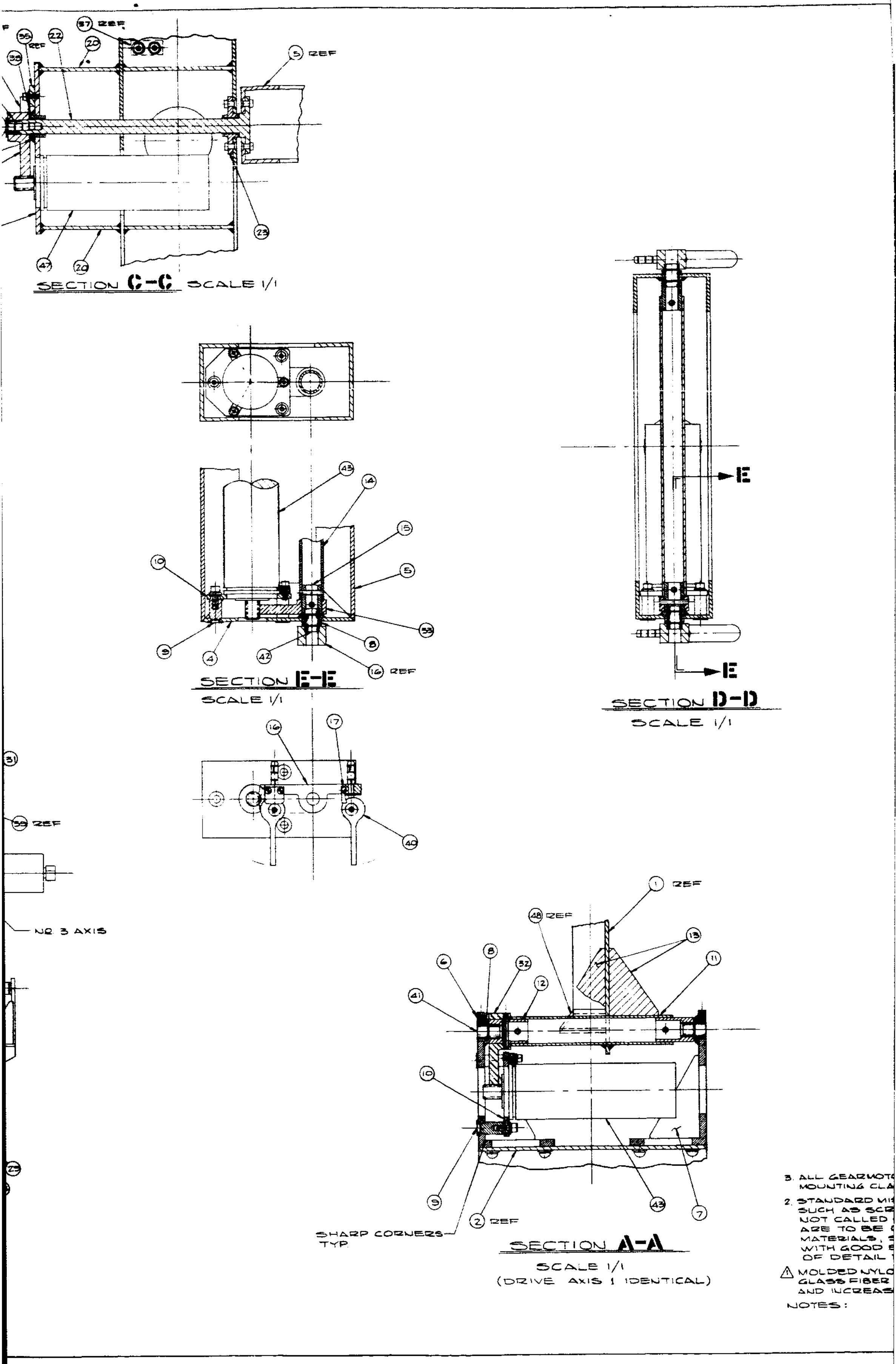
1100204

ORIGINAL APPLICATION

3



VIEW B-B SCALE 1/1
.312 P.D. SPLINE
INDEX ALIGNMENT MARKS
4 REF
5 REF
20 REF
1 REF
10.00
4.50
LANYARD REF
No 4 AXIS
No 3 AXIS
No 2 AXIS
No 1 AXIS
6.00
4.00
.75
1/4-20UNC THDS



SECTION C-C SCALE 1/1
SECTION E-E
SCALE 1/1
SECTION D-D
SCALE 1/1
NO. 3 AXIS
SHARP CORNERS TYP.
SECTION A-A
SCALE 1/1
(DRIVE AXIS 1 IDENTICAL)
NOTES:

FIG. 4-10

57-2

1	49	EGP-3C-3	ADJUSTABLE BUSHING CORP N HLYWD, CALIF. EXPANDO-GRIP PIN	3/16 DIA	CRES	
1	48		GUSSET	.100 THK	6061-T6 AL ALY	
1	47	SIMILAR TO 25068	GAYLORD-RIVES CO PASADENA, CALIF. GEAR MOTOR		ROTATION RATE: 40° PER HOUR 10 T. 32 P PINION	
1	46		SENSOR ADAPTER			
1	45		PROPOSED PRELIM. CONFIGURATION EARTH SENSOR			
1	44		PROPOSED PRELIM. CONFIGURATION SUN SENSOR			
3	43	SIMILAR TO 25068	GAYLORD-RIVES CO PASADENA, CALIF. GEAR MOTOR		ROTATION RATE: 7° PER HR 10 T. 32 P. PINION	
2	42	6012-400	BENDIX CORP UTICA N.Y. FLEXURAL PIVOT	7.5°	CRES	
4	41	5012-600	BENDIX CORP UTICA, N.Y. FLEXURAL PIVOT	15°	CRES	
4	40	EGP-3C-12-4	ADJUSTABLE BUSHING CORP N.HOLLYWOOD EXPANDO-GRIP PIN	3/16 DIA	CRES	
1	39	EGP-4C-21-4	ADJUSTABLE BUSHING CORP N.HOLLYWOOD CAL. EXPANDO-GRIP PIN	1/4 DIA x 1 5/16	CRES	
2	38	TYPE 6 6L6-FK	THOMSON INDUSTRIES INC MANHASSET N.Y. STANDARD FLANGED NYLINER	3/8 I.D.	NYLON, 30% GLASS FIBER FILLED	
1	37	32RJKZ	SIGMA RELAY			MIL-R-5757
2	36	6HM1-1	HONEYWELL MICRO SWITCH			MS 25085-1
2	35		ADJUSTING PLATE	.125 THK	2024-T4 AL ALY	
1	34		GEAR	90 T. 32 P 2.812 P.D.	NYLON, 30% GLASS FIBER FILLED	
1	33		GEAR	90 T. 32 P 2.812 P.D.	NYLON, 30% GLASS FIBER FILLED	
2	32		GEAR	90 T. 32 P 2.812 P.D.	NYLON, 30% GLASS FIBER FILLED	
1	31		BUSHING	1/2 DIA	6061-T6 AL ALY	
1	30		HANDLE	5/8 THK	2024-T4 AL ALY	
1	29		PLATE	.125 THK	6061-T6 AL ALY	
2	28		GUSSET	.125 THK	6061-T6 AL ALY	
1	27		SHAFT	1/4 DIA	2024-T4 AL ALY	
1	26		BOSS	1/2 DIA	6061-T6 AL ALY	
1	25		TUBE	1 9/16 O.D. x 1.385 I.D.	6061-T6 AL ALY	
1	24		PANEL	.090 SHT	6061-T4 AL ALY	
1	23		BUSHING	3/8 THK	2024-T4 AL ALY	
1	22		SHAFT	1 1/2 DIA	2024-T4 AL ALY	
1	21		BUSHING	3/4 DIA	6061-T6 AL ALY	
2	20		RIB	.09 THK	6061-T6 AL ALY	
1	19		PLATE	.125 THK	6061-T6 AL ALY	
1	18		PLATE	.100 THK	6061-T6 AL ALY	
4	17		GUIDE	.032 THK	CLASS 301 CRES FULL HARD	
2	16		SUPPORT	1/2 THK	2024-T4 AL ALY	
2	15		SHAFT, END	1/2 DIA	2024-T4 AL ALY	
1	14		TUBE	5/8 O.D. x .058 WALL	2024-T4 AL ALY	
2	13		GUSSET	.100 THK	6061-T6 AL ALY	
4	12		SHAFT	5/8 DIA	2024-T4 AL ALY	
2	11		TUBE	3/4 O.D. x .06 WALL	6061-T6 AL ALY	
3	10		PLATE	.125 THK	2024-T4 AL ALY	
3	9		STANDOFF	5/16 DIA	6061-T6 AL ALY	
6	8		BUSHING	5/8 DIA	6061-T6 AL ALY	
8	7		GUSSET	.063 THK	6061-T6 AL ALY	
4	6		ANGLE	.188 x 2 1/2 x 4	6061-T6 AL ALY	
2	5		CHANNEL	.094 x 1 x 2	6061-T6 AL ALY	
2	4		CHANNEL	.094 x 1 x 2	6061-T6 AL ALY	
1	3		SUPPORT, SENSOR	.080 SHT	6061-T4 AL ALY	
1	2		BRACKET	.090 SHT	6061-T4 AL ALY	
1	1		FRAME, MAIN	.090 SHT	6061-T4 AL ALY	

LIST OF MATERIALS

RS MOUNT WITH STANDARD SYNCHRO
IPS. 3 PER UNIT, EQUALLY SPACED.

CELLANEOUS FASTENING HARDWARE,
WS, WASHERS, NUTS, PINS, ETC.,
UT IN THE BILL OF MATERIALS
F SUITABLE STAINLESS STEEL
ELECTED AND ITEMIZED IN ACCORDANCE
NGINEERING PRACTICE AT TIME
ESIGN.

I COMPOUNDS WITH 20% TO 30%
ILL FOR HIGHER TEMPERATURE SERVICE
D STRENGTH TO BE INVESTIGATED.

J1100204

ORIGINAL APPLICATION

UNLESS OTHERWISE NOTED:

W WONG

V. PLOTKIN 3/10/66

ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.

MECHANISM ASSEMBLY, TRACKING BEACON

J 1100 203

13.25 LBS

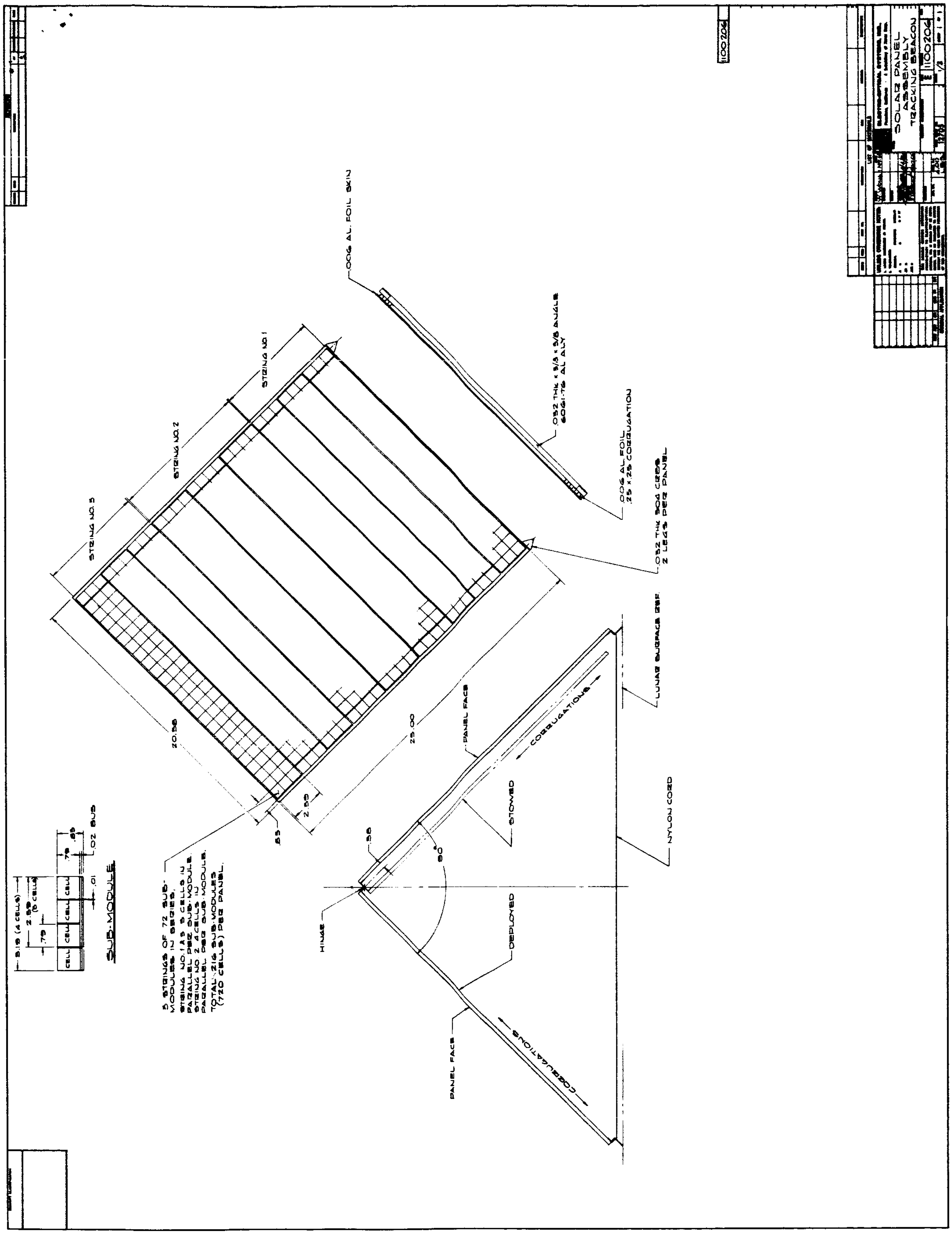
12705

1/2 & NOTED

SHEET 1 OF 1

3

58.



SOLAR PANEL ASSEMBLY TRACKING BEACON
1100206
.006 AL FOIL SKIN
.032 THK x 3/8 x 3/8 ANGLE 6061-T6 AL ALY
.006 AL FOIL .25 x .25 CORRUGATION
.032 THK 304 CRES 2 LEGS PER PANEL
STRING NO.1
STRING NO.2
STRING NO.3
20.56
25.00
2.59
.85
LUNAR SURFACE REF
PANEL FACE
CORRUGATIONS
STOWED
NYLON CORD
DEPLOYED
HINGE
.56
90°
3 STRINGS OF 72 SUB-MODULES IN SERIES. STRING NO.1 & 3 5 CELLS IN PARALLEL PER SUB-MODULE. STRING NO.2 4 CELLS IN PARALLEL PER SUB-MODULE. TOTAL: 216 SUB-MODULES (720 CELLS) PER PANEL.
SUB-MODULE
CELL

FIG. 4-11

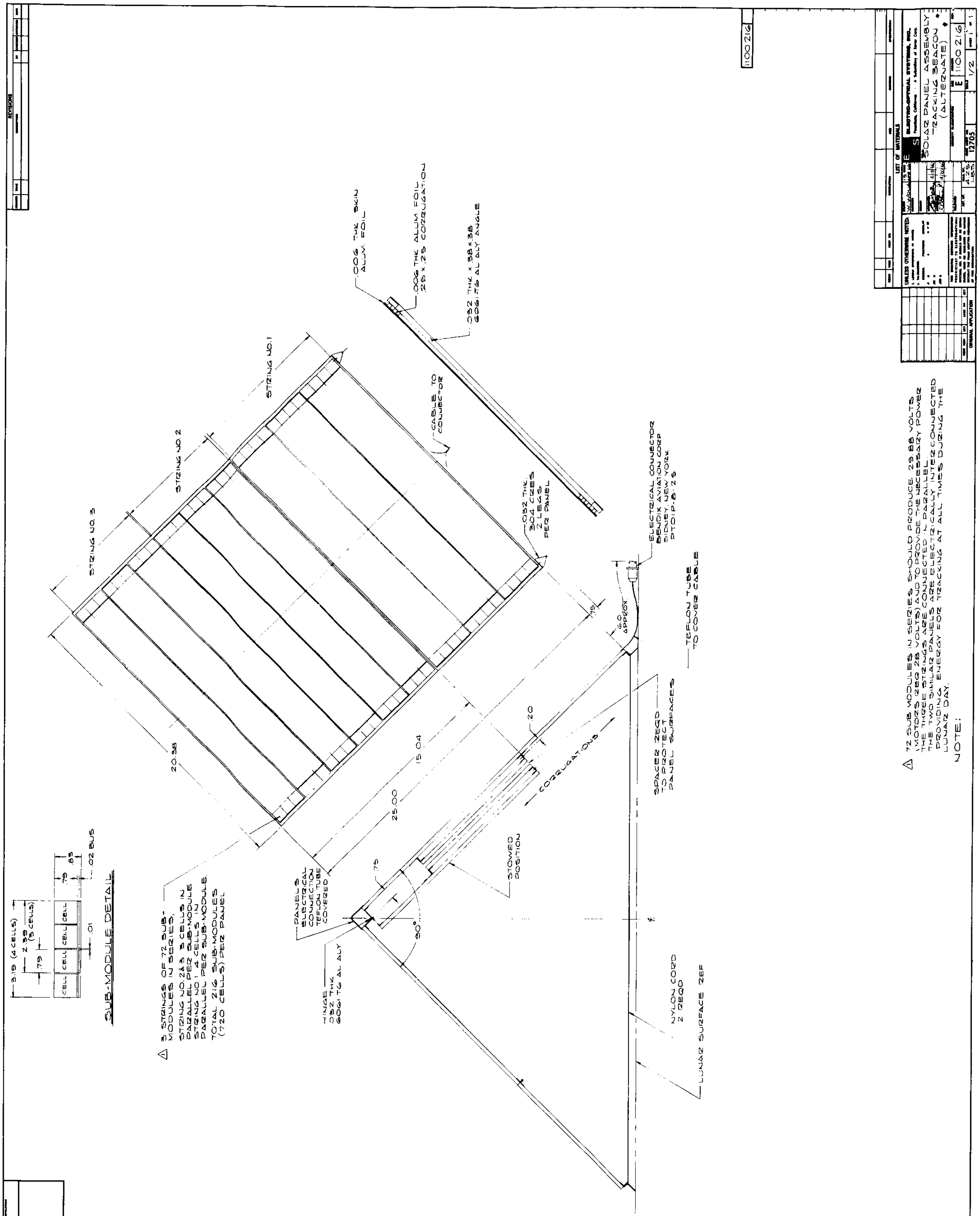
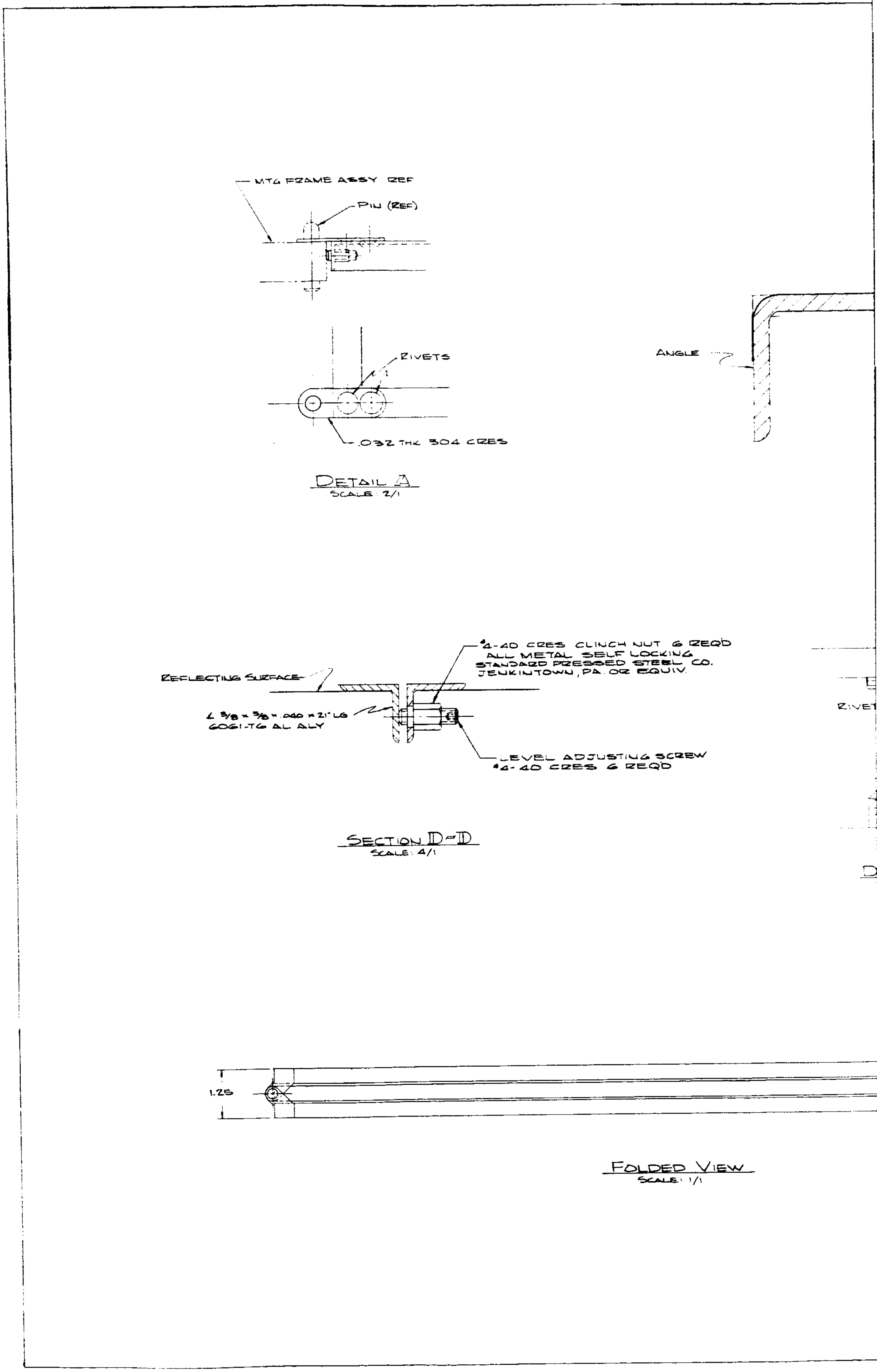

SOLAR PANEL ASSEMBLY TRACKING BEACON (ALTERNATE)
1100216
SUB-MODULE DETAIL
3 STRINGS OF 72 SUB-MODULES IN SERIES. STRING NO. 2 & 3 5 CELLS IN PARALLEL PER SUB-MODULE STRING NO 1 4 CELLS IN PARALLEL PER SUB-MODULE TOTAL 216 SUB-MODULES (720 CELLS) PER PANEL
72 SUB MODULES IN SERIES SHOULD PRODUCE 29.88 VOLTS (MOTORS REQ 28 VOLTS) AND TO PROVIDE THE NECESSARY POWER THE THREE STRINGS ARE CONNECTED IN PARALLEL THE TWO SIMILAR PANELS ARE ELECTRICALLY INTERCONNECTED PROVIDING ENERGY FOR TRACKING AT ALL TIMES DURING THE LUNAR DAY.
NOTE:
STRING NO.1
STRING NO.2
STRING NO.3
.006 THK THE SKIN ALUM. FOIL
.006 THK ALUM FOIL .25 x .25 CORRUGATION
.032 THK x .38 x .38 6061-T6 AL ALY ANGLE
CABLE TO CONNECTOR
.032 THK 304 CRES 2 LEGS PER PANEL
ELECTRICAL CONNECTOR BENDIX AVIATION CORP SIDNEY, NEW YORK
TEFLON TUBE TO COVER CABLE
SPACER 2 REQD TO PROTECT PANEL SURFACES
CORRUGATIONS
STOWED POSITION
PANELS ELECTRICAL CONNECTION TEFLON TUBE COVERED
HINGE .032 THK 6061-T6 AL ALY
NYLON CORD 2 REQD
LUNAR SURFACE REF
20.38
25.00
15.04
90°

