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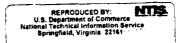
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APOLLO VISIBILITY HANDBOOK

4 October 1968

Prepared for
SYSTEMS ENGINEERING DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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## 1. INTRODUCTION

The requirements and data contained in this document are intended to apply to the Apollo "G" Mission, the manned lunar landing mission. The purpose of the document is to provide a convenient reference to the system requirements for Apollo flight crew visibility and to data that will aid in evaluating the status of the requirements and related visibility problems.

Existing documentation and discussions with the various cognizant MSC and contractor personnel provided the inputs for the handbook.

The basic organization of the handbook is:

- Visibility Requirements (Section 2)
- Hardware Descriptions (Section 3)
- Factors Affecting Visibility (Section 4)
- General Reference Data (Section 5)

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#### VISIBILITY HANDBOOK

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# 2. SYSTEM REQUIREMENTS FOR APOLLO FLIGHT CREW VISIBILITY FOR THE LUNAR LANDING MISSION

The requirements stated in this section were determined as follows:
The Design Reference Mission IIA (MSC Report No. PM3/M-171/66, Dated 30 October 1966) was reviewed. It should be noted here that the Design Reference Mission IIA calls for a Lunar Parking Orbit of 80 nautical miles instead of the 60 nautical miles presently planned. The requirements presented in this section are believed to be unaffected by this change. A series of discussions was then held with numerous MSC and MSC-contractor personnel concerned with problems and data related to flight crew visibility requirements and/or performance. The many documents and verbal information furnished by these individuals, along with documentation available in the MSC Technical Library, constitutes the basis of the requirements stated in this section.

## A. Pre-Launch Visibility Requirements

- 1. Interior Lighting.

  The interior lighting must be adequate for the crew to accurately interpret equipment status indicators, meter readouts, etc. associated with the required pre-launch equipment checkout tasks.
- 2. Boost Protective Cover (BPC) Window.
  For crew safety a window in the BPC is required over the right-hand forward window of the CM. This window will enable the crew to see if it is safe for them to egress. The view through the window will show whether the service structure and emergency escape route has been removed.

### B. Earth Ascent Visibility Requirements

The crew must be able to see inside the CM to perform their programmed functions, monitoring displays and actuating certain controls, throughout the launch acceleration phase.

Contrast of displays must preclude loss of crew ability to monitor instruments when the interior illumination increases when the Boost Protective Cover is jettisoned.

In addition to the normal monitoring and switching actions, the crew must be able to manually control the attitude of the CSM to position the horizon reference line on the commander's forward window coincident with the earth's horizon, with the aid of the FDAI, for the following three about modes:

- 1. SPS Mode III, Retrograde, Blunt End Forward, Heads Up.
- 2. SPS Mode IV, Posigrade, Small End Forward, Heads Down.
- 3. Fixed Time, Variable Av Mode, Retrograde, Blunt End Forward, Heads Up.

The time of launch must be such that the earth's horizon is visible to the crew so that the horizon reference line described above can

property aligned for the three abort modes. This does not preclude launches when the launch pad is in darkness.

# C. Command Module Optical Sighting and Tracking with the Scanning Telescope (SCT) and Sextant (SXT)

#### General.

The SCT and SXT enable the crew to make optical sightings on celestial objects and landmarks (Earth and Moon). These sightings are used to align the guidance inertial reference (IMU) and to update the spacecraft's position.

TELESCOPE. The telescope (SCT) is mounted beside the sextant to permit parallel lines of sight through an opening in the spacecraft. The telescope, with its large field of view (60°), is used for acquisition in midcourse flight and for measuring angles to landmarks during earth orbit.

SEXTANT. The sextant is more precise and, with its 1.8° field of view and resolution of about 10 sec of arc, is more accurate than the telescope, and is used primarily for aligning the IMU to known star lines of sight. It also can be used to obtain backup navigation data by measuring angles between a landmark and a star during midcourse flight, and by tracking objects.

# Star Sightings.

The Apollo Crew is required to make guidance and navigation sightings (both of which include star sightings) with the SCT and SXT.

The stars to be sighted are determined before the mission begins and are selected from a list which is stored in both the Command Module Computer and the Lunar Module Computer.