FIG. 4-12


MTG FRAME ASSY REF
PIN (REF)
RIVETS
.032 THK 304 CRES
DETAIL A
SCALE: 2/1
ANGLE
#4-40 CRES CLINCH NUT 6 REQ'D
ALL METAL SELF LOCKING
STANDARD PRESSED STEEL CO.
JENKINTOWN, PA. OR EQUIV.
REFLECTING SURFACE
∠ 5/8 × 5/8 × .040 × 21" LG
6061-T6 AL ALY
LEVEL ADJUSTING SCREW
#4-40 CRES 6 REQ'D
SECTION D-D
SCALE: 4/1
1.25
FOLDED VIEW
SCALE: 1/1

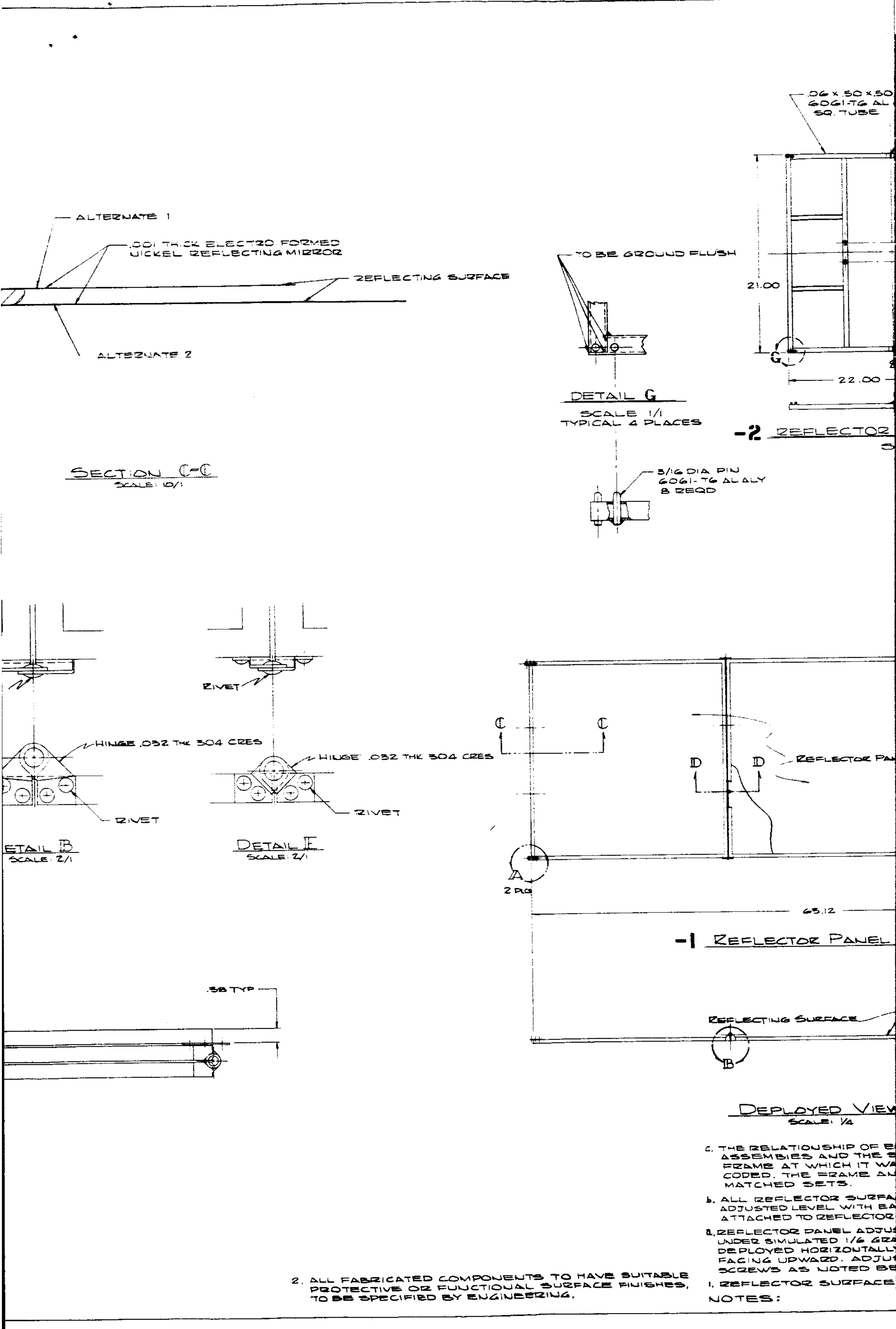
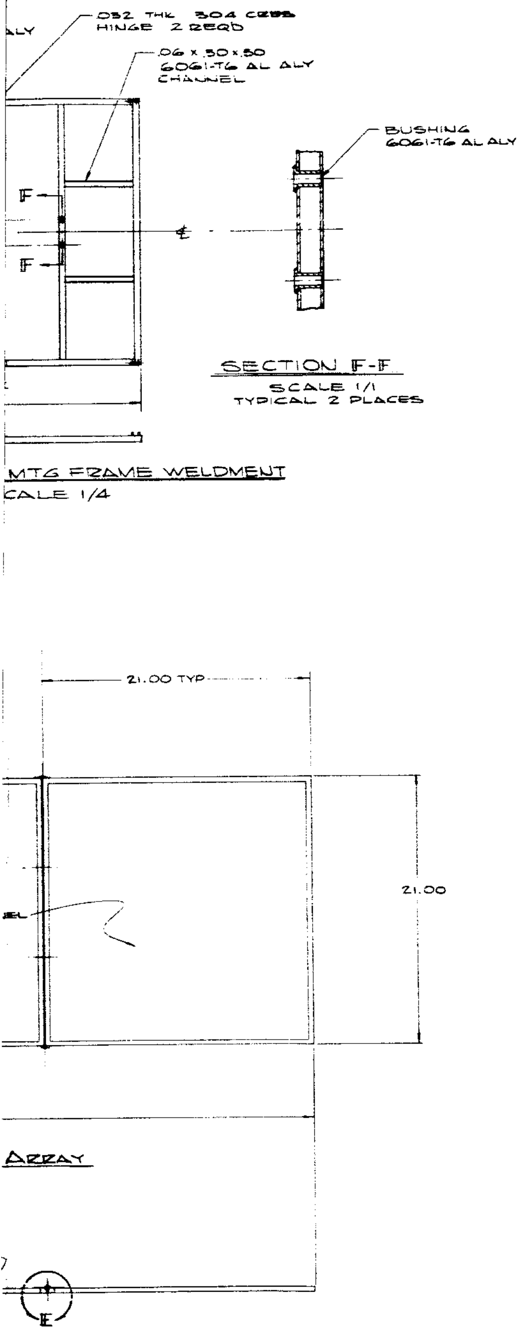

.06 x .50 x .50
6061-T6 AL
SQ. TUBE
21.00
22.00
-2 REFLECTOR
ALTERNATE 1
.001 THICK ELECTRO FORMED NICKEL REFLECTING MIRROR
REFLECTING SURFACE
ALTERNATE 2
SECTION C-C
SCALE: 10/1
TO BE GROUND FLUSH
DETAIL G
SCALE 1/1
TYPICAL 4 PLACES
3/16 DIA PIN
6061-T6 AL ALY
8 REQD
RIVET
HINGE .032 THK 304 CRES
HINGE .032 THK 304 CRES
RIVET
RIVET
DETAIL B
SCALE: 2/1
DETAIL E
SCALE: 2/1
REFLECTOR PA
A
2 PLC
65.12
-1 REFLECTOR PANEL
.38 TYP
REFLECTING SURFACE
B
DEPLOYED VIEW
SCALE: 1/4
2. ALL FABRICATED COMPONENTS TO HAVE SUITABLE PROTECTIVE OR FUNCTIONAL SURFACE FINISHES, TO BE SPECIFIED BY ENGINEERING.
NOTES:
1. REFLECTOR SURFACE

FIG. 4-13

61-2



ACH OF THE 4 REFLECTOR PANEL
IDE OF THE REFLECTOR MOUNTING
S LEVELED ARE TO BE NUMERICALLY
D PANELS ARE TO KEPT IN

CES (12 PANELS) ARE TO BE
CH OTHER WITHIN .010 INCH WHEN
MOUNTING FRAME (1100 205-2).

TMENT IS TO BE PERFORMED
VITY CONDITIONS, WITH PANELS
AND REFLECTING SURFACES
ST WITH THE LEVEL ADJUSTING
LOW.

ADJUSTING PROCEDURE:

1	2	-2	MTG FRAME WELDMENT
4	1	-1	REFLECTOR

LIST OF MATERIALS

UNLESS OTHERWISE NOTED:

ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California A Subsidiary of Xerox Corp.

REFLECTOR PANELS & FRAME
TRACKING BEACON

J 1100 205

1100204 1

ORIGINAL APPLICATION

2.62 LBS

12705

NOTED

SHEET 1 OF 1

3

62

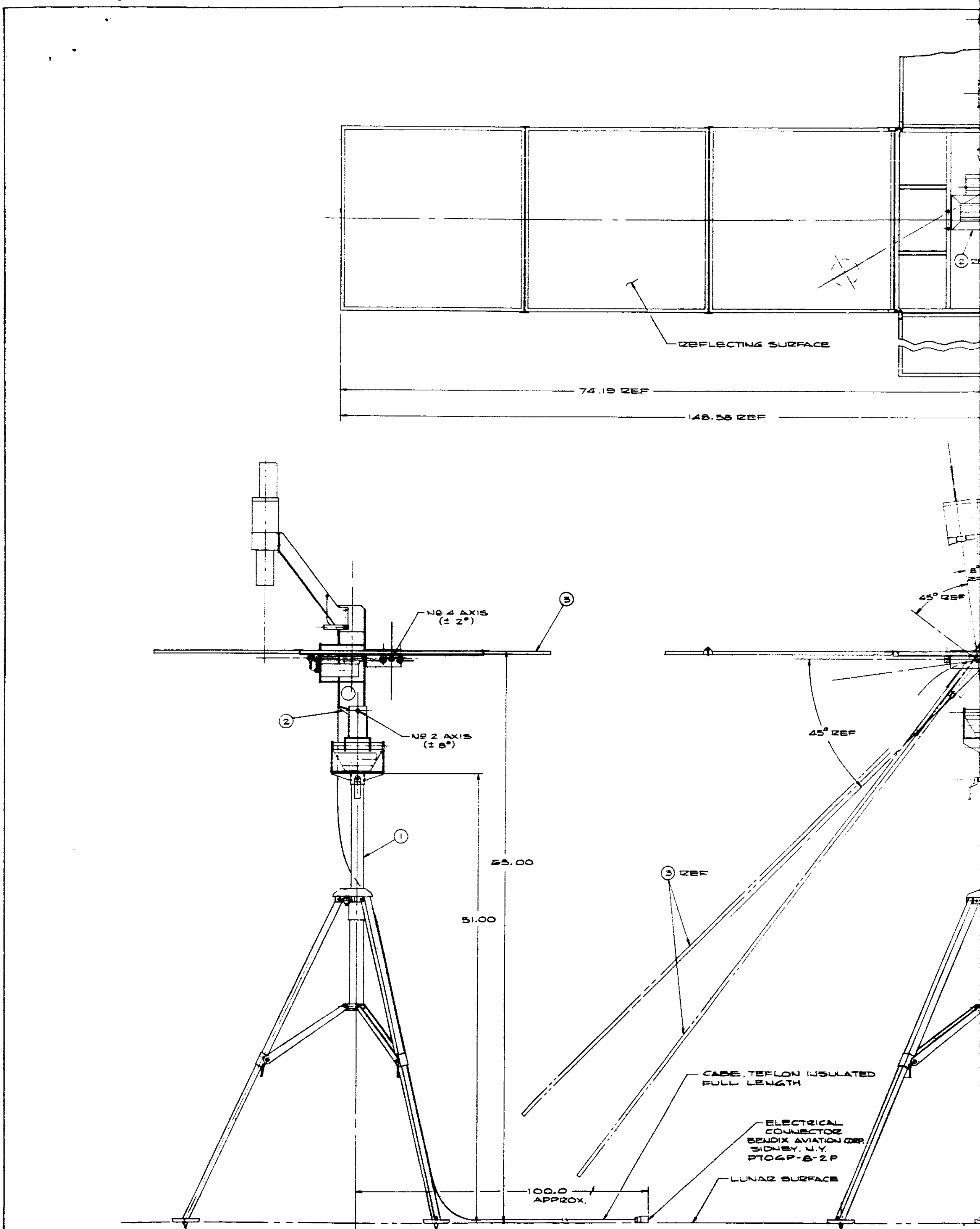
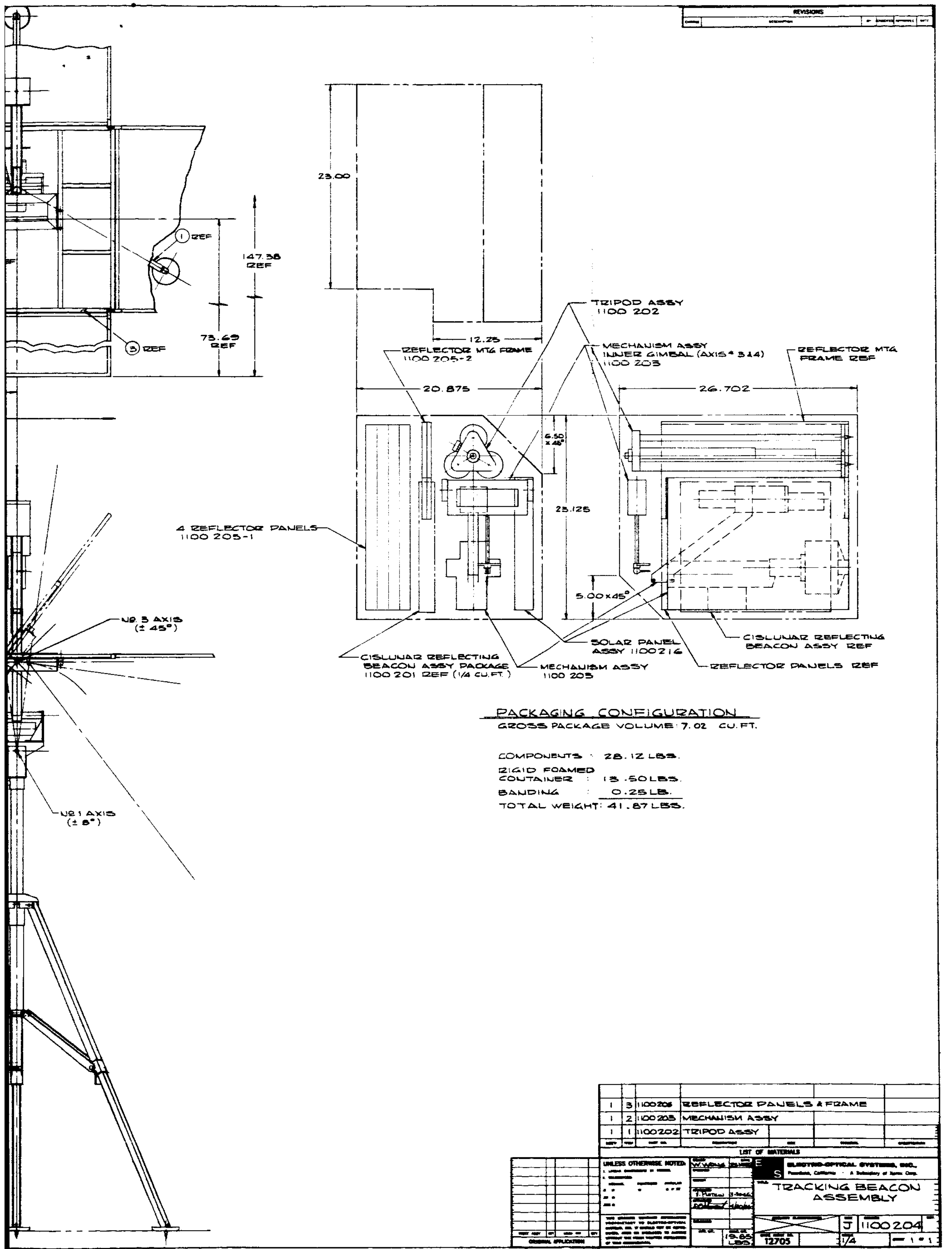

REFLECTING SURFACE
74.19 REF
148.58 REF
Nº 4 AXIS
(± 2°)
Nº 2 AXIS
(± 8°)
65.00
51.00
45° REF
45° REF
3 REF
CABE, TEFLON INSULATED
FULL LENGTH
ELECTRICAL
CONNECTOR
BENDIX AVIATION CORP.
SIDNEY, N.Y.
PTO6P-8-2P
LUNAR SURFACE
100.0
APPROX.

FIG.


REVISIONS
23.00
12.25
147.38 REF
73.69 REF
1 REF
3 REF
TRIPOD ASSY 1100 202
MECHANISM ASSY INNER GIMBAL (AXIS # 3 & 4) 1100 203
REFLECTOR MTG FRAME REF
REFLECTOR MTG FRAME 1100 205-2
20.875
26.702
6.50 X 45°
23.125
4 REFLECTOR PANELS 1100 205-1
5.00 X 45°
NO. 3 AXIS (± 45°)
SOLAR PANEL ASSY 1100216
CISLUNAR REFLECTING BEACON ASSY REF
CISLUNAR REFLECTING BEACON ASSY PACKAGE 1100 201 REF (1/4 CU.FT.)
MECHANISM ASSY 1100 203
REFLECTOR PANELS REF
NO. 1 AXIS (± 8°)
PACKAGING CONFIGURATION
GROSS PACKAGE VOLUME: 7.02 CU.FT.
COMPONENTS : 28.12 LBS.
RIGID FOAMED CONTAINER : 13.50 LBS.
BANDING : 0.25 LB.
TOTAL WEIGHT: 41.87 LBS.
1 3 1100205 REFLECTOR PANELS & FRAME
1 2 1100203 MECHANISM ASSY
1 1 1100202 TRIPOD ASSY
LIST OF MATERIALS
UNLESS OTHERWISE NOTED
ORIGINAL APPLICATION
W. WONG
ELECTRO-OPTICAL SYSTEMS, INC.
TRACKING BEACON ASSEMBLY
J 1100204
19.85 LBS.
T2705
1/4

and represents a stowed packaging volume of 1/2 cubic foot. The height requirement is dictated by the reflector panels' clearance necessary when the reflectors are positioned to a $\pm 45^{\circ}$ angle at lunar dusk and dawn respectively. Tradeoffs between the lengths of the tripod legs and the telescoping column can be made to permit a lower working level than 56 inches during beacon assembly operations. This would require a tripod column of more than one section which could be conveniently raised after beacon assembly.

Additional efforts which should be included on future prototype development and hardware programs include the study of:

1. Weight versus rigidity requirements
2. Tripod tips necessary, based on updated lunar surface conditions
3. Tradeoff between column height and leg height
4. Investigation of erection details in a simulated lunar environment.

The built-in bubble level could be redesigned for greater accuracy to permit presetting to the local gravitational conditions predicted for the landing, and provides a convenient method to assure a proper elevation angle at the landing site.

4.5.2.2 Tracking Beacon Mechanism Assembly, Fig. 4-10

This drawing represents the most sophisticated elements required for the earth tracking beacon. It also represents the design areas which require the most work, including:

1. The sun and earth sensor assembly (items 44, 45, and 46 on the figure)
2. Drive mechanism
   a. Four gear motors (items 43 and 47)
   b. The recycle mechanism (items 36 and 37)
   c. The external axes gear drives (items 32, 33, and 34)
3. The sun-earth sensor logic near 0° phase angle positions

These items are detailed below:

1. Sun and Earth Sensors. Presently there are no sun and earth sensors designed specifically for operation on the lunar surface. Consultation with JPL Guidance and Control Section engineers indicates that there was no simple solution to off-the-shelf tracking instruments and that, while designs are presently being revised, the state of the art sensors have been relatively more bulky than desired for this program. In addition, several reports relative to tracking sensors were classified confidential. Due to the timing and lack of clearance, these were not available for close scrutiny during this design program. Therefore, the sensor packaging outlined represents the latest packaging configurations now being considered by JPL, but does not specifically relate to any proven design.

   Photovoltaic cells are currently favored as detectors in place of the photoconductive cells suggested by JPL, due to temperature problems. Actual design of the sensor presents difficulties due to the fact that during part of the lunar day the earth sensors will tend to lock on the sun in preference to the earth, being attracted to the higher light intensity. This presents a difficult logic problem for the electronics unless the earth sensors can be made inoperable during this period and the beacon allowed to remain fixed.

   Tracking would be achieved using three photovoltaic cells for the sun and three for the earth's fixed arc through space with the others providing elevation control. Consideration should be given for the presentation of a program to develop a realistic sun/earth tracking system capable of operation in a lunar environment.

2. Drive System. Having produced error signals, the drive system consists of photovoltaic panels, inverters, and geared, two-phase induction motor drives. The bearing and gear design has also received considerable attention. After discussions with JPL, Shell Research, Parker Seal Company, Gaylord Rieves Company, Sperry Farragut Company, Ardel, Inc., and EOS technical staff, the most practical solution is to put the drive motors and gear boxes in a one-atmosphere pressure container using either nitrogen, hydrogen, or helium, and using MoS_2 dry lubricants on ball bearings and gears with Teflon seals acting as a barrier between the one atmosphere and 10^{-10} mm Hg lunar pressure; particular reference should be applied to Bal Seal Engineering products. These seals consist of Teflon rings surrounding a helical spring and are suitable from $-400^{\circ}F$ to $+250^{\circ}F$ and changing from an unfilled Teflon to a glass modified type, the upper temperature can be raised to $+300^{\circ}F$. These seals appear to be equally effective in static and dynamic conditions but some redundancy is required to maintain leak rates of 1×10^{-6} cc/sec provided that surface finishes between 4 and 8 rms are maintained dependent upon the gas used. Surfaces finished to Rockwell 50C or chrome-plated surfaces are compatible with Teflon materials to maintain the proposed leak rate.

Inverters can be bought or made giving square wave outputs as high as 100 kc and the suggested frequency for driving the sensor circuit could be 2400 Hz with six stages of binary dividers producing 75 Hz for the motor drives. At this frequency, a two-pole servo-type motor would run at 4280 rpm thus reducing to a minimum the cycles for the ball bearings being used. Motors will be Gaylord Rieves size 10, having cast aluminum rotors and SIG-14 sealed inverters. During discussions relating to the drive motors, the anticipated power levels of the motors running and stalled were defined as 2 watts and 4 watts, respectively, at 28 volts; the inverter loss at stalled condition being 3 to 3 1/4 watts, that is, 83 percent efficiency. The total estimated power load is 19.7 watts.

Torque and speed data are given in Table 4-X; a flexural point selection summary is given in Table 4-XI.

Temperature extremes restrict component selection and the most suitable light sensitive device is a p-n structure photovoltaic cell. To achieve an output, a light sensing element requires a finite area, and this makes accuracy in positioning difficult without provision for additional aperture control--the aperture control plate is mounted on top of the earth sensor (item 45 of Fig. 4-10).

The reflector on the lunar beacon must be positioned so that the correct relationship between the sun and the earth is maintained. Continual adjustment of the reflector is required; therefore, a system for sensing sun and earth positions and providing command control signals is necessary. The system devised must be capable of operation for at least a year and requires a minimum of input power. In addition, extreme conditions of temperature can be expected. The following paragraphs describe a system which will adequately supply the required control signals in expected operational environment:

1. The sun acquisition longitudinal control system commands the system to move in the direction of sun travel during the lunar day and keeps the system rotated slightly ahead of the sun. The system for accomplishing this is illustrated in the block diagram in Fig. 4-15 and the schematic diagram in

TABLE 4-X

TORQUE AND SPEED DATA FOR
BEACON MECHANISM DRIVE AND MOTOR SELECTION

		A	B	C	D	E	F	G	H	J
Axis No.	Brg. Type	Tracking Time (14.5 days) (hours)	Max Total Rotation (deg)	Av Rate "Calendar" Tracking: $\frac{B}{360\ A}$ = (rph)	Axis Shaft Rotation $15 \cdot C$ = (rph)	Gear Motor Pinion Rotation $9 \cdot D$ = (rph)	Max Moment Ref. to 3-24-66 (lb in.)	Torque Required at Gear Motor Pinion Earth (lb in.)	Torque Required at Gear Motor Pinion Moon (lb in.)	Recommended Min Gear Motor Output Torque (lb in.)
1	Pivot	348	16	0.000128	0.00192	0.0173	18.9	2.87	1.12	2.0
2	Pivot	348	16	0.000128	0.00192	0.0173	14.7	2.40	1.04	2.0
3	Sleeve Brg.	348	90	0.000720	0.01080	0.0970	1.3	0.16	0.03	2.0
4	Pivot	348	4	0.000032	0.00048	0.0043	0	0.77	0.77	2.0
					(see Note 1)	(see Notes 2 and 5)	(see Note 3)	(see Note 3)		

NOTES:

1. Rotation of all tracking axes to be at a rate 15 times faster than that required for actual "calendar" tracking. This rate will permit the return of all moving members to lunar morning starting position (where practical), by reversing the drive motors during the last 24 hours of the lunar day, thus utilizing solar power for the return operation.

2. All gear motors to be vacuum sealed and to have a 10-tooth output pinion for mating with a 90-tooth axis drive gear for a 9:1 speed reduction.

3. Torque values are based on summation of moments data (p. 3-24-66) and are compensated for joint bearing efficiency of 80 percent or flex pivot spring rate.

4. All numbers pertain to "earth" values, unless otherwise noted.

5. Recommended gear motor pinion speed: for axes Nos. 1, 2, and 4; 7 deg/hr for axis No. 3; 40 deg/hr.

TABLE 4-XI

FLEXURAL PIVOT SELECTION
(Summary)

Drive Axis No.	Bendix Cat. No.	Type	Diam	Length	Load Capacity (lb)	Max Deflection (deg)	Rate lb in./rad	*Total Torque Due to 2 brgs. per Axis at Axis	at Motor
1 & 2	5012-600	End Pivot	0.375	0.600	80/113	15.0	2.75	0.77	0.086
4	6012-400	Thru-Pivot	0.375	0.600	253	7.5	22.00	0.77	0.086

*Torque due to 2 pivot bearings at axes Nos. 1 and 2 for 8^o rotation:

$$T_1 = \frac{2.7 \times 8 \times 2}{57.3} = 0.77 \text{ lb in. at axis shaft}$$
(or 0.086 lb in. at gear motor)

Torque due to 2 pivot bearings at axis No. 4 for 1^o rotation.

$$T_4 = \frac{22.0 \times 1 \times 2}{57.3} = 0.77 \text{ lb in. at axis shaft}$$
(or 0.086 lb in. at gear motor)

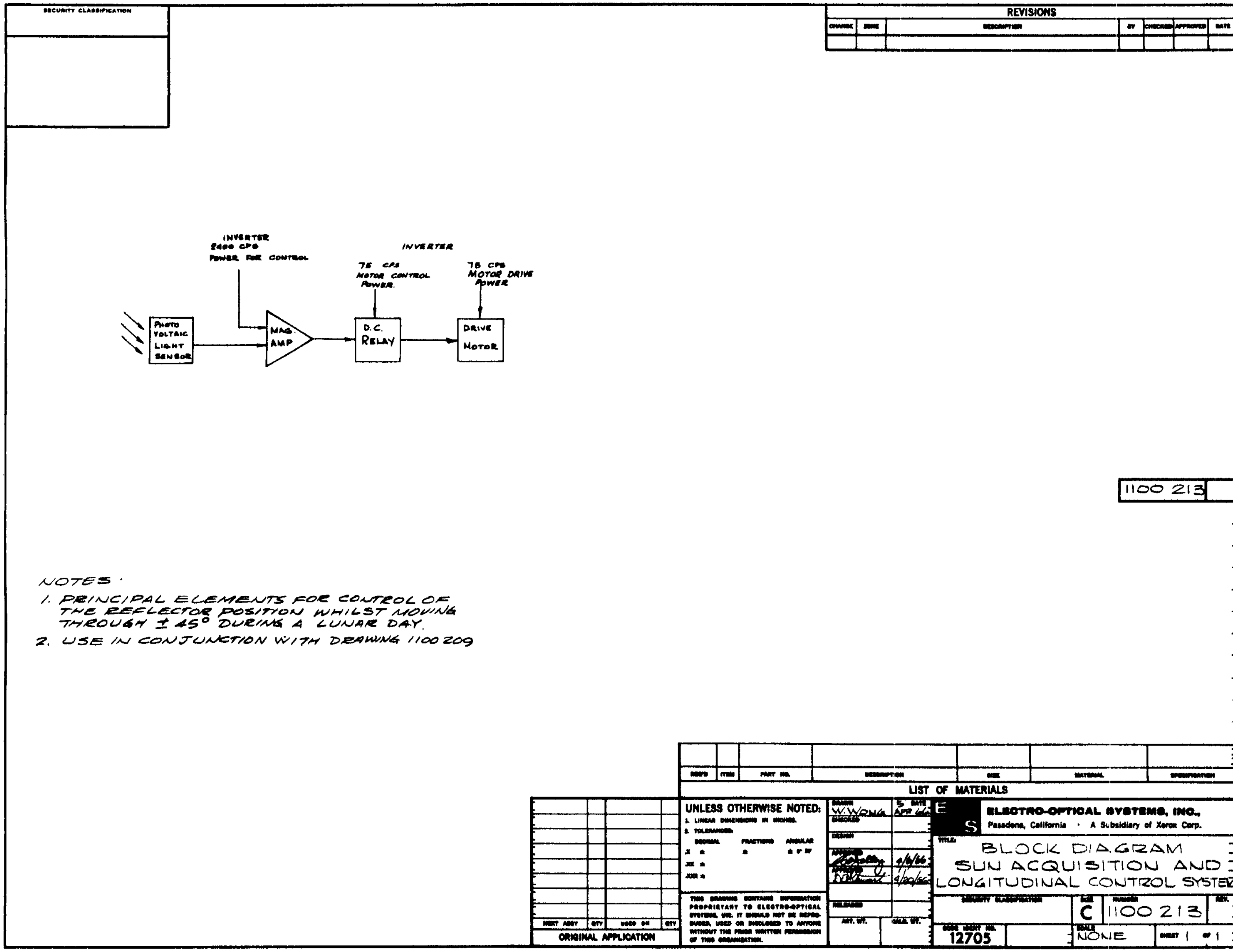

SECURITY CLASSIFICATION
REVISIONS
CHANGE
ZONE
DESCRIPTION
BY
CHECKED
APPROVED
DATE
INVERTER
2400 CPS
POWER FOR CONTROL
INVERTER
75 CPS
MOTOR CONTROL
POWER.
75 CPS
MOTOR DRIVE
POWER
PHOTO
VOLTAIC
LIGHT
SENSOR
MAG.
AMP
D.C.
RELAY
DRIVE
MOTOR
1100 213
NOTES:
1. PRINCIPAL ELEMENTS FOR CONTROL OF THE REFLECTOR POSITION WHILST MOVING THROUGH ± 45° DURING A LUNAR DAY.
2. USE IN CONJUNCTION WITH DRAWING 1100 209
LIST OF MATERIALS
PART NO.
DESCRIPTION
SIZE
MATERIAL
SPECIFICATION
UNLESS OTHERWISE NOTED:
ORIGINAL APPLICATION
W. WONG
ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.
BLOCK DIAGRAM
SUN ACQUISITION AND
LONGITUDINAL CONTROL SYSTEM
C
1100 213
12705
NONE

FIG. 4-15

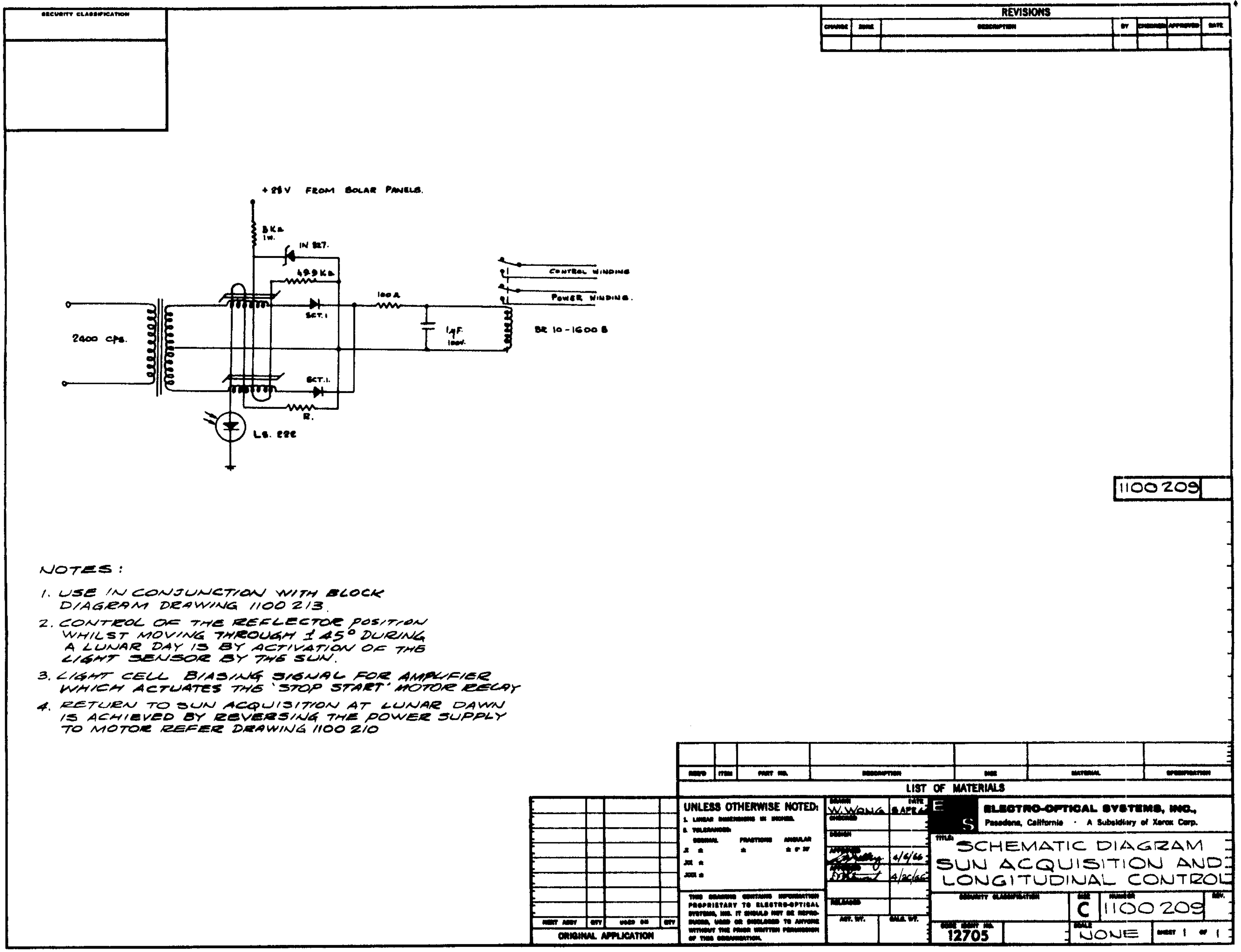
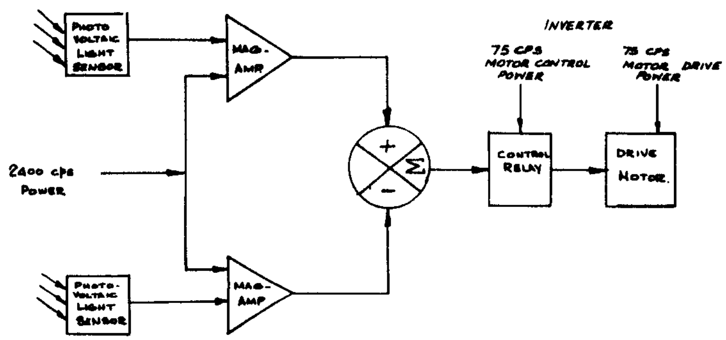

SECURITY CLASSIFICATION
REVISIONS
CHANGE | ZONE | DESCRIPTION | BY | CHECKED | APPROVED | DATE
+28V FROM SOLAR PANELS.
3KΩ 1W.
IN 827.
49.9KΩ
SCT.1
100Ω
1μF. 100V.
CONTROL WINDING
POWER WINDING.
BR 10-1600 B
2400 cps.
SCT.1.
R.
LS. 22E
1100 209
NOTES:
1. USE IN CONJUNCTION WITH BLOCK DIAGRAM DRAWING 1100 213.
2. CONTROL OF THE REFLECTOR POSITION WHILST MOVING THROUGH ± 45° DURING A LUNAR DAY IS BY ACTIVATION OF THE LIGHT SENSOR BY THE SUN.
3. LIGHT CELL BIASING SIGNAL FOR AMPLIFIER WHICH ACTUATES THE 'STOP START' MOTOR RELAY
4. RETURN TO SUN ACQUISITION AT LUNAR DAWN IS ACHIEVED BY REVERSING THE POWER SUPPLY TO MOTOR REFER DRAWING 1100 210
LIST OF MATERIALS
ORIGINAL APPLICATION
UNLESS OTHERWISE NOTED:
W. WONG
4/4/66
ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.
SCHEMATIC DIAGRAM
SUN ACQUISITION AND
LONGITUDINAL CONTROL
C
1100 209
12705
NONE
SHEET 1 OF 1

FIG. 4-16

Fig. 4-16. The sensor, which is a photovoltaic device, provides an output when exposed to light. This output is applied to the control winding of a magnetic amplifier.

The magnetic amplifier provides the power gain necessary to operate the relay which applies operating power to the drive motor. As the reflector rotational velocity will be higher than the rotational speed of the sun, the system will maintain a position just slightly ahead of the sun by starting and stopping the drive motor as required to sustain that position.

2. The lateral control system and earth positioning control system, as the names imply, control the reflector lateral position relative to the sun and the reflector position relative to the earth. The earth positioning control system and the lateral control system use the same type circuitry. Therefore, the system illustrated in the block diagram (Fig. 4-17) and the schematic (Fig. 4-18) will accomplish either task. There are two photovoltaic sensors in this system. The outputs from these sensors are used as control signals for two magnetic amplifiers, the outputs of which are in opposition. These outputs are summed and the magnitude of the resultant signal is proportional to the amount of light-flux impinging upon the light sensors. This resultant signal has been power amplified by means of the magnetic amplifiers and sufficient current and voltage are available to energize a latching relay in either position, depending upon the sun-earth position relative to the sensors. The relay in one position applies the motor control voltage leading the phase of the voltage causing the drive motor to rotate in one direction. When the relay is switched to its opposite position, the motor control voltage is applied, lagging the phase of the power voltage causing the drive motor to reverse direction. Thus, the angular displacement of the sun and the earth relative to the reflector can be controlled.



NOTES:

1. PRINCIPAL ELEMENTS FOR CONTROL OF REFLECTOR WHILST SENSING EITHER SUN OR EARTH DURING THE LATERAL EXCURSIONS OVER A ONE YEAR PERIOD.
2. AFTER SUMMATION OF POSITIVE AND NEGATIVE SIGNALS FROM THE 'MAG-AMP'S' THE RESULTANT DEFINES DIRECTION OF TRAVEL.
3. USE IN CONJUNCTION WITH DRAWING 1100 211

1100 212

LIST OF MATERIALS

UNLESS OTHERWISE NOTED:

DRAWN W. WONG APR 66

ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.

TITLE: BLOCK DIAGRAM, LATERAL CONTROL SYSTEM AND EARTH POSITIONING SYSTEM

SIZE C NUMBER 1100 212

CODE IDENT NO. 12705 SCALE NONE SHEET 1 OF 1

ORIGINAL APPLICATION

FIG. 4-17

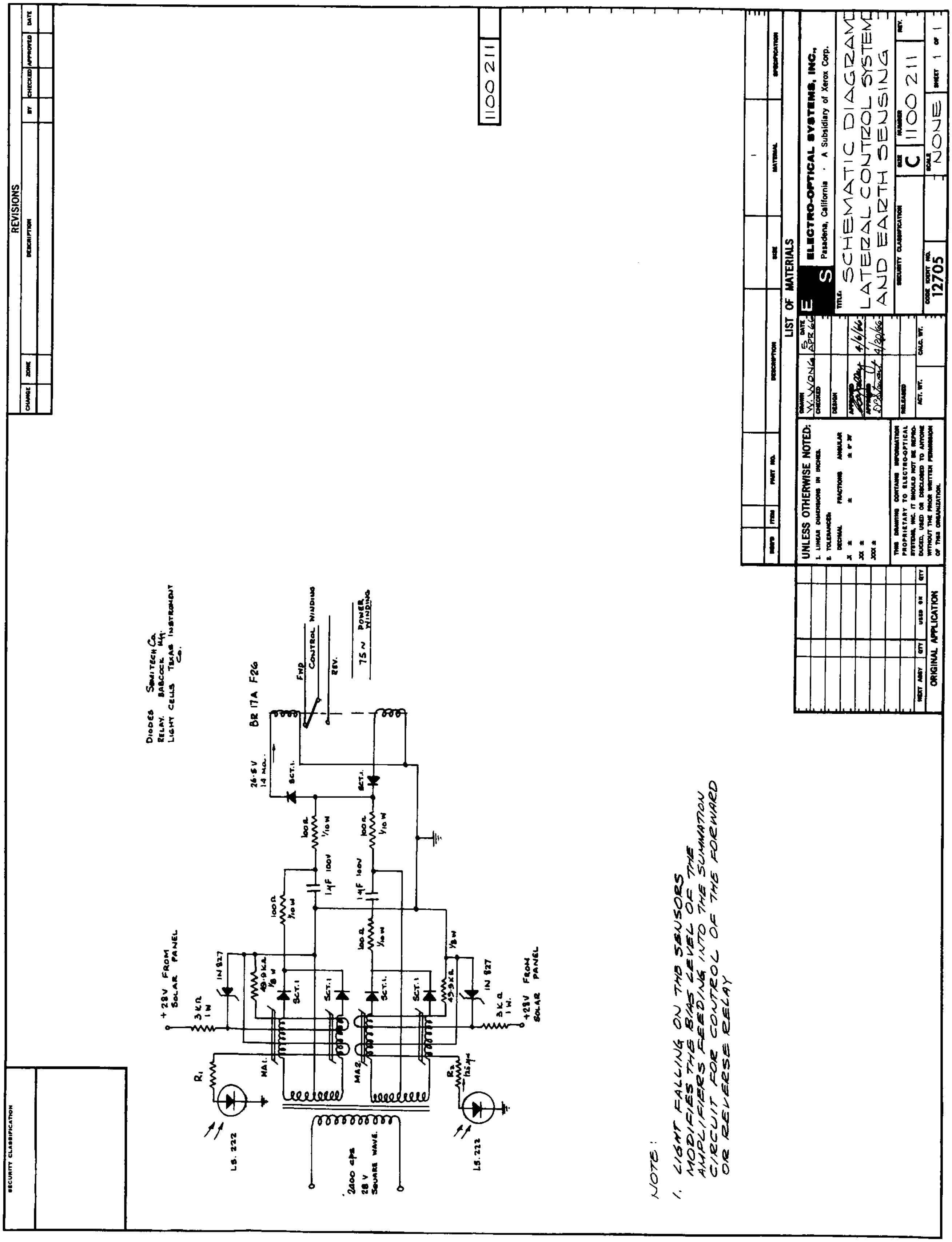

REVISIONS
1100 211
LIST OF MATERIALS
UNLESS OTHERWISE NOTED:
ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.
SCHEMATIC DIAGRAM
LATERAL CONTROL SYSTEM
AND EARTH SENSING
C
1100 211
12705
NONE
SHEET 1 OF 1
W. WONG
APR 66
ORIGINAL APPLICATION
DIODES SEMITECH CO.
RELAY BABCOCK MOD.
LIGHT CELLS TEXAS INSTRUMENT CO.
BR 17A F26
FWD
CONTROL WINDING
REV.
75 Ω POWER WINDING
26.5 V
14 MA.
+28V FROM SOLAR PANEL
3 KΩ
1 W
IN 927
49.9 KΩ
1/8 W
100 Ω
1/10 W
1 μF 100V
SCT.1
MA 1
MA 2
R1
R2
LS. 222
LS. 223
2400 cps
28 V
SQUARE WAVE
NOTE:
1. LIGHT FALLING ON THE SENSORS MODIFIES THE BIAS LEVEL OF THE AMPLIFIERS FEEDING INTO THE SUMMATION CIRCUIT FOR CONTROL OF THE FORWARD OR REVERSE RELAY

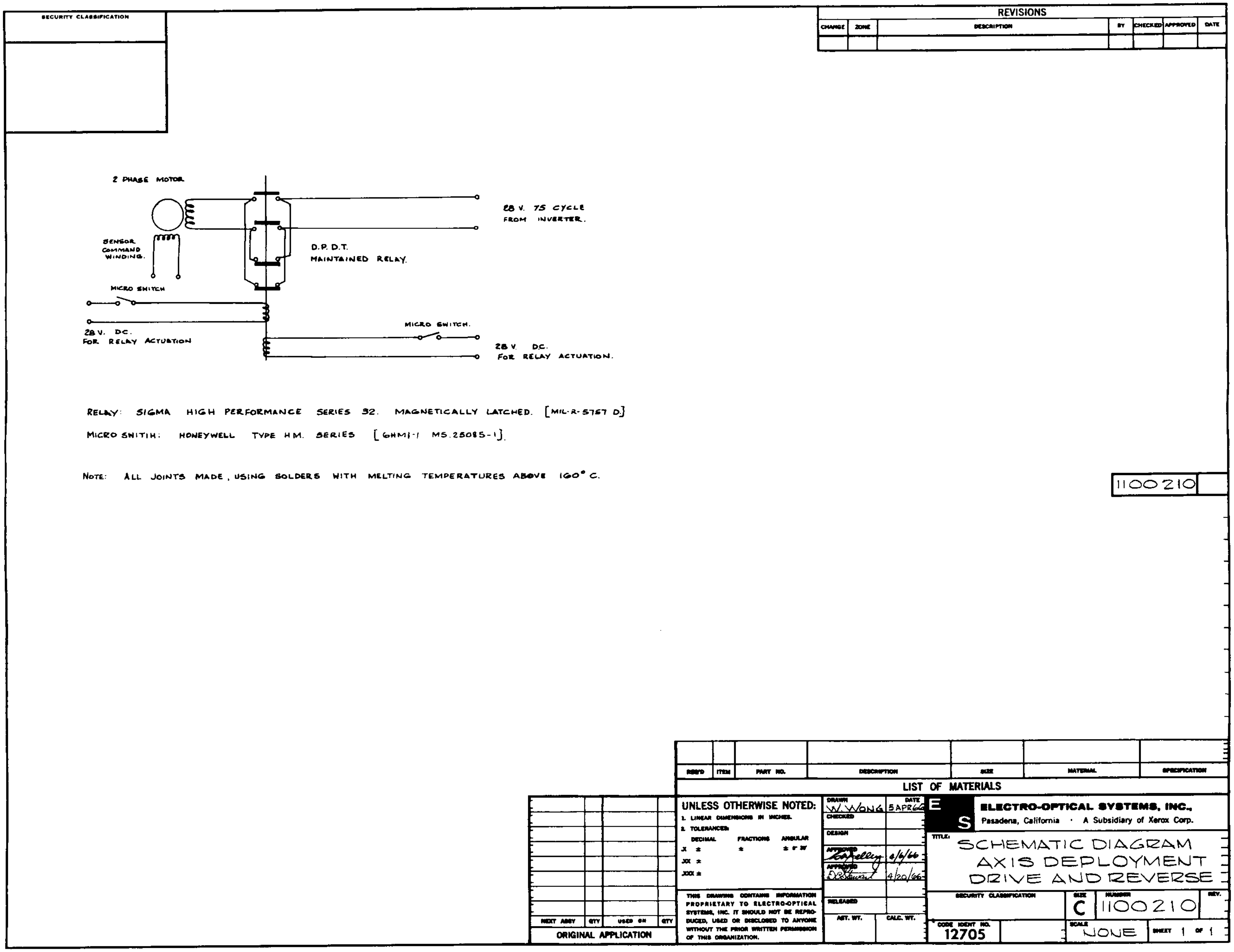
FIG. 4-18

There are some distinct advantages to the illustrated and described use of magnetic amplifiers, such as long life, high power gain, high efficiency, accuracy and high reliability, all of which are highly desirable factors, especially in this application.