Guidance sightings (IMU alignments) require sightings on two stars. If the angle between the two star lines of sight is too large, the spacecraft would have to be reoriented in order to acquire the second star in the sextant field of view because of the trunnion limits. If the angle is too small, the uncertainty in final platform attitudes will be excessive. An angle of 60° between star lines-of-sight is the selection goal for an IMU alignment star pair, and is generally attainable with a maneuver about a single axis.

The maximum permissible angle between a star and a landmark is 50° because of the limited angular freedom of the sextant's "star line-of-sight" and body-fixed "landmark line-of-sight". Star sightings are required:

- A) In Earth orbit (light and dark side),
- B) In cislunar space (transearth and translunar), and
- C) In lunar orbit (light and dark side).

Star charts must be provided the crew for star location and identification.

Navigational sightings (spacecraft position measurements) require star/Earth landmark pairs to be sighted with the sextant.

3. Earth Landmark Sightings.

The Apollo crew is required to sight landmarks on the earth during the earth orbit and translunar coast phases of the Lunar Landing Mission using the SCT and SXT. Earth landmark sightings are required to be made with the SCT during earth orbit on the sunlit side of the planet only. Earth landmark sightings are required to be made with the SXT during translunar coast. There is no requirement to sight landmarks on the dark side of the earth. No earth landmark sightings are required after Lunar Orbit Insertion.

The potential earth landmarks to be sighted will normally be selected before the mission. When the sighting is performed, and the landmark is identified, the crew will enter the earth coordinates of the landmark into the command module computer (CMC) manually. Earth landmark coordinates are not required to be stored in the CMC premission. The sightings, when made with the SXT (during translunar coast), are made by orienting the spacecraft so that the "landmark line-of-sight" points to the landmark.

The landmark selection criteria should include:

- A) The landmark must be in daylight at the time the spacecraft is above it.
- B) The landmark must have non-variable features which can be identified by matching photographs or charts with the view through the scanning telescope or sextant. Shallow lakes with shorelines that depend on local precipitation are undesirable. Unvarying shorelines with outstanding color are good landmarks.
- C) The landmark must be so colored or in sufficient contrast with its surroundings as to be readily located and not confused with other landmarks or objects. When sighting landmarks with the SXT (during translunar coast), the preferred landmarks are water/land interfaces because of the spectral response of the SXT's landmark line-of-sight (the field of view is tinted red).
- D) The landmarks must be selected close enough in time to the time of launch for reasonable assurance that they will not be occluded from the spacecraft by weather. Landmarks in areas of predictable weather are preferable.

Suitable navigation aids must be provided the crew for landmark location and identification.

4. Lunar Landmark Sightings.

Descriptions of 25 lunar landmarks are stored in the CM computer. The CM crew is required to sight on lunar landmarks during lunar

orbit for navigational purposes, using the sextant. Lunar Landmark tracking is required in accordance with MSC Memo No. EG23-67-209.

The landmarks:

- a) Must be adequately illuminated when the spacecraft is above them.
- b) Must be so colored, shaped, or otherwise contrasted with neighboring features as to be readily located.
- c) Must satisfy the following:

<u>Landing Site Landmarks</u> (for landing site determination associated with MSFN primary navigation)

- 1) Landmarks will be chosen within the Orbiter photographic coverage of 40 x 60 km.
- 2) The size of these landmarks should be between 800 feet and 1500 feet. The lower bound is determined by visibility requirements and the upper bounds by navigation accuracy requirements.
- 3) The landmarks should be part of a recognizable pattern with a size of about 25 n mi diameter.
- 4) It is recommended that a lead-in landmark which is approximately 12 degrees central angle in the orbital plane on
  approach to the site landmark and within 2 or 3 degrees of
  the orbital plane also be specified as an aid to recognition.
- 5) Sun elevation at the landmark must be 3° to 20° and, ideally, 6° to 7° above the local horizontal.

General Lunar Landmarks (for CSM state determination in lunar orbit in backup on-board navigation)

- 1) The size of the detail sighting object should be in the order of 1000-2000 feet.
- 2) The landmarks should be separated by a lunar central angle of 16-20 degrees in the orbital plane, and within 2-3 degrees of the orbital plane.
- 3) Sun elevation at the landmark must be 3° to 20° and, ideally, 6° to 7° above the local horizontal.
- 4) The landmarks should lie to the east of the landing site except for possibly one to the west.
  - 5) The landmarks should have a recognition pattern in the range of 25-50 n mi in diameter. This recognition pattern includes a lead-in landmark.