The drive motors are two phase, with the optical sensors controlling one winding for planet acquisition, during a lunar day, from either stop, start or forward and reverse commands; the other winding providing the drive power to maintain speed in a given direction.

Return of the beacon from a sunset to sunrise position is accomplished by reversing power to the drive winding through cam actuated limit switches set at the extremities of the sun-earth acquisition latitudes, during the last 24 hours of a lunar day as shown in Fig. 4-19 (lunar dawn to dusk). The probability of requiring additional control on two axes becomes important. However, difficulty arises in the selection of a suitable approach. One arrangement could be to use a punched optical tape reader command generator to program the motor drives during operation. Such a system maintains correct correlation between the beacon and earth. Another solution is to maintain a given performance continuously through the lunar night, which presents an associated battery problem.

Another possible alternative is to use oriented solar sensors as time switches to drive the axes toward the dawn starting position. The angular loci of the dawn and dusk positions are two sine waves having periods of about 12 to 14 months. The loci of the earth at all times is an amplitude modulated sine wave with a period of about one lunar month. At a first approximation the difference between the absolute values of the dusk and dawn positions is almost 0. Therefore, if the drives are programmed to go forward (in the direction they are proceeding when the time sensor is activated) to a limit switch, then backward for a total fixed time (i.e., absolute angular change),



SECURITY CLASSIFICATION
REVISIONS
CHANGE
ZONE
DESCRIPTION
BY
CHECKED
APPROVED
DATE
2 PHASE MOTOR
SENSOR COMMAND WINDING.
D.P. D.T. MAINTAINED RELAY.
28 V. 75 CYCLE FROM INVERTER.
MICRO SWITCH
28 V. DC. FOR RELAY ACTUATION
MICRO SWITCH.
28 V. DC. FOR RELAY ACTUATION.
RELAY: SIGMA HIGH PERFORMANCE SERIES 32. MAGNETICALLY LATCHED. [MIL-R-5757 D]
MICRO SWITCH: HONEYWELL TYPE H.M. SERIES [6HM1-1 MS.25085-1]
NOTE: ALL JOINTS MADE, USING SOLDERS WITH MELTING TEMPERATURES ABOVE 160° C.
1100210
REQ'D
ITEM
PART NO.
DESCRIPTION
SIZE
MATERIAL
SPECIFICATION
LIST OF MATERIALS
UNLESS OTHERWISE NOTED:
1. LINEAR DIMENSIONS IN INCHES.
2. TOLERANCES:
DECIMAL
FRACTIONS
ANGULAR
.X ±
.XX ±
.XXX ±
±
± 0° 30'
THIS DRAWING CONTAINS INFORMATION PROPRIETARY TO ELECTRO-OPTICAL SYSTEMS, INC. IT SHOULD NOT BE REPRODUCED, USED OR DISCLOSED TO ANYONE WITHOUT THE PRIOR WRITTEN PERMISSION OF THIS ORGANIZATION.
DRAWN W. WONG
DATE 5 APR 66
CHECKED
DESIGN
APPROVED 4/6/66
APPROVED 4/20/66
RELEASED
ACT. WT.
CALC. WT.
NEXT ASSY
QTY
USED ON
QTY
ORIGINAL APPLICATION
E S
ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · A Subsidiary of Xerox Corp.
TITLE:
SCHEMATIC DIAGRAM
AXIS DEPLOYMENT
DRIVE AND REVERSE
SECURITY CLASSIFICATION
SIZE C
NUMBER 1100210
REV.
CODE IDENT NO. 12705
SCALE NONE
SHEET 1 OF 1

FIG. 4-19

the axes will be closely aligned in the dawn start position. Alternatively, one can use a large sensor field of view with the attendant problems of a long sun lock-on time near full moon.

Currently, there is no simple solution to this problem, therefore, it could be the basis for future analysis and design studies.

The external gear drives and bearings utilize stainless steel with a molybdenum disulfide, MoS_2, filled nylon or nylon and glass composite. Other potential materials utilize a silver-mercury, tungsten-disulfide, and Teflon dry lubrication.

3. Sun lock-on by the earth sensor can be eliminated by providing another filtered sensor which is sensitive only to direct solar radiation. When activated, this sensor could switch off a relay to the earth drive axes and therefore prevent permanent lock-on to the sun. The period of inoperation would be more than $(100/180^{\circ})(\phi)$ percent of the lunar day, where ϕ is the field of view of the earth sensors. Additional time would then be required to retrack the earth after the sun passes from the earth sensor field of view. The lost time would run between 1 and 3 days, but this period would correspond to the period of the lowest probability of detection, i.e., at full moon.

4.5.2.3 Solar Panel Assemblies, Figs. 4-11 and 4-12

The solar panel assembly drawings shown are hinged in 1 and 3 places respectively. The included angle between panels was arbitrarily set at 90° with the panel slope measured at 45° from ground level. Depending upon the thermal characteristics of the solar panel and the total tested power requirements of the beacon, other slope and included angles may be more efficient. The panel construction and solar cell string design depicted represent the latest state-of-the-art hardware designs available based on EOS work for the Ranger, Mariner, and Voyager programs. The panel size was determined from the following power requirements:

$$\text{Number of cells:}\quad N = \frac{W}{Fw}$$

$$= \frac{19.7}{0.5 \times 0.0546}$$

$$N = 720 \text{ cells} \approx 20 \times 25 \text{ inch panel}$$

where

W = power required

F = temperature degradation factor

w = wattage 2 x 2 cm cell

A typical array consists of 0.003 inch filter glass, 0.012 inch, 2 x 2 cm NP type solar cells, 0.001/0.003 inch tinned copper connecting strips, and 0.001/0.005 inch DuPont H film insulation cemented on the substrate which is supported by a frame.

The temperature power degradation factor used in the calculation applies to a solar panel during full moon conditions. At the lunar dawn, the power output would be over twice the level indicated. Conversely, at the lunar dusk the power output should increase. However, the net power increase will be less than the comparative dawn to noonday decrease because the panel temperature will not decrease rapidly. The solar panel will be mounted outboard of the south reflector arm as shown in Fig. 4-14.

4.5.2.4 <u>Tracking Beacon, Reflector Panels, and Frame Fig. 4-13</u>

The reflector panel and frame design is dictated by:

1. A requirement for 33 ft^2 of flat reflector area
2. The maximum storage dimensions
3. The desirability of hinging as many components as possible to minimize the total subassemblies and permit easier fabrication
4. The working room necessary to erect the beacon.

Basically, the reflector panels represent a plus sign. The reflector surface is produced by electroforming and is rigidized by an angle rim frame. The electroforming process utilized with this and the cislunar beacon metal spherical segments is detailed in Appendix D. Two alternative locations are shown for the reflector skin with respect to the angle support. Alternate 2 presents the least difficulties due to scratching during assembly or packing. However, probably alternate 1 is easier to fabricate and would present fewer thermal expansion difficulties. If any alternative reflector materials were considered, alternate 1 would probably be the method of attachment. In any case, the combination of rim and reflector materials and their thermal control overcoatings must result in stretching of the reflector membrane during the lunar day.

Previous experience with circular rim-supported membrane reflectors indicates that there are no major structural or optical difficulties in producing a circular stretched reflector. However, a rectangular stretched mirror may present some structural problems due to the nonuniformity of stress in the stretched condition.

Potential stress problems during the stretched mode can be reduced or eliminated by:

1. Using rim materials whose thermal expansion closely matches the reflector membrane thermal expansion
2. Increasing the moment of inertia of the rim
3. Decreasing the membrane thickness

4. Applying the thermal control coatings to minimize the stretching stress
5. Varying the moment of inertia of the rim to correlate with the stress

More detailed analytical or empirical analysis is required. With either reflector alternate the highly reflective surface will terminate at the edge of the rim due to electroforming process. However, if the rim is polished prior to electroforming, the net reflectance loss of the rim surface, after a 0.001 inch thick electroformed coating is applied, should be only between 30 to 40 percent so that some advantage is realized from the reflector rim area. The standard reflectance coatings applied will be an aluminum vacuum deposited metal coating followed by a silicon monoxide overcoating, which will provide both abrasion and thermal control protection. The exact thickness of the silicon monoxide should be specified after solar-simulation investigations of the stretched membrane design. Normally the thickness will be governed by the maximum reflectance attainable over the integrated solar spectrum and by the ratio of the α/ϵ which results from the specific silicon monoxide overcoating thickness. Two minor optical questions are raised by this design:

1. The degree of flatness alignment actually attainable by the frame and membrane reflector design
2. The reflector distortion due to rim deflection by the level adjustment screws

These questions should be answered by additional investigations on subsequent programs.

4.5.2.5 Tracking Beacon Erection Procedure, Fig. 4-19

The tracking beacon erection procedures are straightforward. However, extensive training may be required to erect the components in 10 minutes because of the many hinge and pin joints, the electrical connections, and the optical alignment required.

If the beacon height depicted is too high for ease of erection, alternate tripod designs can be used to minimize the erection height. No external dust protection has been provided. If the beacon is placed eastward of the ascent trajectory, the majority of the dust will strike the rear of the reflector panels or bounce from the upper panel surfaces as the particles settle. The use of photolytic materials, which could sublime to yield a gas bearing for residual dust on the reflector surface, should be considered.

4.6 Specifications

The proposed QC inspection plan for the prototype beacon fabrication is given in Appendix F. Since the prototype drawings are to be scaled for fabrication, there are few mechanical inspection procedures required. However, an inspection plan should be written and approved before prototype fabrication starts.

A proposed specification for an earth and sun sensor package is given in Appendix G.

All components and assemblies shall be built to withstand the Environment Specifications for Apollo Scientific Equipment.

4.7 Projected Schedules and Costs

Projected cislunar beacon costs and schedules are shown in Table 4-XII and Fig. 4-20, respectively. These costs total over $170,000 for an all-metal beacon and over $140,000 for an inflatable beacon. These costs include the prototype, testing, and flight unit phases and are about twice those projected for the static cislunar beacons during Phase I. Both the costs and the 2-year delivery appear realistic; however, the 2-year schedule could be markedly improved at an increase in cost. Three inflatable reflectors are projected to secure a desired prototype. The miscellaneous engineering category covers the program management requirements for all the estimates.

TABLE 4-XII

CISLUNAR BEACON COSTS

Alternate and Subassembly	Prototype Fabrication	Environmental and Type Testing*	Flight Units
1. All-metal Reflector			
1.1 Tripod	$ 1,000	$ 2,000	$ 500
1.2 Frame and Miscellaneous Hardware	1,000	1,000	500
1.3 Reflectors	50,000	5,000	18,000
1.4 Packaging	5,000	3,000	1,000
1.5 Assembly, Inspection, and Checkout	20,000	5,000	13,000
1.6 Reports	3,000	2,000	1,000
1.7 Liaison with NASA and Miscellaneous Engineering	13,000	11,000	6,000
TOTAL	$93,000	$29,000	$40,000
2. Inflatable Reflector			
2.1 Tripod	1,000	2,000	500
2.2 Miscellaneous Hardware	1,000	1,000	500
2.3 Reflector	30,000	20,000	6,000
2.4 Packaging	5,000	3,000	1,000
2.5 Assembly Inspection and Checkout	20,000	4,000	10,000
2.6 Reports	3,000	2,000	1,000
2.7 Liaison with NASA and Miscellaneous Engineering	13,000	11,000	6,000
TOTAL	$73,000	$43,000	$25,000

*Does not include costs of high vacuum solar simulation.

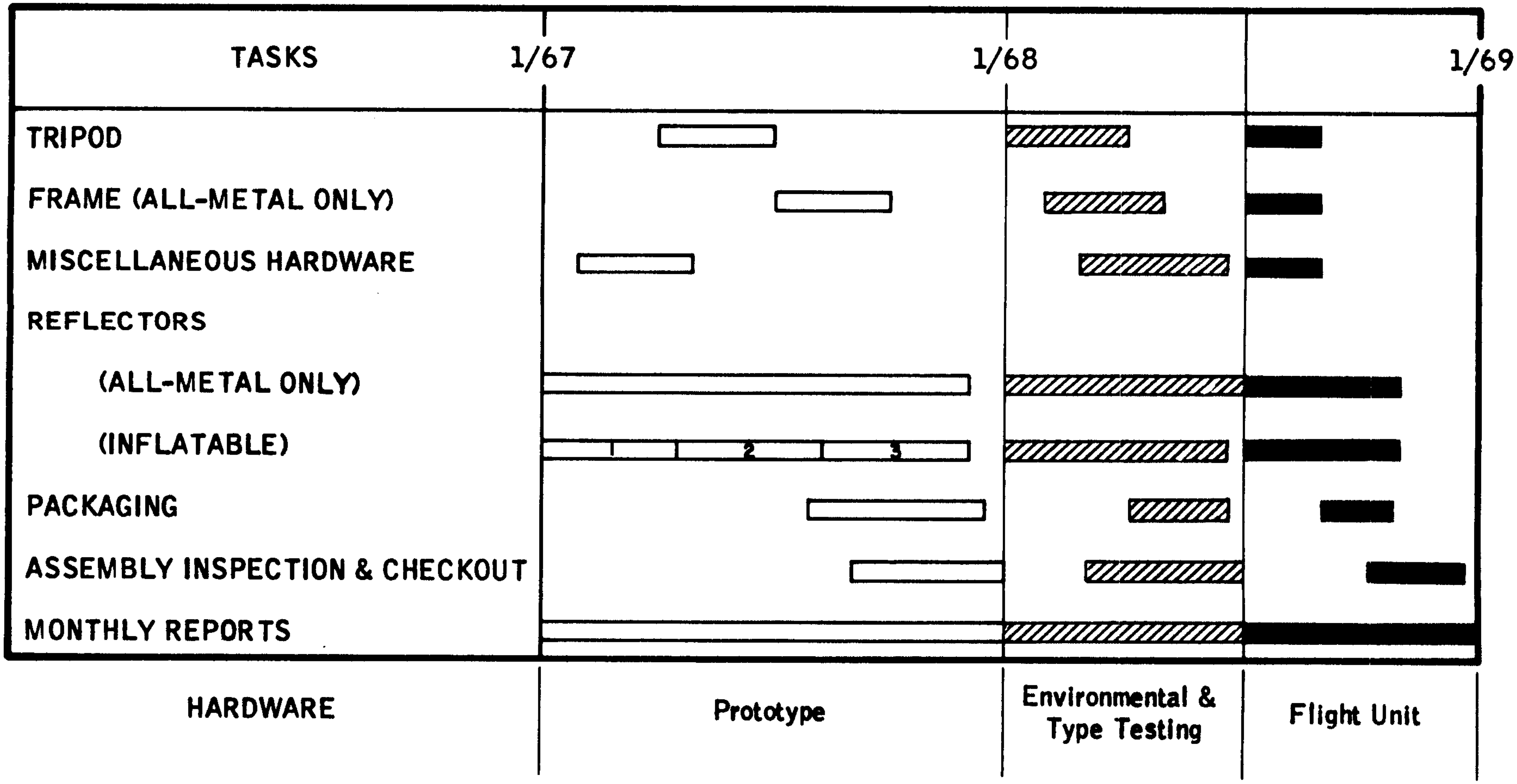


FIG. 4-20 CISLUNAR BEACON PROGRAM SCHEDULE

The projected earth beacon costs and schedule are shown in Table 4-XIII and Fig. 4-21. These costs are over 4 times the Phase I estimates and represent the increased knowledge of the sensing and dynamic problems relative to the Phase I program.

TABLE 4-XIII

EARTH TRACKING BEACON COSTS

	Beacon Subassembly	Prototype Fabrication	Environmental and Type Testing*	Flight Units
1.	Sensors — Earth and Sun	$ 90,000	$ 50,000	$ 8,000
2.	Mechanism —			
	Motors	16,000	35,000	12,000
	Bearings and Flexural Joints	16,000		
	Gimbal	1,000		
	Miscellaneous	13,000		
3.	Reflector Panels and Frame	35,000	15,000	12,000
4.	Tripod	2,000	3,000	1,000
5.	Solar Panel	40,000	5,000	22,000
6.	Assembly, Inspection and Checkout	50,000	15,000	5,000
7.	Packaging	4,000	4,000	2,000
8.	Liaison with NASA and Miscellaneous Engineering	40,000	25,000	14,000
9.	Reports	13,000	8,000	4,000
	TOTALS	$320,000	$160,000	$80,000

*Does not include costs of high vacuum solar simulation tests.

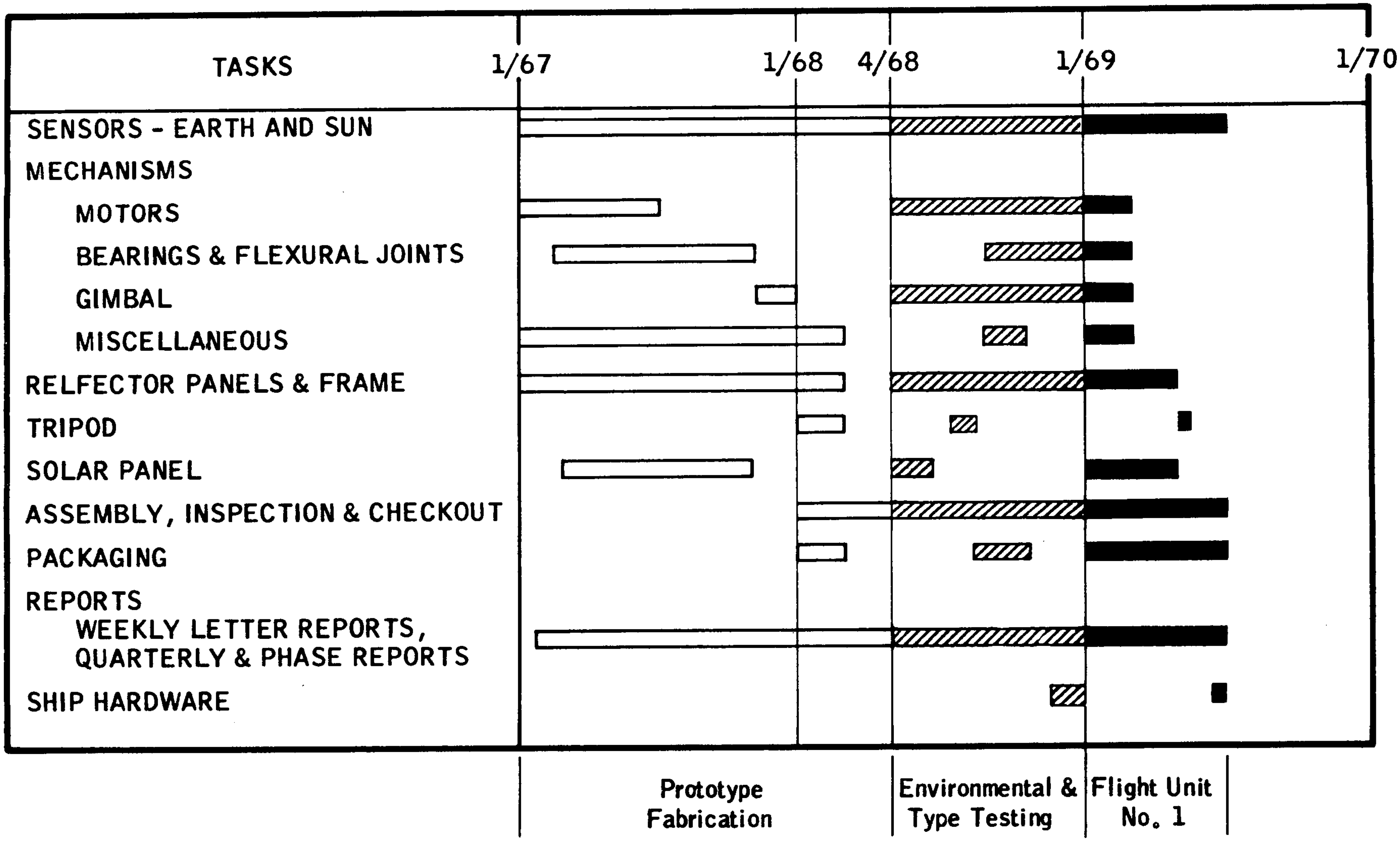


FIG. 4-21 EARTH TRACKING BEACON SCHEDULE BASED ON 1 JANUARY 1967 FUNDING

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APPENDIX A

BEACON PHOTOMETRIC ANALYSIS

APPENDIX A
BEACON PHOTOMETRIC ANALYSIS

1. DETECTION VARIABLES

The reflective area required for the detection of lunar beacons depends upon the following variables:

1. Background brightness, B_f
2. Beacon reflectance, r_b
3. Sun-moon-instrument phase angle, θ
4. Instrument beacon range, R
5. Integrated instrument optical transmittance, T_t
6. Integrated instrument angular resolution as a function of aperture, instrument errors, atmospheric seeing (and for photographic records of the detector errors), β
7. Atmospheric transmittance, T_e
8. Contrasts required for a given detector and probability of detection, C_v - visual, C_p - photographic
9. Lunar beacon location

The following sections describe the analysis required for beacon sizing, the major variables in detail, representative calculations, and beacon area recommendations.

2. CAMERA PHOTOMETRY THEORY

With a camera, the field brightness, B_f, is decreased only by the atmospheric and camera transmittance losses, T_e and T_t, so that the apparent field brightness, B_{af}, at the detector is

$$B_{af} = T_e \, T_t \, B_f \tag{1}$$

But B_f is related to the lunar field albedo or reflectance at 0^o phase angle, a_f, the phase angle reflection ratio for a given lunar location, K_θ, the solar illuminance of the moon, E_s, and π so that

$$B_f = \frac{K_\theta \; a_f \; E_s}{\pi} \tag{2}$$

Therefore, from Eqs. 1 and 2

$$B_{af} = \frac{T_e \; T_t \; K_\theta \; a_f \; E_s}{\pi} \tag{3}$$

and

$$E_{af} = B_{af} \; \omega \tag{4}$$

where

$$\omega = \frac{\pi}{4 \; N^2} \tag{5}$$

where

$$N = \frac{f.l.}{D_o} \tag{6}$$

Therefore, from Eqs. 3, 4, and 5,

$$E_{af} = \frac{T_e \; T_t \; K_\theta \; a_f \; E_s}{4 \; N^2} \tag{7}$$

Since the beacon size will be less than the resolution limit of the detection instruments, it can be considered as a point source having an image which is a diffraction pattern, 84 percent of the energy falling into the Airy or first-diffraction disc. The illuminance of the image from a point source, E_{ab}, is then related to the incident illuminance, E_{ob}, the objective diameter, D_o, focal length, f.l., the transmittance loss, T_t, and the integrated resolution limit, β, by

$$E_{ab} = 0.84\ T_t\ E_{ob} \left[\frac{D_o}{\beta\ f.l.}\right]^2 \tag{8}$$

Note that the angle, β, approaches $[1.22\ \lambda/D_o]$ for perfect seing where λ is the light wavelength. E_{ob} is related to the beacon apparent solid angular subtend, Ω_b, the solar solid angular subtend at the beacon, Ω_s, and the beacon illuminance, E_b, and the atmospheric transmittance, T_e, so that

$$E_{ob} = T_e \frac{\Omega_b}{\Omega_s} E_b \tag{9}$$

but the beacon illuminance is directly related to the incident solar illuminance, E_s, and beacon reflectance, r_b:

$$E_b = E_s\ r_b \tag{10}$$

and the beacon angular subtend is related to the projected beacon area, a $\cos\theta/2$ (i.e., the beacon mirror must be perpendicular to the bisector of the phase angle to be seen) and the range, R, so that:

$$\Omega_b = \frac{a \cos\frac{\theta}{2}}{R^2} \tag{11}$$

Combining Eqs. 6, 8, 9, 10, and 11

$$E_{ab} = \frac{0.84\ T_e\ T_t\ a \cos\frac{\theta}{2}\ E_s\ r_b}{\Omega_s\ R^2\ \beta^2\ N^2} \tag{12}$$

The apparent field and beacon illuminances are related to the photographic contrast for detection, C_p, by the term

$$C_p = \frac{E_{ab} - E_{af}}{E_{af}} = \frac{E_{ab}}{E_{af}} - 1 \tag{13}$$

By direct substitution of Eqs. 7 and 12 into Eq. 13

$$C_p + 1 = \frac{3.36\ a \cos\frac{\theta}{2}\ r_b}{K_\theta\ a_f\ \Omega_s\ \beta^2\ R^2} \tag{14}$$

Transposing

$$\frac{ar_b}{(C_p + 1)} = \frac{K_\theta\ a_f\ \Omega_s\ R^2\ \beta^2}{3.36 \cos\frac{\theta}{2}} \tag{15}$$

Note that this relationship is independent of the solar illuminance, transmittance values, and f/number (N), except as they affect the contrast and resolution values, of the system. In cases where seeing conditions govern the resolution angle, β, the camera diameter will only affect the film speed used and the time over which seeing conditions are integrated.

A log-log plot of the area factor, $ar_b/(C_p + 1)$, versus β yields a series of straight lines for each phase angle. The visual and photographic beacon areas are both closely related. Figures 1 and 2 are plots for ranges of 400 nautical miles* and 207,000 nautical miles, earth-moon mean distance, respectively.

Let us now compare visual telescope theory with the above.

3. VISUAL TELESCOPE PHOTOMETRY THEORY

The apparent field brightness of a telescope can be reduced if the exit pupil, d, is smaller than the eye pupil, d_e, which is the case for astronomical telescopes, by the ratio of their areas, $(d/d_e)^2$ so that

$$B_{af} = T_e\ T_t \left(\frac{d}{d_e}\right)^2 B_f \tag{16}$$

which is the same as Eq. 1 when $d = d_e$

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* The cislunar beacon range and detection specifications presented herein reflect the Phase I requirements.

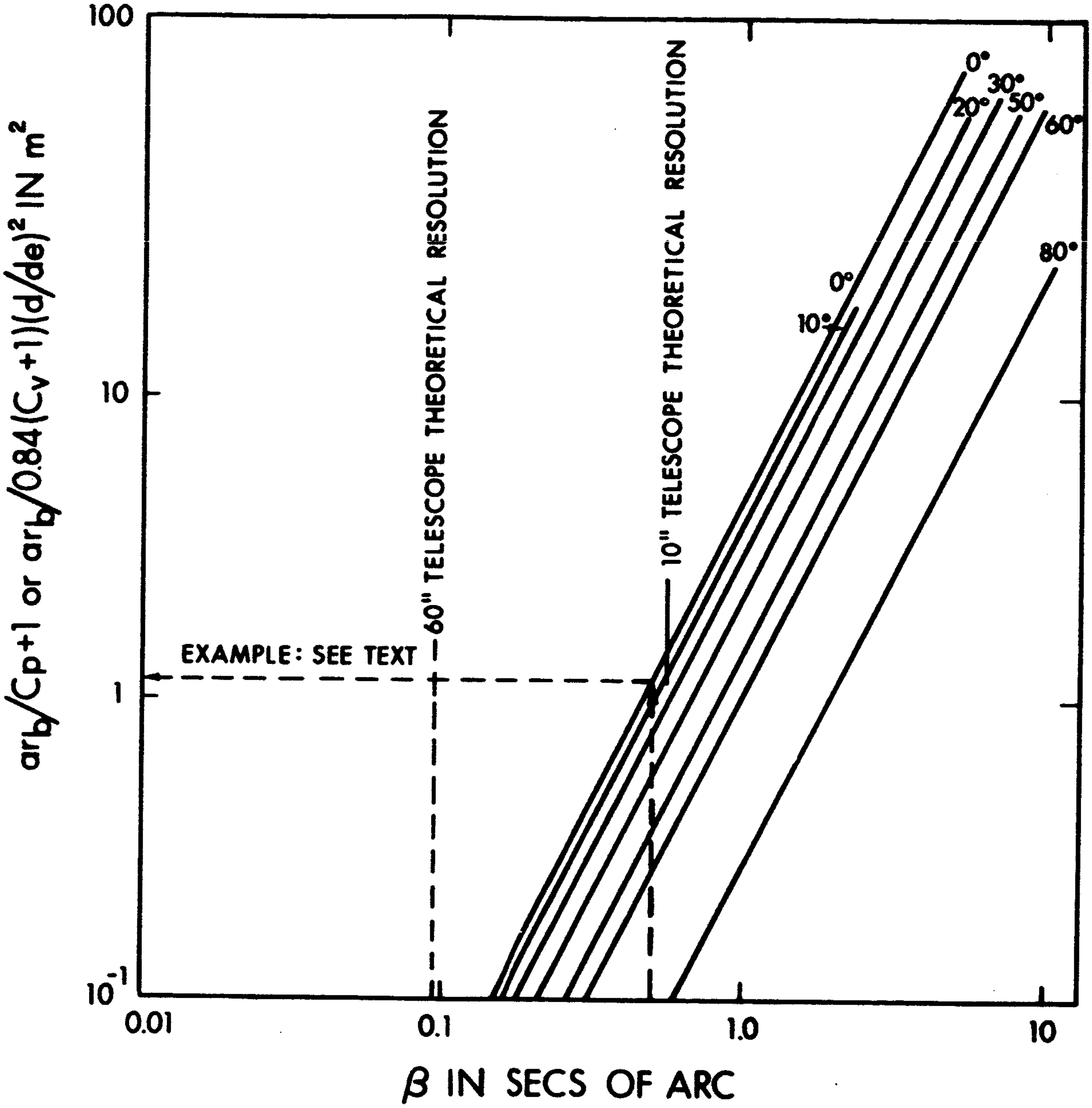

FIG. 1 AREA FACTOR VS RESOLUTION LIMIT FOR VARIOUS PHASE ANGLES FOR 0° LONGITUDE AT A 207,000 NAUTICAL MILE RANGE

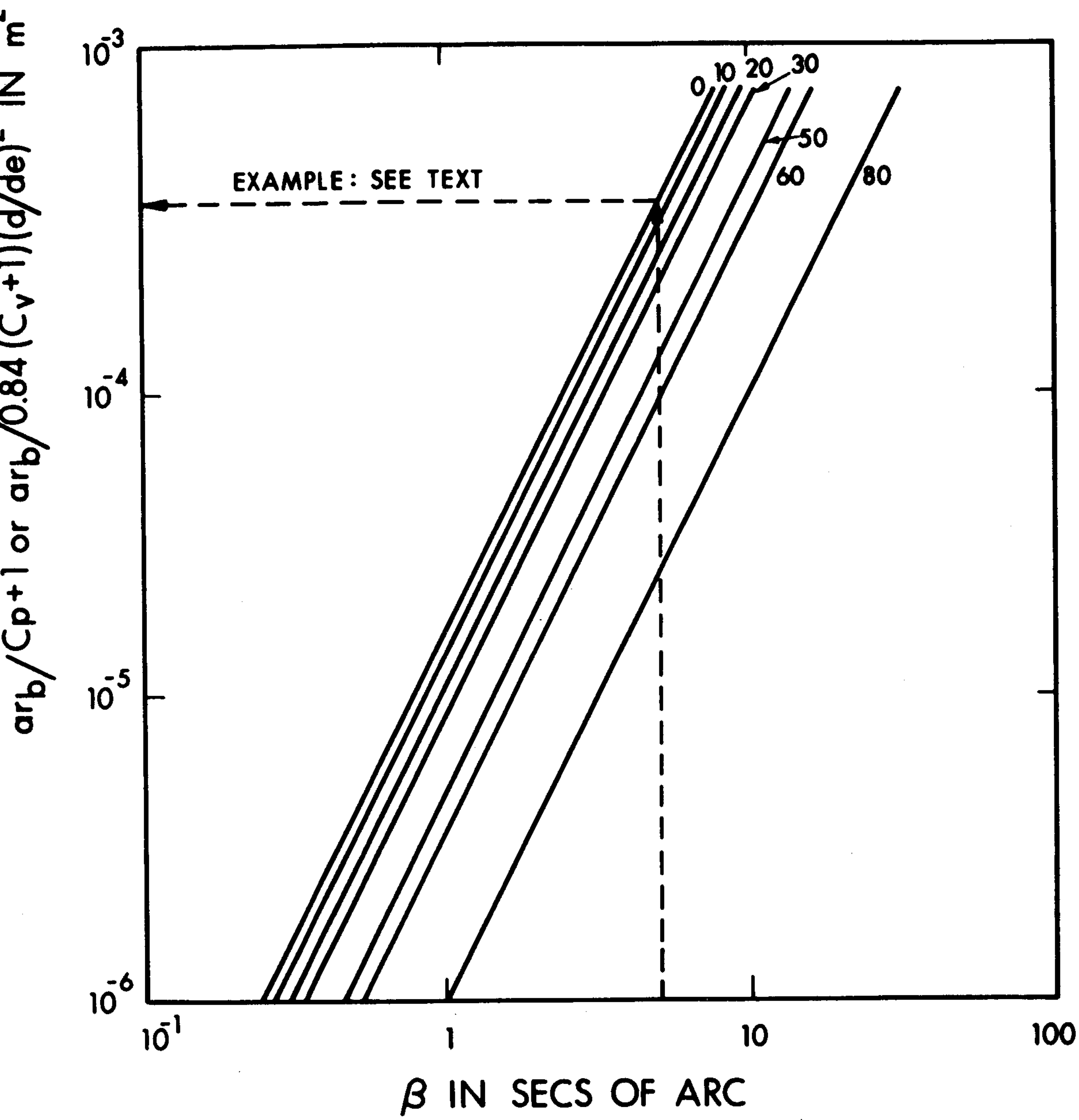

FIG. 2 AREA FACTOR VS RESOLUTION LIMIT FOR VARIOUS PHASE ANGLES FOR 0° LONGITUDE AT 400 NAUTICAL MILES

By combining Eqs. 2 and 16

$$B_{af} = T_e \, T_t \left(\frac{d}{d_e}\right)^2 \frac{K_\theta \, a_f \, E_s}{\pi} \tag{17}$$

The apparent brightness of the beacon, B_{ab}, and the apparent illuminance are related to the solid angle subtended by the eye, ω_e, after magnification, M, of the angle resolved, β, by

$$B_{ab} = \frac{E_{ab}}{\omega_e} \tag{18}$$

$$= \frac{E_{ab}}{\frac{\pi}{4} \, (\beta M)^2} \tag{19}$$

Now E_{ab} is related to the incident illuminance, E_{ob}, and the magnification and transmittance by

$$E_{ab} = T_t \, E_{ob} \, M^2 \tag{20}$$

By substituting Eqs. 9, 10, 11, and 20 into Eq. 19

$$B_{ab} = \frac{T_t \, T_e \, E_s \, r_b \, a \cos\frac{\theta}{2}}{\frac{\pi}{4} \, \Omega_s \, \beta^2 \, R^2} \tag{21}$$

Now the visual contrast, C_v, required for beacon reflection is related to B_{ab} and B_{af} by

$$C_v = \frac{B_{ab} - B_{af}}{B_{af}} = \frac{B_{ab}}{B_{af}} - 1 \tag{22}$$

Therefore, combining Eqs. 17, 21, and 22 yields

$$C_v + 1 = \frac{4\ a \cos\frac{\theta}{2}\ r_b\ d_e^2}{K_\theta\ a_f\ \Omega_s\ d^2\ \beta^2\ R^2} \tag{23}$$

Recombining and setting 4 = [3.36/0.84]

$$\frac{ar_b}{0.84\ (C_v + 1)} \left[\frac{d_e}{d}\right]^2 = \frac{K_\theta\ a_f\ \Omega_s\ R^2\ \beta^2}{3.36\ \cos\frac{\theta}{2}} \tag{24}$$

Note that the right side of the equation is the same as Eq. 15 and that the left side differs only by the substitution of C_v for C_p and the field brightness reduction ratio of $(d/d_e)^2$ and the fact that eye contrast values already integrate the 0.84 Airy disc energy collection factor. Therefore, with the substitution of the left side of Eq. 24 for the left side of Eq. 15, Figs. 1 and 2 can be used for both photographic and visual beacon calculations. Note that Eq. 24 is independent of the solar illuminance, transmittance, and telescope diameter values except as they affect the contrast and resolution values of the detection system.

The exit pupil, d, is a function of the telescope objective diameter and magnification so that

$$d = \frac{D_o}{M} \tag{25}$$

Equation 24 then becomes

$$\frac{ar_b\ d_e^2}{0.84\ (C_v + 1)} \left[\frac{M}{D_o}\right]^2 = \frac{K_\theta\ a_f\ \Omega_s\ R^2\ \beta^2}{3.36\ \cos\frac{\theta}{2}} \tag{26}$$

where M/D_o is the magnification per unit diameter.

Now let us analyze Eqs. 15 and 16 before discussing C_p and C_v in depth. For any given phase angle and landing site, the terms $K_\theta \, a_f \, \Omega_s/3.36$ are constant. Both K_θ and a_f are discussed in another section. Therefore, the beacon area varies as the square of the range and the square of the resolution angle. For any given viewing case, the range will be constant. Therefore, the resolution angle chosen will be a major factor in determining beacon area. This choice is, therefore, the subject of a complete section. Looking at the left side of Eqs. 15 and 16, the area will be inversely proportional to the beacon reflectance. Of all the variables in each equation, this probably has the greatest possible range in values depending on the degradation analysis and space micrometeoroid data one uses. Therefore beacon reflectance is also the subject of a separate section.

Both equations have similar terms (C_p + 1) and C_v + 1) related to photographic and visual detection contrast respectively. It will be shown that both C_p and C_v are less than 1 so that the beacon areas required are relatively insensitive to contrast changes. The contrast values will be discussed in the next section.

Finally, the visual detection is highly dependent on the magnification per unit telescope diameter where in practice the ratio will be between 0.4 and 2.0 for most conditions. Since the practical magnification per unit telescope diameter seems inversely proportional to seeing conditions which limit β most of the time, using limited data by Bowen, then the area of the beacon appears to vary as β^4 which indicates the great dependence of beacon detection on seeing conditions.

4. CONTRAST

The degree of photographic or visual contrast required for detection is dependent on both the desired probability of detection and the detector efficiency.

4.1 Photographic contrast

Photographic contrast used herein is given by

$$C_p = \frac{E_{ab} - E_{af}}{E_{af}} = \frac{E_{ab}}{E_{af}} - 1$$

Films are classified in terms of development contrast, γ, density differences, ΔD, where D = log 1/transmission, and Δ log I, the differences in the logs of the exposures in meter-candle-seconds, so that

$$\gamma = \frac{\Delta D}{\Delta \log I} \tag{27}$$

but

$$I = Et \tag{28}$$

so that

$$\gamma = \frac{\Delta D}{\Delta \log Et} = \frac{\Delta D}{\log E_{ab} t - \log E_{af} t} = \frac{\Delta D}{\log \frac{E_{ab}}{E_{af}}} \tag{29}$$

For each photographic film there is an rms graininess density variation of standard deviation, σ, where σ is measured in the same units as D. For a detection probability of 99.7 percent, a density difference ΔD

of 3σ is required. γ is the slope of the D versus log I curve measured at field brightness exposure energy, I_f, level. σ is measured from microdensitometer readings and will vary according to the slit width, d, of the microdensitometer, which ranges from 5 to 25 microns (0.0002 to 0.001 inch) wide according to the relationship

$$\sigma \cdot d = k \tag{30}$$

Therefore, the microdensitometer used to evaluate lunar photographs should have the same width as the slit used in the rms graininess measurement, to achieve the results predicted from theory.

For minimum seeing disturbances, the film exposure time should be short and, therefore, the exposure index high. Exposures, t, 1/25 second or less are desirable. The exposure energy, I, is given by the following term derived by combining Eqs. 7 and 28:

$$I = \frac{T_e\ T_t\ K_\theta\ a_f\ E_s\ t}{4N^2} \tag{31}$$

and

$$\text{A.S.A. film reading} = \frac{1}{I} \tag{32}$$

For $T_e = 0.70$, $T_f = 0.70$, $K_\theta = 1$, $a_f = 0.065$, $E_s = 140{,}000$ lumens/m^2
N = 16, and t = 0.04

$$\text{A.S.A.} = \frac{1}{0.174} = 5.75$$

For films of equal or higher A.S.A. value, many have γ's equal or greater than 3.0 and σ's less than or equal to 0.1. Therefore

$$C_p + 1 = \log^{-1} \frac{0.1}{3.0} = 1.08 \qquad \text{(by combining Eqs. 13 and 29)}$$

This value has been used in all photographic calculations and appears quite conservative due to the conservative film assumptions.

Assume that 1/2 sec seeing, $\beta = 1/2$ sec, is practical for a given site, i.e., at least 10 percent of the time at Pic-du-Mich in France and that the telescope has a resolution better than 1/2 sec of arc. Then from Fig. 1 drawn with this example the area factor $ar_b/(C_p + 1)$ is 1.13 square meters for a 0-degree phase angle sighting at 0 degree longitude. Therefore, for a reflectance of 0.80 and $(C_p + 1) = 1.08$ above, a = 1.53 square meters (16.5 square feet).

Other photographic detection beacon areas were calculated in a similar fashion.

4.2 Visual Contrast

Visual contrast required for detection has been the subject of numerous investigations, many of which are summarized by Taylor (1964). In general, most calculations refer to the work of Blackwell (1946) who reported the Tiffany Data. These data represented special viewing conditions characterized by the following factors:

1. Uniform circular targets
2. Uniform background
3. Binocular vision
4. Known time of stimulus
5. Known direction of stimulus
6. Trained observers

The Tiffany data are reported for a 50-percent probability of detection, C_{50}. Taylor has summarized various correction factors for modifying the original Blackwell data for application to practical conditions. These are summarized in Table 1. For beacon calculations, the contrast, C_v, used is related to the correction values in the table, K_p, K_b, K_v, K_t, and the original data, Tiffany Data C_{50}, by

$$C_v = K_p K_b K_v K_t C_{50} \tag{33}$$

TABLE 1

CORRECTION FACTORS FOR BLACKWELL DATA

					Factor
1. 1. Detection Probability, K_p					
	50%				1.0
	90%				1.50
	95%				1.64
	99%				1.91
2. Target Properties, K_b					
	Known Factors				
	Location	Time	Size	Duration	
	X	X	X	X	1.00
	X		X	X	1.40
	X		X		1.60
	X			X	1.50
	X				1.45
		X	X	X	1.31
3. Vigilance, K_v					1.19
4. Training, K_t					
	Trained				1.00
	Untrained				1.90

Values of $K_p = 1.91$, $K_b = 1.40$, $K_v = 1.19$, and $K_t = 1.00$ were chosen representing a 99-percent detection probability, unknown flash time (i.e., not an omnidirectional beacon), a vigilant and trained observer or $C_v = 3.18\ C_{50}$. This is the range of presently accepted conversion factors for the Tiffany data. Even if this factor is in error by a factor of 2, beacon areas will only increase by 20 percent for the worst practical telescopic visual case.

The visual contrast is a function of apparent field brightness, B_{af}, and apparent beacon angular subtend, $M\beta$. B_{af} can be determined from a plot of $B_{af}\, d_e^2$ versus B_{af} (Fig. 3) where by rearranging Eq. 16

$$B_{af}\, d_e^2 = T_e\, T_t\, d^2\, B_f \tag{34}$$

which by substitution of Eq. 25 is

$$B_{af}\, d_e^2 = T_e\, T_t \left[\frac{D_o}{M}\right]^2 \frac{K_\theta\, a_f\, E_s}{\pi} \tag{35}$$

For the 28X, 1.58-inch CM sextant sighting on 0-degree phase angle at $T_e = 1.0$, $T_t = 0.27$, $D_o/M = 1.443$ mm = d, $K_\theta = 1$, $a_f = 0.065$, $E_s = 14.0$ candles/cm^2. Therefore, $B_{af}\, d_e^2 = 1.61 \times 10^{-3}$ candles (and log $B_{af}\, d_e^2 = -3.206$).

Reading from Fig. 3, which is drawn showing this example, the apparent field brightness is 1.58×10^{-2} candles/cm^2.