Cislunar Landmarks (CSM state determination in cislunar orbit in backup on-board navigation and G, N&C checkout)

Lunar landmarks shall be available for navigation for the TL midcourse correction (MCC) and the first TE midcourse correction. These landmarks should be chosen for visibility with the sextant from the TL MCC and TE MCC sighting range. These landmarks should subtend an angle of 20-40 arc seconds.

5. Tracking of LM with Sextant.

It is desirable that the crewman in the CM track the LM for backup navigation data during LM descent coasting, lunar stay and lunar ascent. It is required that the crewman in the CM track the LM during rendezvous for backup guidance data. For optical tracking during rendezvous, an optical beacon is required on the LM. This beacon can also facilitate optical tracking of LM during descent if electrical power and flight dynamics considerations permit.

# D. Lunar Module, Optical Sighting and Tracking with the Alignment Optical Telescope (AOT)

#### General.

The Apollo LM crew is required to make optical guidance sightings (IMU alignments) with the AOT, a unity power, 60° field of view telescope that can be pointed in any one of six discrete directions with respect to the LM. A guidance sighting requires the acquistion and line-of-sight angular measurement of two stars.

## 2. Star Sightings.

Star sightings are required for LM IMU alignments when the LM is in lunar orbit, dark side or light side, and during the lunar stay.

The stars to be sighted are selected before each mission from the same list that exists for the CM. The entire list is stored in the lumar module computer, even though not all the stars may be used on the given mission.

# E. CM Interior Visibility Requirements

Standard Human Factors Engineering Practices and Military Standards provide the basis for the interior visibility requirements in this section, unless otherwise specified.

## 1. Illumination

Floodlighting - Floodlights are required as backup to illuminate the MDC and to generally illuminate the crew compartment and lower equipment bay areas. The color of the illumination shall be bluewhite. A dimming capability is required. Utility Lighting - A portable light is required for illumination in the areas under the couches.

Window Shades - Opaque shades are required for all windows.

Interior Surfaces - The reflectivities shall be such as to minimize glare and window reflections while minimizing the total illumination required. The colors shall enhance the contrast of placards and labeling and not interfere with the visibility of instruments or annunciators.

Tunnel Lights - Lighting is required in the CM tunnel for docking mechanism and transfer operations illumination.

Illumination Controls - Each illumination control shall be visible both in its ON and OFF positions.

Dimming Controls - Integrally lighted units grouped in the same general field of view with a common dimming control shall have, as closely as is practicable, the same brightness for a given control position. The maximum brightness ratio between any two such units at any control setting shall be three to one.

# 2. Equipment Status Indicators

Display Instruments - Shall be readable to at least 30° off the perpendicular to the face plate. Optical illusions, parallax, distortion, and reflections shall be reduced to minimum practical values. Each shall contain its own light source. The general color of the lighting shall be white with special purpose colors of red, yellow, and green(aviation standard).

Annunciators - Shall be employed as attention-attracting devices. There shall be three types: Warming type (aviation red), caution type (aviation yellow), and advisory type (aviation white or green).

Integral Lighted Display Panels - Shall have illuminated white markings on a non-illuminated gray background. Lettering style and height to width ratio shall maximize legibility.

Switches - Electroluminescent pushbutton switches shall conform to the requirements for integral lighted display panels. Incandescent lighted pushbutton switches shall satisfy the requirements for advisory type annunciators.

Alpha-Numeric Display Lighting - Alpha-Numeric readout devices shall use electroluminescent direct display. Dimming capability is required.

# 3. Viewability

Equipment shall be located to minimize crew movements for viewing purposes. Mirrors are required to enable the crew to adjust their restraint harnesses, to assist in doffing or donning the EMU, and to verify CM parachute deployment.

### 4. Readability

All displays, nomenclature, etc., must be readily interpreted for appropriate and expected ranges of lighting conditions, viewing angles, and viewing distances.

## F. LM Interior Visibility Requirements

The Standard Human Factors Engineering Practices and Military Standards provide the basis for the interior visibility requirements in this section, unless otherwise specified.

#### 1. Illumination.

Floodlighting - Floodlights are required to provide illumination within the crew compartment as necessary for data reading and housekeeping operations. They are also necessary as a secondary means of illuminating all display and control panel areas. The color of the illumination shall be white. A dimming capability is required.