Original smoothed Tiffany data, taken from Blackwell (1946) and converted to brightnesses in candles/cm^2, are shown in Fig. 4. Assuming a sextant resolution of 5 seconds, which is conservative compared with the 3.5 seconds value determined from $(1.22\ \lambda/D_o)$, the apparent beacon angular subtend will be 2.33 minutes of arc. A cross plot of C_v versus θ, not shown here, for constant, $B_{af} = 1.58 \times 10^{-2}$, using Fig. 4 for cross plot data, shows that $C_{50} = 4.95 \times 10^{-2}$ at $\theta = 2.33$ minutes. From above, $C_v = 3.18\ C_{50}$. $\therefore C_v + 1 = 1.157$. Knowing $B_{af}\, d_e^2$ and B_{af}

$$d_e = \sqrt{\frac{B_{af}\, d_e^2}{B_{af}}} \tag{36}$$

$$= 3.2 \text{ mm for the above case}$$

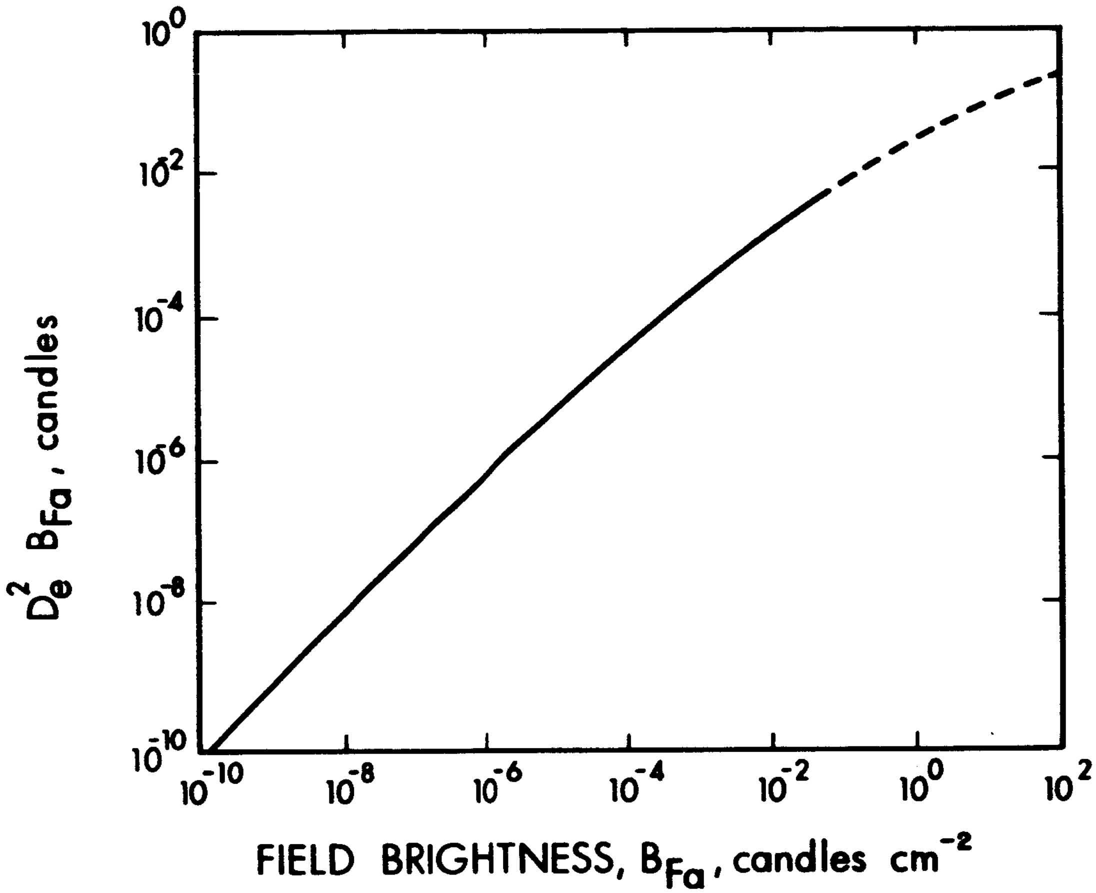

FIG. 3 RESPONSE OF THE PUPIL OF THE EYE TO FIELD BRIGHTNESS LEVEL

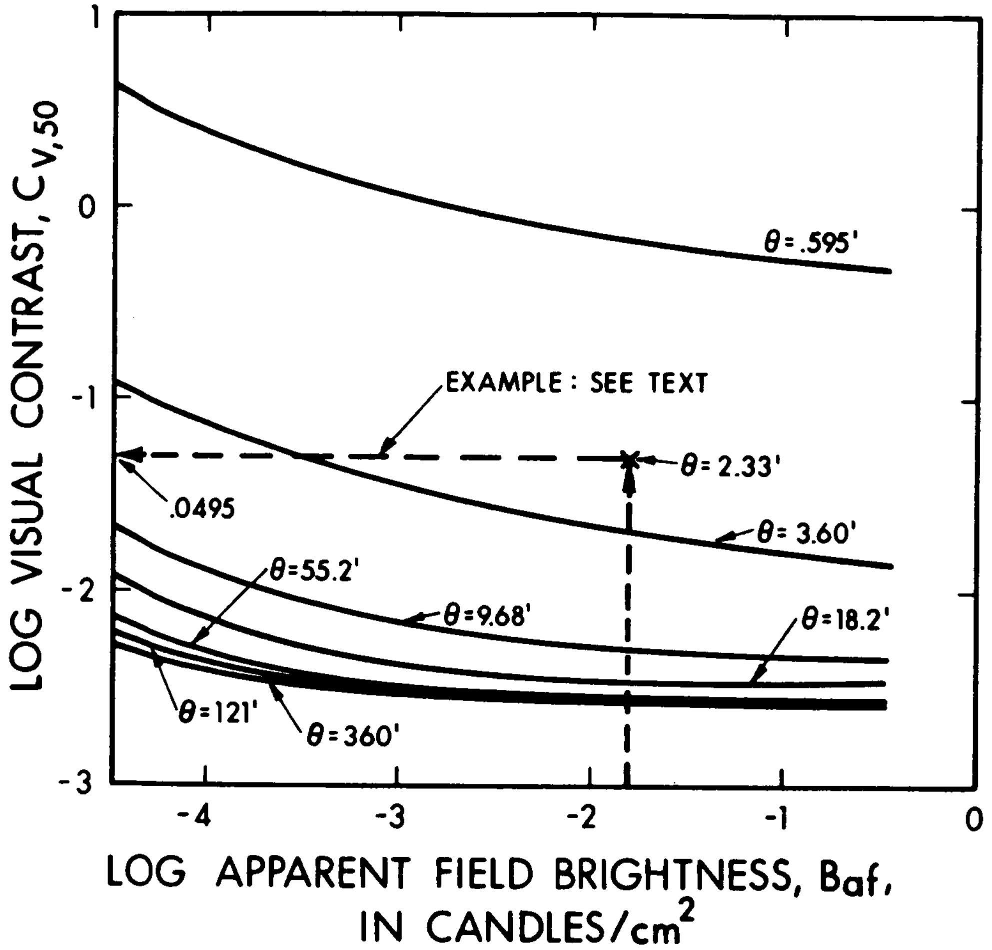

FIG. 4 VISUAL CONTRAST VS FIELD BRIGHTNESS FOR VARIOUS ANGULAR SUBTENDS, θ

Assume $r_b = 0.80$; d was 1.443 mm from above. From Fig. 2 for a $\beta = 5$ seconds of arc resolution

$$\frac{a r_b}{0.84\,(C_v + 1)\left(\frac{d}{d_e}\right)^2} = 4.21 \times 10^{-4}\ m^2$$

Substitution of the values listed above yields a required beacon area of 1.03 cm^2 or 0.16 square inch. Other beacon areas for visual detection were calculated in a similar fashion. This corresponds to a spherical beacon diameter, d_s, of 4.95 meters (or 16.3 feet) disregarding the negative contrast effects of the apparently nonreflective portions of the moon. The spherical diameter is related to the area by the relationship

$$d_s = \frac{8}{\alpha}\sqrt{\frac{a}{\pi}} \qquad (37)$$

where α is the solar angular subtend.

5. BEACON REFLECTANCE

Possible degradation in the beacon reflectance is the major unknown in sizing the lunar beacon. Empirical and experimental analysis of the problem by Button (1964), Marks (1964), and others have predicted or extrapolated losses in spectral reflectance from between 1 and 50 percent due to uv, high energy proton, and micrometeorite impingement. No space experimental data are available to corroborate these analyses, though an experiment is now being planned to study the degradation of reflective samples in space.

Unprotected aluminum has a practical visible reflectance of 91 percent. Therefore, the assumed reflectance value of 0.80 percent would allow an 11-percent reflectance loss due to lunar dust, coating transmittance, micrometeorite damage, etc., and appears valid based on some reflectance predictions.

Silicon-monoxide-overcoated aluminum has a visible reflectance of 87 percent, when deposited under standard development conditions. Though this reflectance system is 4 percent lower than aluminum and although silicon monoxide coatings are more susceptible to failure when folded over sharp corners as in an inflatable beacon, aluminum coatings overcoated with a 1000Å-micron-thick silicon monoxide coating show 1.2 times less degradation over comparable intensities of simulated micrometeorite flux. Silicon monoxide overcoatings have the added advantage that they are much more easily cleaned than aluminum alone. Quartz-overcoated aluminum will yield reflectance values of 88 percent over the visible spectrum and have high abrasion resistance also. However, quartz overcoatings are supplied by only a limited number of installations at this time.

Note that the reflectances cited are lower than textbook or experimental reflectance values. These lower values represent practical minimum limits for a metal mirror for this beacon program. Beacons with plastic substrates will have lower reflectance values.

6. SEEING CONDITIONS

For terrestrial telescopes, used either as photographic or visual instruments, the limiting angular resolution will determine to a large extent the detectability of a given beacon size. Since for most observatories the theoretical resolution of the telescope is achieved 10 percent or less of the night time, seeing is used in this analysis almost interchangeably with the integrated angular resolution of the detector instrument.

Seeing is a function of the changes in the index of refraction of the atmosphere through which the object rays pass to reach the telescope. Seeing is therefore an angular condition rather than a uniform loss of intensity which is a transmittance loss, or a nonuniform loss of intensity over the aperture called scintillation.

Irregularities in the index of refraction are due primarily to thermal nonhomogeneities, water vapor variations and ozone variations. Seeing is adversely affected by the following factors summarized from Stock and Keller, and Meinel (1960).

1. Moist climate
2. Cold fronts
3. Jet streams (high-velocity high-altitude air streams)
4. Observatory dome radiation
5. Observatory heat sources-instruments astronomers
6. Observations located close to the ground
7. Aircraft condensation trails
8. Air pollution
9. Temperature inversion
10. Skyglow
11. Haze

Seeing will be generally improved by using short time exposures in photographic work. Excellent high-altitude sights such as Pic-du-Mich in France and Kitt Peak have 1/2-second seeing between 10 and 20 percent of the time from Kopal (1963) and Meinel (1960) while 1 to 1-1/2 seconds seeing is "normal" for such observatories as Mount Wilson and Mount Palomar.

Earth-photographed beacon areas have been based initially on 1/2 second seeing conditions; visual observations on 1-second seeing.

7. MISCELLANEOUS FACTORS

The diameter magnification factor $\frac{M}{D_o}$ varies practically between 0.4 and 2.0. For "normal" magnification, i.e., $d = d_e$, the factor is between 0.3 and 0.5, depending on B_{af}. Generally the larger the telescope the lower the magnification factor. Bowen (1947) has reported a magnification factor of 0.56 for the Mount Wilson 60-inch telescope under 1 to 2 seconds seeing conditions and 1.31 for a 6-inch telescope.

The effect of diameter magnification factor and magnification upon beacon area is shown in Fig. 5 for 10 inches, 24 inches

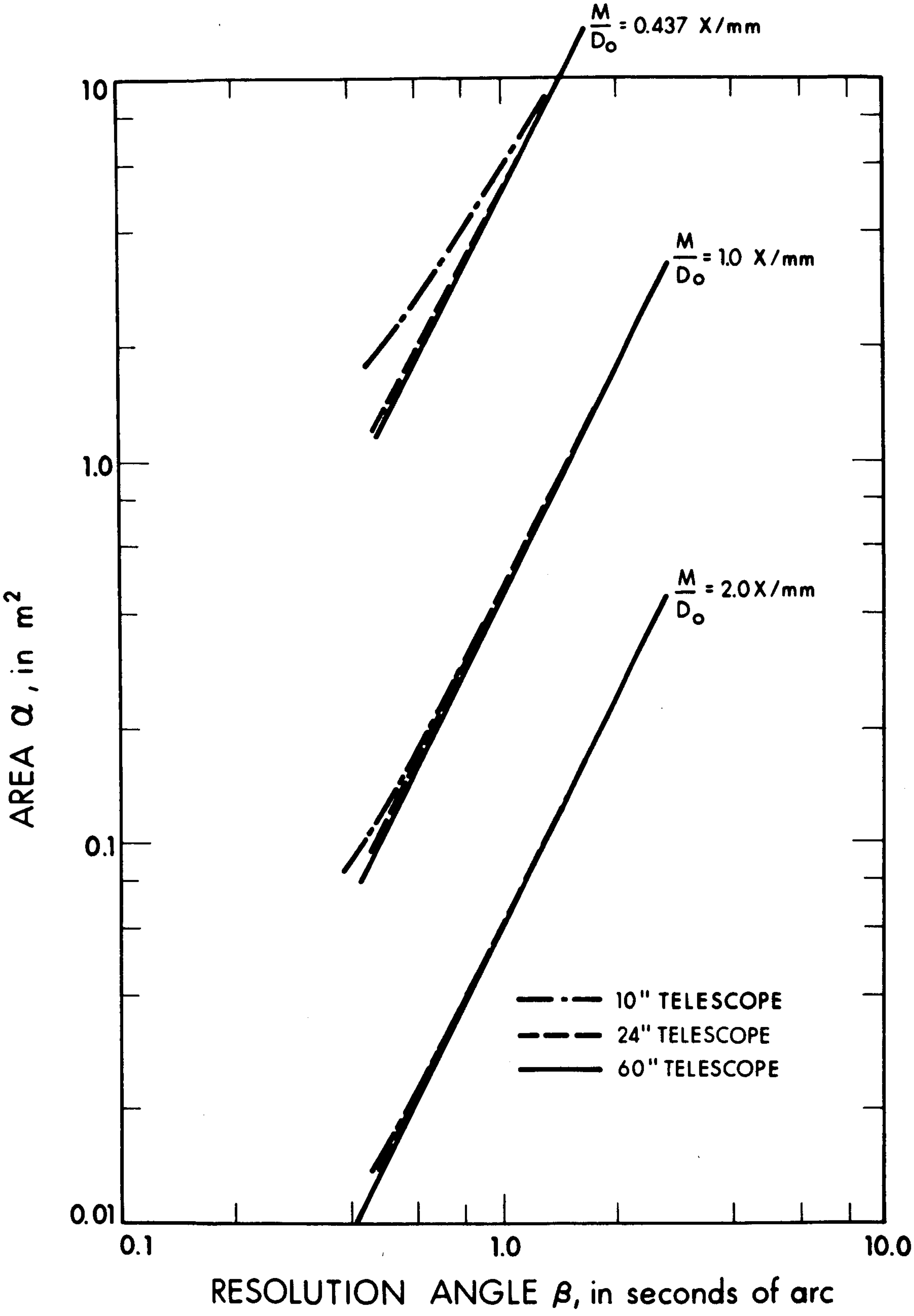

FIG. 5 BEACON AREA VS RESOLUTION ANGLE FOR VARIOUS DIAMETRICAL MAGNIFICATION FACTORS AND TELESCOPE APERTURES

(size of Pic-du-Mich in France) and 60 inches (Mount Wilson) telescopes. The area difference between telescopes are greater with smaller magnification factors so that with large factors there is little value in increasing the telescope aperture above 24 inches. Scintillation effects also practically limit lunar observation to telescopes in the range of 10 to 40 inches since little if anything is gained in going to larger diameters, since seeing and scintillation limit the usefulness of large apertures except for energy-gathering purposes.

The phase angle factor, K_θ, relates to the variation in albedo as a function of both phase angle and longitudinal location. The factors used to calculate Figs. 1 and 2 were taken from Minnaert (1961) for zero degree longitude. The phase angle factors do not vary with latitude, i.e., are constant along north-south meridians. The factors will vary with other longitude angles.

The atmospheric transmission factor, T_e used in calculating the beacon sizes was 0.7. Depending upon the observatory altitude, the telescope elevation angle, and the water vapor in the atmosphere, the actual atmospheric transmission can be greater or less than the 0.7 factor. Figure 6 depicts the air masses for various observatory altitudes for a telescope with a 90 degree elevation angle. Figure 7 depicts the air mass versus elevation angle for various elevation angles. By multiplying the air mass factors in Fig. 6, the total air mass through which the earth-lunar solar reflecting beacon signal must pass can be determined. From this calculated air mass plus the curves shown in Fig. 8 for various amounts of percipitable water vapor in the atmosphere, the fractional atmospheric transmission to either solar radiation or the beacon reflected signal can be determined.

Figure 7 indicates that those observatories that are close to the artic or antarctic circles will have relatively larger transmission losses when viewing the moon than those observatories located closer to the equator.

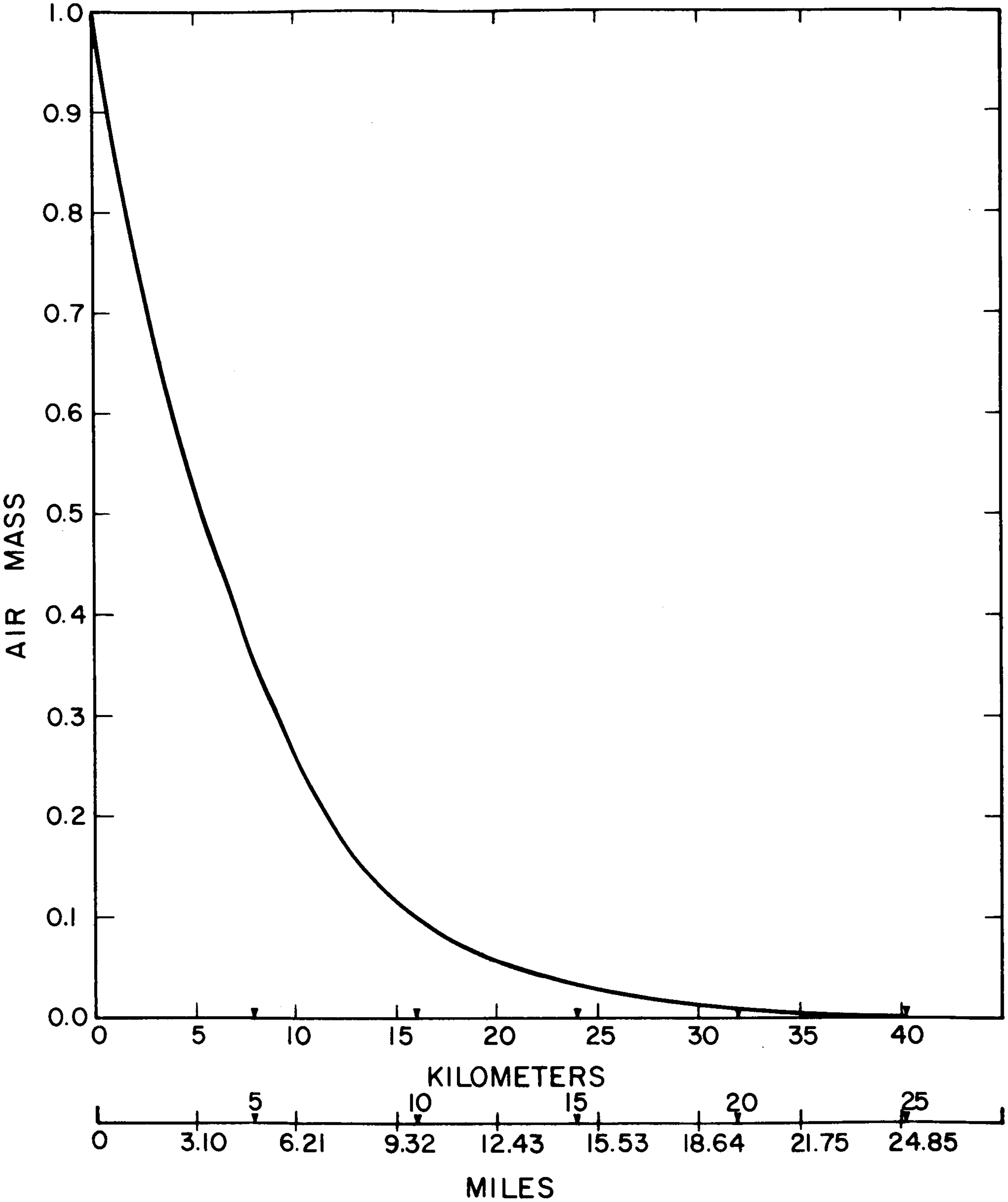

FIG. 6 AIR MASS VERSUS ALTITUDE FOR 90° ELEVATION

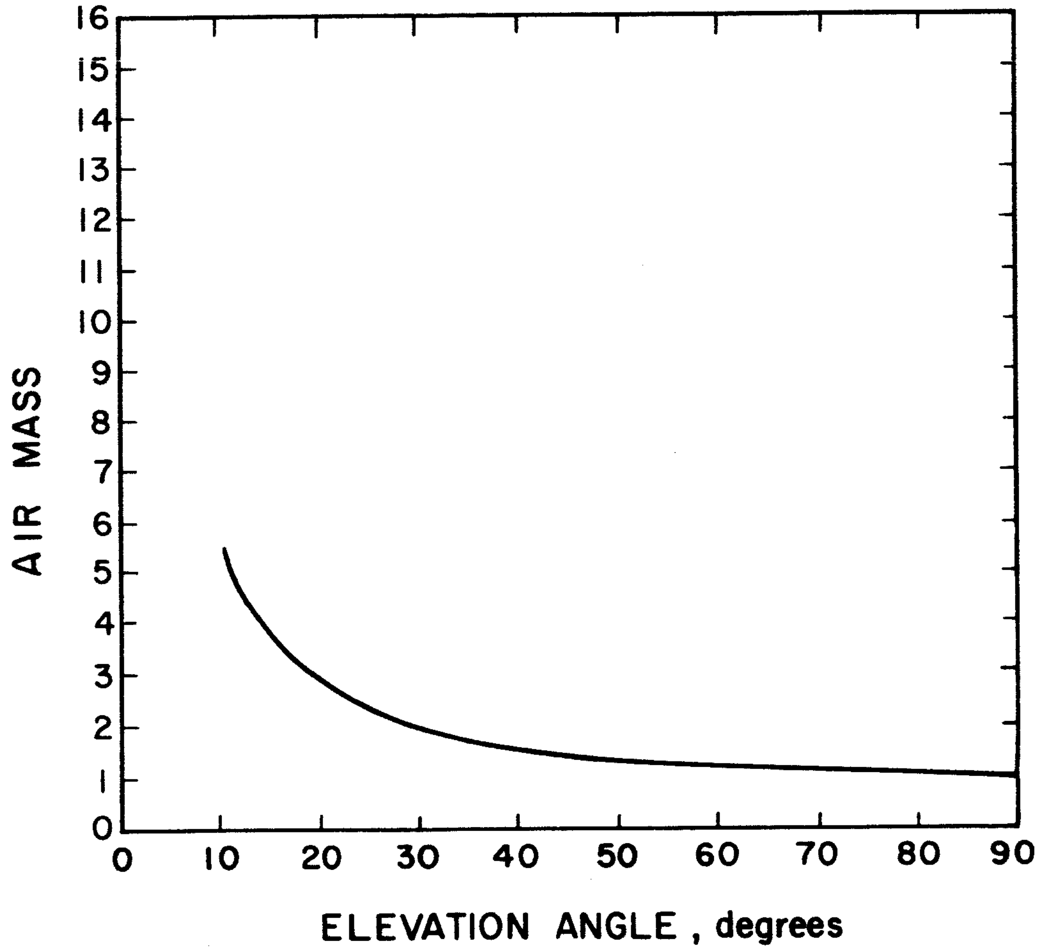

FIG. 7 AIR MASS VERSUS ELEVATION ANGLE

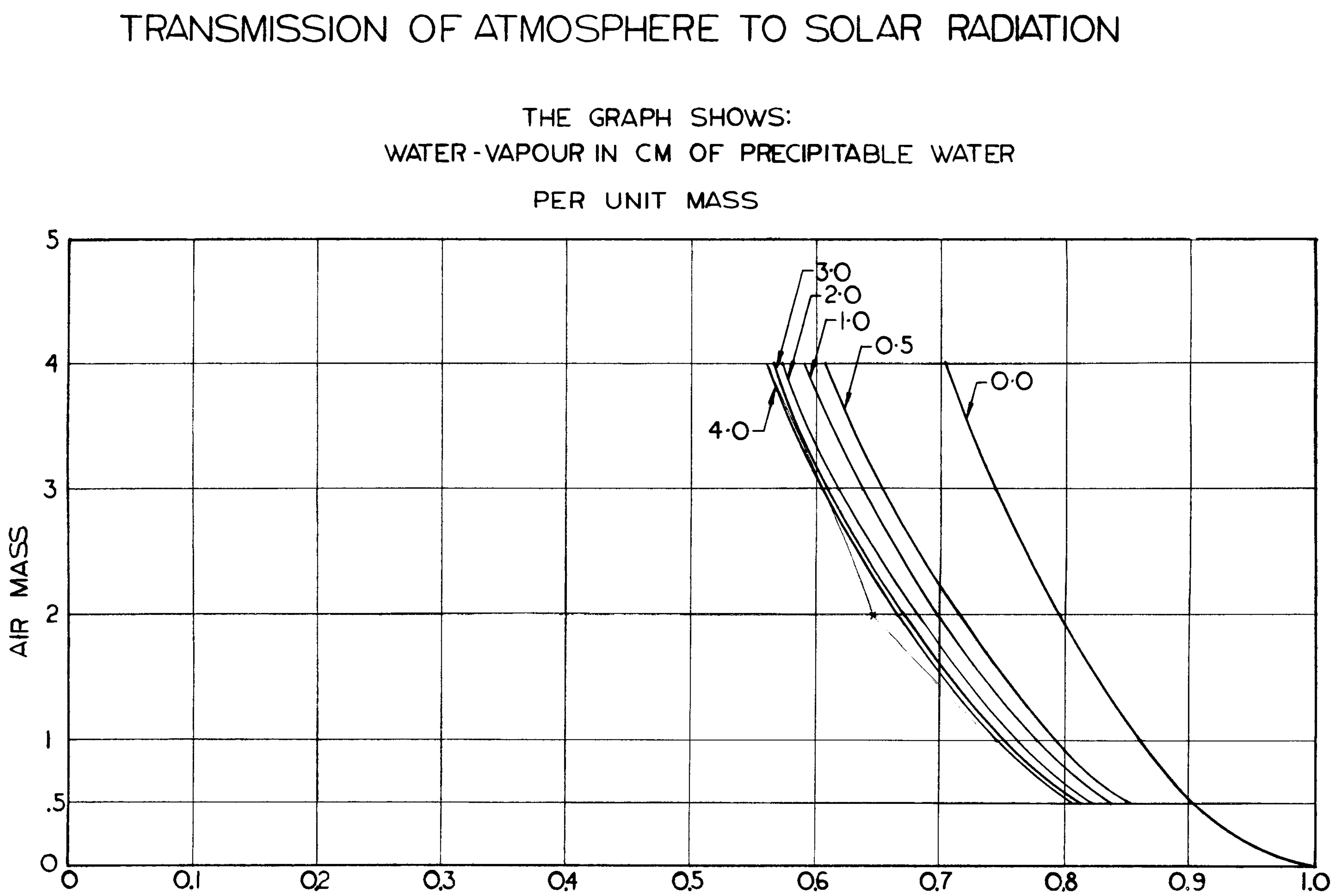

FIG. 8 FRACTIONAL ATMOSPHERIC TRANSMISSION TO SOLAR RADIATION

8. ACKNOWLEDGMENT

The work of many previous authors has been helpful in understanding and presenting the beacon detection problem. These are listed in a bibliography at the end of this report.

APPENDIX B

DIFFUSE BEACON PHOTOMETRIC ANALYSIS

APPENDIX B

DIFFUSE BEACON PHOTOMETRIC ANALYSIS

The nomenclature and formulae of Appendix A will be helpful in understanding this section.

1. Flat Beacon

For a diffuse flat reflector, the illuminance at the instrument objective, E_{ob}, is related to the diffuse beacon area, a_d, range, R, solar illuminance, E_s, beacon albedo, a_b, the angle of solar incidence, ψ, the angle of reflection or observation, ϕ, and the atmospheric transmission, T_e, by the relationship

$$E_{ob} = \frac{T_e E_s a_b \ a \cos\psi \ \cos\phi}{\pi R^2} \tag{1-B}$$

From 1-B and 6, 7, 8, and 15 of Appendix A

$$\frac{a_d a_b}{(C_p + 1)\pi} = \frac{k_\theta a_f R^2 \beta^2}{3.36 \cos\psi \ \cos\phi} \tag{2-B}$$

So that the ratio of the ratio of the diffuse and specular flat beacon areas from 2-B and 15 of Appendix A is

$$a_d/a_s = \frac{\pi r_b}{\Omega_s \ a_b} \ \frac{\cos\frac{\theta}{2}}{\cos\psi \ \cos\phi} \tag{3-B}$$

Since the solar solid angle in steradians is 6.76×10^{-5}, then the ratio of the beacon areas for diffuse and specular flats which can be detected photographically is

$$\frac{a_d}{a_s} = 4.65 \times 10^4 \frac{\cos \frac{\theta}{2}}{\cos\psi \cos\phi} \frac{r_b}{a_b}$$

Similarly it can be shown that the same ratio holds for visual observations.

At 0° phase, incident, and observation angles, the related areas for flat specular and diffuse beacons having the same diffuse and specular reflectance would be:

Case	Recommended Specular Area	Corresponding Diffuse Area
Earth Beacon 207,000 nm	$32.9\ ft^2$	$1.53 \times 10^6\ ft^2$
Cislunar Beacon 400 nm*	1.09×10^{-2}	$5.05 \times 10^2\ ft^2$

2. Spherical Beacons

From equation 37 of Appendix A, the spherical diameter of a specular sphere is

$$d_s = \frac{8}{\alpha} \sqrt{\frac{a_s}{\pi}} = 4.86 \times 10^2 \sqrt{a_s}$$

Therefore relative illuminance of a diffuse spherical beacon, E_{bd}, to a specular spherical beacon, E_{bs}, is a function of the phase angle, θ,

* As in Appendix A, the cislunar specifications used herein reflect the Phase I requirements.

specular and diffuse reflectances, r_b and a_b, and the spherical diameters for the specular and diffuse spheres, d_{ss} and d_{sd}, as given by

$$\frac{E_{bd}}{E_{bs}} = \frac{8}{3\pi} \left(\sin\theta + [\pi-\theta] \cos\theta \right) \frac{a_b}{r_b} \frac{d_{sd}^2}{d_{ss}^2} \qquad (4\text{-B})$$

Therefore a diffuse sphere of the same diameter as a specular sphere would have an intensity of

$$\frac{2.67\, a_b}{r_b}$$

times that of the speculat sphere at 0^o phase angle. The intensities of specular and diffuse spheres of equal diameter are equivalent when the phase angle, θ, is $\pm 0.46\pi$ radians or ± 83 degrees.

Therefore the relative diameters of diffuse and specular spheres having the same reflectances would be as follows:

Case	Recommended Specular Sphere Diameter	Recommended Diffuse Sphere Diameter for $\theta = \pm 83^o$	Recommended Diffuse Sphere Diameter for 0^o phase angle
Earth Beacon 207,000 nm	2790 ft	2790 ft	1740 ft
Cislunar Beacon 400 nm	50.5 ft	50.5 ft	31 ft

APPENDIX C

REFLECTOR ORIENTATION COMPUTER PROGRAMS

APPENDIX C

REFLECTOR ORIENTATION COMPUTER PROGRAMS

1. $\underline{i, \Lambda, \Omega'}$

$$\cos i = \cos(I + \rho) \cos(\bar{\epsilon} + \Delta\epsilon) + \sin(I + \rho) \sin(\bar{\epsilon} + \Delta\epsilon) \cos(\Omega + \sigma + \Delta\psi)$$

$$\underline{21^\circ < i < 25^\circ}$$

$$\Lambda = \Delta + \mathbb{C} + \tau - \Omega - \sigma$$

$$\underline{0 < \Lambda < 360^\circ}$$

$$\sin\Omega' = - \sin(\Omega + \sigma + \Delta\Psi) \csc i \sin(I + \rho)$$

$$\underline{-4^\circ < \Omega' < 4^\circ 10'}$$

where

$$\bar{\epsilon} = 23^\circ.4457874 - 0^\circ.01301376\ T = \text{mean obliquity of date}$$

$$\Delta\epsilon = 0^\circ.255833(10^{-2}) \cos\Omega - 0^\circ.25(10^{-4}) \cos 2\,\Omega + 0^\circ.1530555(10^{-3}) \cos 2\,L$$

$$= \text{nutation in obliquity}$$

$$\Delta\Psi = - [0^\circ.47895611(10^{-2}) + 0^\circ.47222(10^{-5})\ T] \sin\Omega$$

$$+ 0^\circ.58055(10^{-4}) \sin 2\,\Omega - 0^\circ.3533(10^{-3}) \sin 2\,L$$

$$I = 1^{\circ}\ 32.1'$$

$$\Omega = 12^{\circ}.1127902 - 0^{\circ}.0529539222\ d + 0^{\circ}.20795(10^{-2})T + 0^{\circ}.2081(10^{-2})T^2$$

$$☾ = 64^{\circ}.37545167 + 13^{\circ}.1763965268\ d - 0^{\circ}.1131575(10^{-2})T - 0^{\circ}.113015(10^{-2})T^2$$

$$\sin\Delta = -\sin(\Omega + \sigma + \Delta\Psi)\ \csc i\ \sin(\bar{\epsilon} + \Delta\epsilon),$$

$$\cos\Delta = -\cos(\Omega + \sigma + \Delta\Psi)\ \cos\Omega' - \sin(\Omega + \sigma + \Delta\Psi)\ \sin\Omega'\ \cos(\bar{\epsilon} + \Delta\epsilon)$$

$$L = 280^{\circ}.08121009 + 0^{\circ}.9856473354\ d + 0^{\circ}.302(10^{-3})\ T + 0^{\circ}.302(10^{-3})T^2$$

$$\sigma \sin I = -0^{\circ}.0302777 \sin g + 0^{\circ}.0102777 \sin (g + 2\omega) - 0^{\circ}.305555(10^{-2}) \sin (2g + 2\omega)$$

$$\tau = -0^{\circ}.3333(10^{-2}) \sin g + 0^{\circ}.0163888 \sin g' + 0^{\circ}.5(10^{-2}) \sin 2\omega$$

$$\rho = -0^{\circ}.0297222 \cos g + 0^{\circ}.0102777 \cos (g + 2\omega) - 0^{\circ}.305555(10^{-2}) \cos (2g + 2\omega)$$

$$g = 215^{\circ}.54013 + 13^{\circ}.064992\ d$$

$$g' = 358^{\circ}.009067 + 0^{\circ}.9856005\ d$$

$$\omega = 196^{\circ}.745632 + 0^{\circ}.1643586\ d$$

Here, d is measured in Julian days from January 1.0, 1950, and T is measured in Julian centuries (of 36,525 days) from January 1.0, 1950.

2. PROGRAM I

$$\sin\mu_e = \sin i \cos\delta_m \sin(\alpha_m - \Omega') - \cos i \sin\delta_m$$

$$\tan\lambda_e = \frac{B - \tan\Lambda \cos(\alpha_m - \Omega')}{B \tan\Lambda + \cos(\alpha_m - \Omega')}$$

$$B = \cos i \sin(\alpha_m - \Omega') + \sin i \tan\delta_m$$

$$\sin\mu_s = \frac{R_{se}}{R_{sm}} [\sin\delta_s \cos i - \cos\delta_s \sin i \sin(\alpha_s - \Omega')] + \frac{R}{R_{sm}} \sin\mu_e$$

$$\tan\lambda_s = \frac{\cos\delta_s \cos\Lambda [- \tan\Lambda \cos(\alpha_s - \Omega') + F] + \frac{R}{R_{se}} \sin\lambda_e \cos\mu_e}{\cos\delta_s \cos\Lambda [\cos(\alpha_s - \Omega') + F \tan\Lambda] + \frac{R}{R_{se}} \cos\lambda_e \cos\mu_e}$$

$$F = \cos i \sin(\alpha_s - \Omega') + \sin i \tan\delta_s$$

$$\cos\lambda_s = \frac{\cos\delta_s \cos\Lambda [\cos(\alpha_s - \Omega') + F \tan\Lambda] + \frac{R}{R_{se}} \cos\lambda_e \cos\mu_e}{\frac{R_{sm}}{R_{se}} \cos\mu_s}$$

$$|\mu_e| < 8^\circ, \ |\lambda_e| < 8^\circ, \ |\mu_s| < 2^\circ$$

Here,

$$\alpha_m = \sin^{-1} \frac{y_m}{(x_m^2 + y_m^2)^{1/2}} = \cos^{-1} \frac{x_m}{(x_m^2 + y_m^2)^{1/2}}; \qquad \delta_m = \sin^{-1} \frac{z_m}{R}$$

$$\alpha_s = \sin^{-1} \frac{y_s}{(x_s^2 + y_s^2)^{1/2}} = \cos^{-1} \frac{x_s}{(x_s^2 + y_s^2)^{1/2}}; \qquad \delta_s = \sin^{-1} \frac{z_s}{R_{se}}$$

$$x_m = R_e \left[X_{em} \cos\tau - Y_{em} \sin\tau \cos\bar{\epsilon} - Z_{em} \sin\tau \sin\bar{\epsilon}\right]$$

$$y_m = R_e \left[X_{em} \sin\tau \cos\bar{\epsilon} + Y_{em} (\cos^2\bar{\epsilon} \cos\tau + \sin^2\bar{\epsilon})\right.$$

$$\left. + Z_{em} \sin\bar{\epsilon} \cos\bar{\epsilon} (\cos\tau - 1)\right]$$

$$z_m = R_e \left[X_{em} \sin\tau \sin\bar{\epsilon} + Y_{em} \sin\bar{\epsilon} \cos\bar{\epsilon} (\cos\tau - 1)\right.$$

$$\left. + Z_{em} (\cos\tau \sin^2\bar{\epsilon} + \cos^2\bar{\epsilon})\right]$$

$$x_s = Au \left[- X_{se} \cos\tau + Y_{se} \sin\tau \cos\bar{\epsilon} + Z_{se} \sin\tau \sin\bar{\epsilon}\right]$$

$$y_s = Au \left[- X_{se} \sin\tau \cos\bar{\epsilon} - Y_{se} (\cos^2\bar{\epsilon} \cos\tau + \sin^2\bar{\epsilon})\right.$$

$$\left. - Z_{se} \sin\bar{\epsilon} \cos\bar{\epsilon} (\cos\tau - 1)\right]$$

$$z_s = Au \left[- X_{se} \sin\tau \sin\bar{\epsilon} - Y_{se} \sin\bar{\epsilon} \cos\bar{\epsilon} (\cos\tau - 1)\right.$$

$$\left. - Z_{se} (\cos\tau \sin^2\bar{\epsilon} + \cos^2\bar{\epsilon})\right]$$

$$R = R_e (X_{em}^2 + Y_{em}^2 + Z_{em}^2)^{1/2} = \text{earth-moon distance}$$

$$R_{se} = Au (X_{se}^2 + Y_{se}^2 + Z_{se}^2)^{1/2} = \text{sun-earth distance}$$

$$R_{sm} = \left[(R_e X_{em} + Au X_{se})^2 + (R_e Y_{em} + Au Y_{se})^2 + (R_e Z_{em} + Au Z_{se})^2\right]^{1/2}$$

$$= \text{sun-moon distance}$$

R_e = radius of earth = 6378.3255 km; Au = astronomical unit = 149,599,000 km

$\tau = 1^\circ\!.3846\ T$ (This τ is not to be confused with the τ appearing in part 1 above.)

(X_{em}, Y_{em}, Z_{em}) = coordinates of moon in geocentric equatorial reference frame of the mean equator and equinox of 1950.0

(x_m, y_m, z_m) = - - - mean equator and equinox of date.

(X_{se}, Y_{se}, Z_{se}) = coordinates of earth (actually earth-moon center of mass) in heliocentric equatorial (earth's equator) reference frame of the mean equator and equinox of 1950.0

(x_s, y_s, z_s) = - - - mean equator and equinox of date.

3. PROGRAM II

$$\cos\gamma = \cos\varphi\ (n_x \cos\theta + n_y \sin\theta + n_z \tan\varphi); \qquad \underline{0 \le \gamma \le 90^\circ}$$

$$\sin\sigma = \frac{1}{\sin\gamma}\ (n_x \sin\theta - n_y \cos\theta)$$

$$\cos\sigma = \frac{1}{\sin\gamma}\ [-\sin\varphi\ (n_x \cos\theta + n_y \sin\theta) + n_z \cos\varphi]; \quad \underline{0 \le \sigma \le 360^\circ}$$

$$n_x = \frac{\rho_x + \cos\lambda_s \cos\mu_s}{N}, \quad n_y = \frac{\rho_y + \sin\lambda_s \cos\mu_s}{N}, \quad n_z = \frac{\rho_z + \sin\mu_s}{N}$$

$$N = [2\ (1 + \rho_x \cos\lambda_s \cos\mu_s + \rho_y \sin\lambda_s \cos\mu_s + \rho_z \sin\mu_s)]^{1/2}$$

$$\rho_x = \frac{1}{L}\ (A + q_x), \quad \rho_y = \frac{1}{L}\ (B + q_y), \quad \rho_z = \frac{1}{L}\ (C + q_3)$$

$$q_x = R \cos\lambda_e \cos\mu_e - R_m \cos\theta \cos\varphi = p_x\ D$$

$$q_y = R \sin\lambda_e \cos\mu_e - R_m \sin\theta \cos\varphi = p_y\ D$$

$$q_z = R \sin\mu_e - R_m \sin\varphi = p_z\ D$$

$$L = (D^2 + R_e^2 + 2Aq_x + 2Bq_y + 2Cq_z)^{1/2}$$

$$D^2 = R^2 + R_m^2 - 2RR_m\ [\cos\varphi \cos\mu_e \cos(\theta - \lambda_e) + \sin\varphi \sin\mu_e]$$

$$A = R_{ex}\, x_{11} + R_{ey}\, x_{12} + R_{ez}\, x_{13}$$

$$B = R_{ex}\, x_{21} + R_{ey}\, x_{22} + R_{ez}\, x_{23}$$

$$C = R_{ex}\, x_{31} + R_{ey}\, x_{32} + R_{ez}\, x_{33}$$

$$x_{11} = \cos\Omega' \cos\Lambda - \sin\Omega' \sin\Lambda \cos i$$

$$x_{12} = \sin\Omega' \cos\Lambda + \cos\Omega' \sin\Lambda \cos i$$

$$x_{13} = \sin\Lambda \sin i$$

$$x_{21} = -\cos\Omega' \sin\Lambda - \sin\Omega' \cos\Lambda \cos i$$

$$x_{22} = -\sin\Omega' \sin\Lambda + \cos\Omega' \cos\Lambda \cos i$$

$$x_{23} = \cos\Lambda \sin i$$

$$x_{31} = \sin i \sin\Omega'$$

$$x_{32} = -\sin i \cos\Omega'$$

$$x_{33} = \cos i$$

$$R_{ex} = R_e \cos(\Theta + \alpha_s - 180^\circ + 15.0\, t_o) \cos\Phi$$

$$R_{ey} = R_e \sin(\Theta + \alpha_s - 180^\circ + 15.0\, t_o) \cos\Phi$$

$$R_{ez} = R_e \sin\Phi$$

Here, R = earth-moon distance, R_m = radius of moon = 1738 km

Also, φ, θ are the latitude and longitude, respectively, on the moon's surface of the reflector, and Φ, Θ are the latitude and longitude, respectively, of the "target point" on the earth's surface.

The condition which must be satisfied in order that the reflector on the moon's surface be visible from the point Φ, Θ on the earth's surface, at the time t_o, is

$$Aq_x + Bq_y + Cq_z < 0$$

The condition which must be satisfied in order that the sun be visible from the reflector on the moon's surface (φ, θ), at the time t_o, is

$$\cos(\theta - \lambda_s) + \tan \varphi \tan \mu_s > 0$$

4. PROGRAM III

$$\Phi = \sin^{-1}\left(\frac{Rez}{Re}\right) \qquad \underline{-90^\circ < \Phi < 90^\circ}$$

$$\Theta = \tan^{-1}\left(\frac{Rey}{Rex}\right) - \alpha_s + 180^\circ - 15.0\ t$$

$$\Theta = \sin^{-1}\frac{R_{ey}}{\left(R_{ex}^2 + R_{ey}^2\right)^{1/2}} - \alpha_s + 180^\circ - 15.0\ t \qquad \underline{-180^\circ < \Theta < 180^\circ}$$

Here,

$$R_{ex} = A\ X_{11} + B\ X_{21} + C\ X_{31} \qquad A = L\ \rho_x - D\ p_x$$

$$R_{ey} = A\ X_{12} + B\ X_{22} + C\ X_{32} \qquad B = L\ \rho_y - D\ p_y$$

$$R_{ez} = A\ X_{13} + B\ X_{23} + C\ X_{33} \qquad C = L\ \rho_z - D\ p_z$$

$$L = D\left[\cos\Gamma - \left(\frac{R_e^2}{D^2} - \sin^2\Gamma\right)^{1/2}\right] \qquad \cos\Gamma = p_x\ \rho_x + p_y\ \rho_y + p_z\ \rho_z$$

$$p_x = \frac{R}{D}\left(\cos\lambda_e \cos\mu_e - \frac{R_m}{R}\cos\theta\cos\phi\right)$$

$$p_y = \frac{R}{D}\left(\sin\lambda_e \cos\mu_e - \frac{R_m}{R}\sin\theta\cos\phi\right)$$

$$p_z = \frac{R}{D}\left(\sin\mu_e - \frac{R_m}{R}\sin\phi\right)$$

$$\rho_x = \frac{n_x\left[(1-2\ n_z^2)\ \vec{\zeta}\cdot\vec{n} + n_z \sin\mu_s\right] - n_y \cos\mu_s\ (n_y \cos\lambda_s - n_x \sin\lambda_s)}{1 - n_z^2}$$

$$\rho_y = \frac{n_y \left[(1-2\, n_z^2)\, \vec{\zeta} \cdot \vec{n} + n_z \sin\mu_s \right] + n_x \cos\mu_s \,(n_y \cos\lambda_s - n_x \sin\lambda_s)}{1 - n_z^2}$$

$$\rho_z = 2\, n_z\, \vec{\zeta} \cdot \vec{n} - \sin\mu_s$$

$$n_x = \cos\gamma \cos\theta \cos\phi + \sin\gamma \sin\sigma \sin\theta - \sin\gamma \cos\sigma \sin\phi \cos\theta$$

$$n_y = \cos\gamma \sin\theta \cos\phi - \sin\gamma \sin\sigma \cos\theta - \sin\gamma \cos\sigma \sin\phi \sin\theta$$

$$n_z = \cos\gamma \sin\phi + \sin\gamma \cos\sigma \cos\phi$$

$$\zeta_x = \cos\lambda_s \cos\mu_s, \quad \zeta_y = \sin\lambda_s \cos\mu_s, \quad \zeta_z = \sin\mu_s$$

The axis of the cone of the reflected light will strike the earth if $\cos\Gamma > S$, and will miss the earth if $\cos\Gamma < S$, where

$$S = \left(1 - \frac{R_e^2}{D^2}\right)^{1/2}$$

5. PROGRAM VII

$$K_1 = \sin\frac{\epsilon}{2} - \sin H_1 .$$

When, $K_1 < 0$, the reflected light is not visible from Θ_1, Φ_1;

When, $K_1 > 0$, the reflected light is visible from Θ_1, Φ_1;

When, $K_1 = 0$, the reflected light becomes visible, or just ceases to to be visible, from Θ_1, Φ_1 .

Here, Θ_1, Φ_1 are the longitude and latitude, respectively, of an observer on the earth. Also, $\epsilon/2$ = half angle of light cone ($\epsilon/2 \sim 16$ min. of arc), where

$$\frac{\epsilon}{2} = \frac{R_s}{R_{sm}}$$

Here, R_s = radius of sun = 6.965×10^5 km

$$\sin H_1 = \frac{\left(V_1{}^2 + V_2{}^2 + V_3{}^2\right)^{1/2}}{DuZ_1}$$

where

$$V_1 = p_z(B - B_1) + p_y(C_1 - C) + \frac{BC_1 - B_1C}{D}$$

$$V_2 = p_z(A_1 - A) + p_x(C - C_1) + \frac{A_1C - AC_1}{D}$$

$$V_3 = p_y(A - A_1) + p_x(B_1 - B) + \frac{AB_1 - A_1B}{D}$$

$$u = \left[\left(p_x + \frac{A}{D}\right)^2 + \left(p_y + \frac{B}{D}\right)^2 + \left(p_z + \frac{C}{D}\right)^2\right]^{1/2}$$

$$Z_1 = \left[\left(p_x + \frac{A_1}{D}\right)^2 + \left(p_y + \frac{B_1}{D}\right)^2 + \left(p_z + \frac{C_1}{D}\right)^2\right]^{1/2}$$

$$A_1 = R_{elx}\, x_{11} + R_{ely}\, x_{12} + R_{elz}\, x_{13}$$

$$B_1 = R_{elx}\, x_{21} + R_{ely}\, x_{22} + R_{elz}\, x_{23}$$

$$C_1 = R_{elx}\, x_{31} + R_{ely}\, x_{32} + R_{elz}\, x_{33}$$

where

$$R_{elx} = -R_e \cos\Phi_1 \cos(\Theta_1 + \alpha_s + 15.0\ t)$$

$$R_{ely} = -R_e \cos\Phi_1 \sin(\Theta_1 + \alpha_s + 15.0\ t)$$

$$R_{elz} = R_e \sin\Phi_1$$

6. PROGRAM IV

$$\cos\psi = n_x\, p_x + n_y\, p_y + n_z\, p_z$$

$$(0 < \psi < \pi)$$

$$\cos\beta = [(u_2\, p_z - u_3\, p_y)\,(n_y\, p_z - n_z\, p_y) + (u_3\, p_x - u_1\, p_z)\,(n_z\, p_x - n_x\, p_z)$$

$$+ (u_1\, p_y - u_2\, p_x)\,(n_x\, p_y - n_y\, p_x)]\left[(1 - e_n^2)^{1/2}\,(1 - e_s^2)^{1/2}\right]^{-1}$$

$$\sin\beta = p_x\,(\chi_y\, \eta_z - \chi_z\, \eta_y) + p_y\,(\chi_z\, \eta_x - \chi_x\, \eta_z) + p_z\,(\chi_x\, \eta_y - \chi_y\, \eta_x)$$

$$(0 < \beta < 2\,\pi)$$

Here,

$$u_1 = \cos\lambda_s\, \cos\mu_s,\quad u_2 = \sin\lambda_s\, \cos\mu_s,\quad u_3 = \sin\mu_s$$

$$e_n = \cos\psi$$

$$e_s = u_1\, p_x + u_2\, p_y + u_3\, p_z$$

$$\chi_x = \frac{n_x - e_n\, p_x}{(1 - e_n^2)^{1/2}},\quad \chi_y = \frac{n_y - e_n\, p_y}{(1 - e_n^2)^{1/2}},\quad \chi_z = \frac{n_z - e_n\, p_z}{(1 - e_n^2)^{1/2}}$$

$$\eta_x = \frac{u_1 - e_s\, p_x}{(1 - e_s^2)^{1/2}}, \quad \eta_y = \frac{u_2 - e_s\, p_y}{(1 - e_s^2)^{1/2}}, \quad \eta_z = \frac{u_3 - e_s\, p_z}{(1 - e_s^2)^{1/2}}$$

7. PROGRAM IV(A)

$$\cos\zeta = \frac{\cos\psi \cos\psi_{es} + \sin\psi \cos\beta \sin\psi_{es}}{Q}, \qquad \underline{0 < \zeta < 180^{o}}$$

$$\sin\xi = \frac{-\sin\beta \sin\psi_{es}}{\sin\zeta}$$

$$\cos\xi = \frac{Q}{2 \sin\zeta}, \qquad \underline{0 < \xi < 360^{o}}$$

Here,

$$Q = \left[2 \left(1 + \sin\psi_{es} \cos\beta \cos\psi - \cos\psi_{es} \sin\psi\right)\right]^{1/2}$$

$$\cos\psi_{es} = p_x \cos\lambda_s \cos\mu_s + p_y \sin\lambda_s \cos\mu_s + p_z \sin\mu_s, \qquad \underline{0 < \psi_{es} < 180^{o}}$$

8. PROGRAM V

$$\cos M = \rho_x \left(\frac{x' - R_m \cos\theta \cos\varphi}{W}\right) + \rho_y \left(\frac{y' - R_m \sin\theta \cos\varphi}{W}\right) + \rho_z \left(\frac{z' - R_m \sin\varphi}{W}\right)$$

Here, ρ_x, ρ_y, ρ_z, are those defined in Program III, and

$$W = [(x' - R_m \cos\theta \cos\varphi)^2 + (y' - R_m \sin\theta \cos\varphi)^2 + z' - R_m \sin\varphi)^2]^{1/2}$$

9. PROGRAM VI

The expressions for γ, σ are given in Program II. However, the expressions for ρ_x, ρ_y, ρ_z are given by

$$\rho_x = \frac{x' - R_m \cos\theta \cos\varphi}{W}, \quad \rho_y = \frac{y' - R_m \sin\theta \cos\varphi}{W}, \quad \rho_z = \frac{z' - R_m \sin\varphi}{W}$$

APPENDIX D

ELECTROFORMED REFLECTOR FABRICATION AND COATING

APPENDIX D

ELECTROFORMED REFLECTOR FABRICATION AND COATING

The cislunar metal spherical panels and the stretched membrane metal flat panels are designed to use the electroforming process. By electroforming is meant the process of depositing metal atoms from solution electrochemically, i.e., by the reduction of metal ions in solution, onto a conductive master or cathode to produce a metal shell. When the desired metal thickness is achieved, the plating is terminated and the electroformed shell is removed from the master. In optical replication, the master is optically polished or otherwise finished to produce the desired specularity and surface accuracy. Metal masters are preferred since they do not catastrophically fail due to replication stresses. The control of replication stresses is critical to the formation of high accuracy reflectors.

Figure D-1 shows the reflector panel plating schematics for both the cislunar spherical and earth flat reflectors. Note that the joining of an angle rim to a thin membrane and the formation of a sharp angle rim requires the use of a conductive fillet to bridge the transition. Control of the electroforming conditions, as well as excellent tooling, is essential for high quality replicas.

Electroformed reflectors are normally made using electroformed nickel deposited in a near zero residual stress condition. Nickel is favored because of its relatively high strength and modulus plus the ease with which nickel can be deposited compared with other metals with higher specific rigidity or strength.

The surfaces produced by electroforming will duplicate the master finish and will approach the surface finish of glass. Being very thin

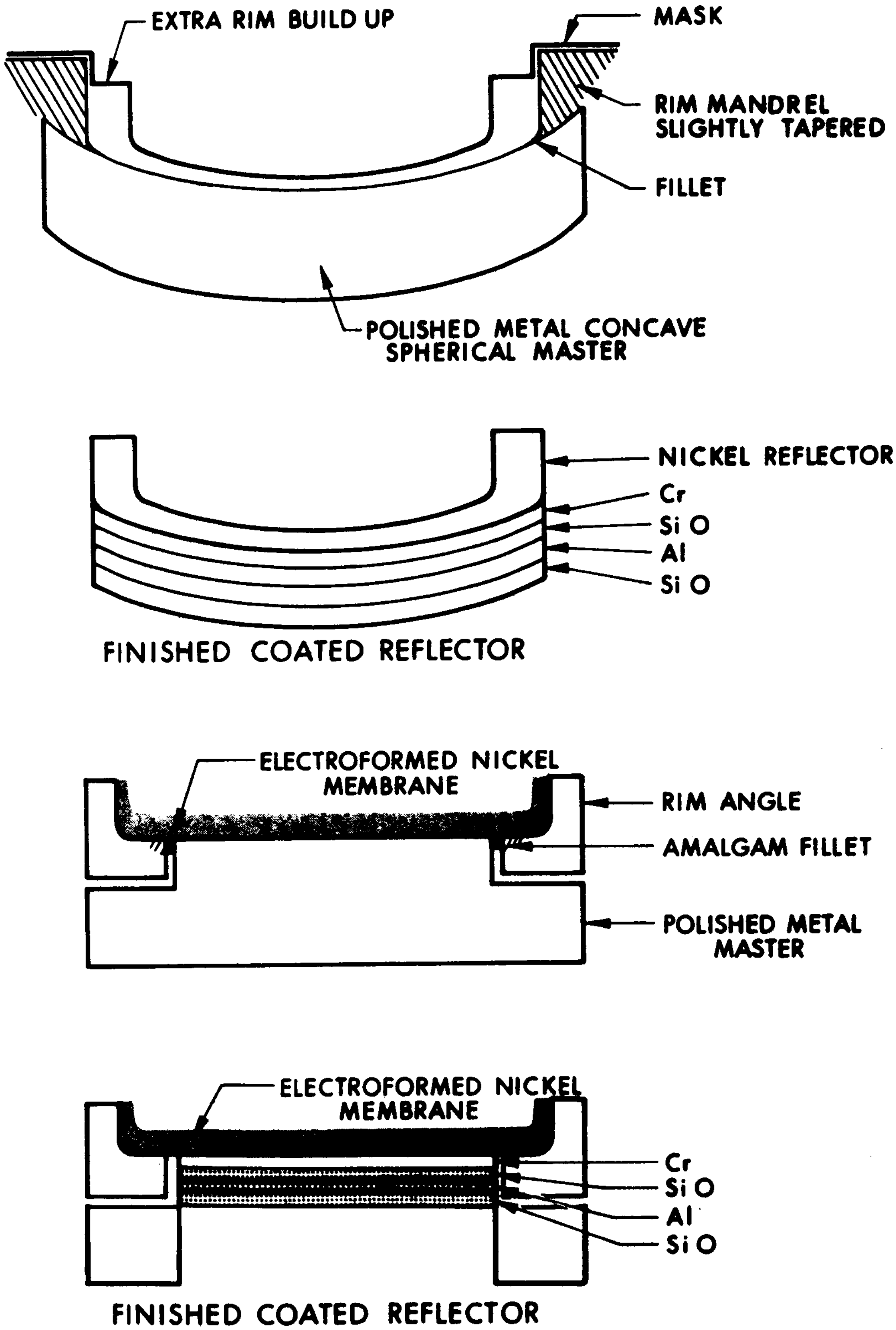

FIG. D-1 CISLUNAR REFLECTOR DETAILS

and fine-grained, the membranes produced should have very high physical properties, yield, and ultimate strengths of over 150,000 and 120,000 psi, respectively.

Vacuum coatings having average solar reflectances between 88 and 92 percent, depending on whether silicon monoxide overcoated aluminum or bare aluminum is used, can easily be achieved with high durability and abrasion resistance. Depending on the thickness of overcoating used, the α/ϵ can be varied over a wide range for thermal control of the panels.

Chromium and silicon monoxide undercoatings are used for adhesion and electrical insulation purposes, respectively, beneath the aluminum reflective coating. The thicknesses used are normally 300Å and 1000Å, respectively. A 1000Å aluminum coating is used followed by silicon monoxide overcoatings to various thicknesses.

The above electroforming and vacuum processing methods are now widely used on solar concentrator and simulator mirrors produced at EOS.

APPENDIX E

REVISED CISLUNAR BEACON CALCULATIONS

APPENDIX E

REVISED CISLUNAR BEACON CALCULATIONS

From Eq. 24 of Appendix A:

$$\frac{a\ r_b \left(\frac{d_e}{d}\right)^2}{0.84\ (C_v + 1)} = \frac{K_\theta\ a_f\ \Omega_s\ R^2\ \beta^2}{3.36\ \cos\frac{\theta}{2}} \tag{24}$$

where

$d_e = d$

$r_b = 0.80$

$R = 10\ \text{nm} = 1.953 \times 10^6\ \text{cm}$

$\beta = 0.00029$ radians $=$ 1 min resolution

$\theta = 0$

$\cos\frac{\theta}{2} = 1$

$a_f = 0.065$

$\Omega_s = 6.75 \times 10^{-5}$ steradians

From Eq. 35:

$$B_{af}\ d_e^2 = T_e\ T_t \left(\frac{D_o}{M}\right)^2 \frac{K_\theta\ a_f\ E_s}{\pi} \tag{35}$$

where

$\frac{D_o}{M} = d$

$T_e = 1.0$

$T_t = 0.1$

$d_e = d$

$$E_s = 14.0 \text{ candles/cm}^2$$
$$C_{50} \approx 1.0$$
$$C_v = C_{50} K_p K_b K_v K_t$$
$$K_p = 1.91$$
$$K_b = 1.31$$
$$K_v = 1.19$$
$$K_t = 1.0$$
$$\therefore C_v = 2.98$$
$$\therefore a \approx 1.6 \text{ cm}^2$$
$$R_{beacon} = \frac{4}{\alpha}\sqrt{\frac{a}{\pi}}$$
$$= 10 \text{ ft radius}$$

which agrees generally with the beacon range projected for other lunar landing aids previously proposed.

The LEM range and elevation angle, with the corresponding reflector angle, are shown below tabulated from the maximum Final Phase LEM Landing Trajectory provided by MSC.

Range	Elevation Angle	Reflector Angle	Reflector Radius Required
10	15	30.0 degrees	10 feet
6	15	30.0 degrees	6 feet
5	16	30.5 degrees	5 feet
2	18	31.5 degrees	2 feet
1	24	35.0 degrees	1 foot

From this table, the reflector panel radii and heights were drawn as shown in Dwg. No. 1100201, Fig. 4-5.

APPENDIX F

INSPECTION PLAN FOR PROTOTYPE SOLAR REFLECTING BEACON

APPENDIX F

INSPECTION PLAN FOR PROTOTYPE SOLAR REFLECTING BEACON

1. PURPOSE

This document describes the inspection plan and procedures to be used for the manufacture of the cislunar and earth lunar emplaced solar reflecting beacons designed under Contract NAS9-4790.

2. APPLICABLE DOCUMENTS

2.1 The change and revision letter in effect on date of proposal or as amended by purchase order.

2.2 Drawing numbers 1100201 through 1100205
1100207 through 1100216

2.3 Company Product Assurance Manual.

2.4 NASA Quality Publication NPC 200-2 "Quality Program Provisions for Space System Contractors".

2.5 NASA Quality Publication NPC 200-3 "Inspection System Provisions for Suppliers of Space Materials, Parts, Components and Services".

2.6 NASA Quality Publication NPC 200-4 "Quality Requirements for Hand Soldering of Electrical Connections".

2.7 Company Manufacturing Practices Manual.

3. ORGANIZATION

The Product Assurance Organization at the company should be established as a functional unit to assure an end product of the highest possible reliability and quality. The Product Assurance Manager should report directly to the Company Executive Vice President, or President assuring the necessary line of authority and objectivity needed for implementation and control of the Product Assurance Program.

4. QUALITY REQUIREMENTS

4.1 Instrument Calibration

All test, inspection, and measurement equipment used on this program will be calibrated and maintained in accordance with the Company Product Assurance Manual. Each item of equipment will be designated as either "requiring calibration" or "for indication only". Instruments used for measurement and acceptance testing, such as micrometers, digital voltmeters, ammeters, and recorders are all maintained within a specified calibration accuracy by the Standards Laboratory. Each instrument carries a label that includes the recalibration due date. Records should be on file in the Product Assurance Department to assure traceability to the National Bureau of Standards. Equipment that is not used as a direct measurement transfer device should be labeled "for indication only" and requires no calibration to verify operational characteristics.

4.2 Material Control

4.2.1 Control of Purchased Material

4.2.1.1 Review of Purchase Orders

All purchase requests (P.R.'s) should be reviewed by Product Assurance for adequacy of product definition and the inclusion of quality requirements. No purchase orders (P.O.'s) should be written against these P.R.'s by the Purchasing Department without the cognizant Product Assurance Engineer's initials on the P.R. Each P.O. will include the following information in addition to the basic technical requirements:

1. "The Government reserves the right to inspect any or all of the work included in this order at the supplier's plant".
2. "Company Q/C Inspection required".
3. "Certificates of compliance required". If it is determined that Customer Source Inspection is required, an additional statement to that effect will be placed on the P.O., and inspection performed in accordance with PAM.

4.2.1.2 Vendor Surveys

The Company Vendor Surveillance Department closely monitors the procurement of all purchased material. Surveys are performed by this department as described in the PAM to determine the vendor's ability to perform the quality assurance and reliability requisites.

Suppliers of off-the-shelf or commercial items will not necessarily be surveyed. As with other off-the-shelf items, this type of hardware will be subjected to 100 percent incoming inspection.

Source inspection will be employed where needed as a means of properly monitoring the product or material being made, processed, or assembled by outside vendors; company inspectors will achieve this goal by verifying conformance of materials with contractual requirements where complex or unusual requirements make it necessary to inspect the equipment prior or during assembly. This type of inspection is desirable where the inspection and testing of the final product does not normally insure that parts are all completely in compliance with the specifications describing them.

4.2.1.3 Receiving Inspection

All material and parts to be used in fabricating the beacon subassemblies shall be routed through a receiving inspection function. This group shall perform the necessary tests, measurements, and inspections for verification to applicable purchase order data. Accepted materials shall be stamped or tagged and are transferred to a bonded stores area in their original or necessary packaging containers to prevent damage during storage and handling.

Rejected materials should be identified and physically segregated to a bonded storage area for disposition. Documentation related to rejected material remains with the item until material review disposition. When these decisions have been made, a corrective action requisite will be reported to the vendor for immediate return.

4.2.1.4 Vendor Performance Records

Copies of all receiving reports should be retained within the Receiving Inspection area, and the accept-reject information is posted to the Supplier History Cards. By maintaining a supplier rating system, this affords the company ample historical data to maintain a Product Assurance Vendor Rating List.

A Manufacturing Order will accompany all fabricated subassemblies on this program. The cognizant inspector will buy off all items at the in-process inspection points designated on the M.O.

Required testing will be conducted during fabrication and on the completed subassemblies in accordance with applicable test procedures. These tests will be monitored and certified by inspectors to insure compliance with specification requirements. All test data sheets will be stamped by inspectors to signify satisfactory completion and acceptance of the data. These data will include both conforming and nonconforming items and will be made available to the cognizant NASA representative upon request.

4.2.2 Discrepant Material Control

All materials found discrepant in any phase of the operation should be segregated into a separate bonded area for material review. Documentation accompanying the item to material review clearly should state the part number, part name, operation, point of defect, quantity, acceptable levels, and causes for rejection. A Material Review Board (MRB) will convene to evaluate the cause, corrective action requirements, and disposition of material. The Material Review Board shall consist of a representative from Company Engineering, Product Assurance, and NASA, as required. Any defect which adversely affects safety, reliability, performance, weight, interchangeability of parts or assemblies, or prime objectives of the contract must have written approval by the NASA/Technical Officer prior to usage.

4.3 Drawing and Change Control

All drawings and manufacturing instructions are issued by the Engineering Section to those departments concerned. Changes will be controlled by Engineering where the cognizant Program Office has the responsibility to issue and recall documents related to the program. The Product Assurance Manual should assure that the correct and latest documents are in use and dictate the removal of obsolete material from the system.

4.4 Inspection Stamps

Company should maintain a stamp issuance and control program wherein each stamp is traceable to a particular inspector and the type of inspection action (i.e., in-process or final inspection). Stamp design is such that it does not conflict with or resemble Government inspection identification.

5. GOVERNMENT-FURNISHED PROPERTY

Any material furnished by the Government will be handled in accordance with the Product Assurance Manual.

6. MANUFACTURING FLOW PLAN

Prototype assembly flow plans shall be submitted and approved prior to receipt of the contract.

7. SAMPLING PLAN

One hundred percent inspection will be required for all components.

8. MARKING, PACKAGING, HANDLING, STORAGE, AND SHIPPING

Each beacon subassembly shall be identified with consecutive subassembly numbers. The package markings shall be in accordance with MIL-STD-129C and be marked in two-inch red lettering with one word to a line.

The beacons will be packaged for shipment in a manner which will preclude any damage or deterioration. Materials used in-house are handled and stored in a manner to prevent damage or deterioration. Where necessary, special boxes and containers will be utilized during handling and storage of articles. Product Assurance, as a part of their audit system, maintains surveillance of these activities to assure compliance.

9. TRAINING AND CERTIFICATION OF PERSONNEL

Personnel performing soldering operations, and soldering inspectors where applicable, will hold current NASA certification of the appropriate classification under the provisions of NPC 200-4. Certified persons will be issued cards indicating their status and period of certification. Certification status and performance histories on each individual will be among items investigated during periodic quality audits.

10. QUALITY AUDITS AND ANALYSIS

The cognizant Product Assurance engineer is responsible for coordinating the collection and analysis of all trouble, failure, and quality data resulting from all phases of the program. Supporting groups in these efforts include project, fabrication, test, inspection, and vendor surveillance personnel.

Periodic unannounced audits of the quality program will be performed to determine:

1. Effectiveness of inspection procedures
2. Availability and completeness of all historical records

3. Effectiveness of test procedures
4. Effectiveness of corrective actions taken
5. Completeness of failure analyses
6. Adequacy of all accept-reject criteria
7. Effectiveness of change control procedures

The resulting data will be analyzed to provide the basis for initiation of preventative and/or corrective action in all areas affecting product quality and reliability.

A written report will be submitted to the Project Manager (distributed to other appropriate management) with specific deficiencies, recommendations, and need for corrective action indicated, where applicable. Salient points of the audits will be included in the Monthly Quality Status Report as submitted in the Monthly Progress Report.

Follow-up audits and reports will be made on a weekly basis until all noted deficiencies are resolved. Quarterly summaries of the above will be distributed to top EOS management.

11. FAILURE REPORTING, ANALYSIS, AND CORRECTIVE ACTION

The Company Failure Reporting System shall be described in the Product Assurance Manual. This system shall provide for prompt notification of all concerned parties in the event of a failure, expedient and complete analysis of all failures, and prompt and effective corrective action implementation.

12. CHANGE CONTROL

A change control system, as outlined below, shall be implemented to ensure

1. Control of all documents affecting the quality program
2. The incorporation of changes thereto

12.1 Quality Control Procedures

All such procedures shall be included in the Quality Program Plan. Copies will be controlled and distributed by the Product

Assurance Department. Upon change or revision, the Plan will be redistributed to the original assignee list. Obsolete copies will be confiscated and destroyed. The distribution list will indicate:

1. Assignee
2. Date of distribution
3. Revision letter
4. Date of revised distribution
5. Status of obsolete document
    a. Not retrieved
    b. Retrieved and destroyed (date and initial)

12.2 Manufacturing Orders and Instructions

This documentation is controlled by the fabrication supervisor. Any revisions must be approved by Manufacturing and Product Assurance and are distributed by hand by the fabrication supervisor. Obsolete documents shall be picked up at the same time assuring that only the latest documentation is available in the fabrication areas.

13. SPECIAL INSPECTION REQUIREMENTS

13.1 Beacon Reflectance

The reflectance of the reflector surfaces shall be determined from measurements made on flat electroformed or foil-plastic samples coated at the same time as the reflector surface. Measurements shall be made over the visible spectrum, from 4000 to 7000Å, and shall be reported as an integrated average.

Where specified, the thickness of the silicon monoxide overcoating, used to change the α/ϵ ratio shall be measured by optical interference techniques.

13.2 Beacon Field of View and Accuracy

The beacon field of view and accuracy shall be determined by a Hartmann type test which utilizes a laser or other highly collimated source and an image screen having predetermined test circles which will aid in determining the surface accuracy.

13.3 <u>Mechanical Fits and Tolerances</u>

All prototype mechanical subassemblies shall be measured by an operational test. No packaged or individual components shall exceed the packaging dimensions - 0.100 inches as listed on the LEM Descent Stage Scientific Containers Stowage (Ref. LID-360-22810).

APPENDIX G
SUN AND EARTH SENSOR SPECIFICATIONS

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SUN AND EARTH SENSOR SPECIFICATIONS

1. PURPOSE

This document describes the specifications for the manufacture of prototype sun and earth sensors to be emplaced on the lunar surface for use with an earth tracking beacon.

2. APPLICABLE DOCUMENTS

   1. The change and revision letter in effect on date of proposal or as amended by purchase order.
   2. Drawings - 1100203
      1100209
      1100210
      1100211
      1100212
      1100213
   3. Environmental Specifications for Apollo Scientific Equipment.

3. OPTICAL SPECIFICATIONS

3.1 Sun Sensor

FOV - $\pm 90^{\circ}$ latitudinal and longitudinal

Activation illuminator ≥ 5 lumens/cm^2

Spectral response - within solar spectrum, preferably near the visible

3.2 Earth Sensor

FOV - $\pm 2^{\circ}$ to $\pm 16^{\circ}$ (with less than a $\pm 16^{\circ}$ FOV a recycle program is required)

Activation illumination - 1×10^{-3} lumens/cm^2

Spectral response — visible, near IR and far IR

Sun lock-on switch — 5 lumens/cm^2 — cutoff intensity

$\pm 3^\circ$ to $\pm 17^\circ$ FOV

4. MECHANICAL SPECIFICATIONS

4.1 <u>Sun Sensor</u>

Dimensions - 2" x 2" x 4"

2" x 4" x 1/16" baffle

Weight - 2 lb - x lb including packaging

(i.e., Sun and Earth sensor = 2 lb)

4.2 <u>Earth Sensor</u>

Dimensions - 3 x 3 x 4 inches

Weight - x lb including packaging

5. ELECTRICAL SPECIFICATIONS

Voltage - 28 to 29.88 volts

Power total - 1 watt

6. ANGULAR ACCURACY

Earth sensor - $1/4^\circ$

Sun sensor - $1/4^\circ$

7. RELIABILITY

> 0.98 for one year in the lunar environment

8. LUNAR ENVIRONMENT

(See Environment Specifications for Apollo Scientific Equipment.) Electrons shall withstand temperature extremes between 85°K and 385°K without degradation.