Window Shades - Shades with a minimum but positive transmissibility are required for all windows.

Interior Surfaces - The reflectivities shall be such as to minimize glare and window reflections while minimizing the total illumination required. The colors shall enhance the contrast of placards and labeling and not interfere with the visibility of instruments or annunciators.

Illumination Controls - Each illumination control shall be visible both in its ON and OFF positions.

Dimming Controls - Integrally lighted units grouped in the same general field of view with a common dimming control shall have, as closely as is practicable, the same brightness for a given control position. The maximum brightness ratio between any two such units at any control setting shall be three to one.

# 2. Equipment Status Indicators.

Display Instruments - Each shall have its own light source within the display enclosure:

Annunciators - These include: Warning type (red), caution type (yellow), and the blue landing probe touchdown light.

Intégrally Lighted Panels - All shall have white illuminated markings on non-illuminated backgrounds.

### 3. Viewability.

Equipment shall be located to minimize crew movements for viewing purposes. Mirrors are required to aid the crew in adjusting their restraint harnesses and in completing the EMU donning operation.

## 4. Readability.

All displays, nomenclature, placards, markings, etc., must be readily interpreted for appropriate and expected lighting conditions, viewing angles, and viewing distances.

# G. Transposition and Docking Visibility Requirements

1. Docking Target on LM (Passive Vehicle)..

A self-luminous docking target shall be provided to aid the crew in visually aligning the CM to the LM.

2. Illumination of LM (Passive Vehicle).

Since Apollo ground rules require that transposition and docking (a visual task) be accomplished in daylight or darkness, illumination of the LM can be either sunlight or a CSM floodlight. Due to the high specularity of most of the LM surface, some combinations of LM-CSM-sun relative orientations are to be avoided.

3. Crewman Optical Alignment Sight (COAS).

A COAS is required in the CM to provide (using the LM docking target) relative attitude and an indication of range and range rate to the CM pilot.

# 4. General.

The aids on each vehicle shall provide the crew member(s) in the other vehicle with the following visual cues for the full range of mission lighting environments:

- a. Acquisition and gross attitude determination at a minimum distance of 1,000 feet.
- b. Indication of relative attitude and alignment from a minimum distance of 200 feet.
- c. Range and range rate indication from a distance of 200 feet.
- d. Indication of fine alignment from a distance of approximately 50 feet to the precontact alignment position.

# H. CM Inspection of LM in Lunar Orbit

1. Illumination of LM.

There shall be enough time in the sunlight between CSM/LM separation and TOI for the CSM to visually inspect the LM landing gear, touchdown probes, descent engine skirt, and the general condition of the LM exterior.

Intervehicular Attitudes.

Due to the high specularity of most of the LM surface, some combinations of LM-CSM-sun angles are to be avoided.

#### I. Lunar Landing

1. Landing Site Illumination.

At lunar touchdown, it is desired that the sun be from behind the LM 6° to 12° above the lunar horizon. Sun elevations of 12° to 20° are acceptable, provided that the descent trajectory incorporates a "dog-leg." These sun elevations provide acceptable visibility of lunar landing site features with the expected LM approach flight path angles. After touchdown, the LM must be adequately illuminated for visual inspection of the effects of landing.

2. View of Lunar Surface Through LM Window.

The lunar surface must be visible through the LM window(s) during the Final Approach Phase (about 105 seconds duration; 9000 ft to 500 ft altitude) so that the crew can assure safety, generally assess the landing site to which the automatic guidance system is taking them, and redesignate if desired. The lunar surface must also be visible during the Landing Phase (following Final Approach Phase) so that the pilot can make a detailed visual assessment of the area prior to touchdown, and, if necessary, control his descent manually to avoid an undesirable landing site local feature, such as a rock or hole.

3. Landing Point Designator.

A visual aid is required to furnish the LM pilot with a visual correlation between computer output symbols defining the landing sight to which the LM is being automatically guided during the final approach phase and the view through the window of the lunar terrain. This "landing point designator" is necessary in order for the pilot to determine whether to redesignate or not.

4. Landing Site Recognition Aids.

To assure the crew that their vehicle is headed for the correct landing area, visual aids may be desired to correlate the view through the window with the desired landing area to supplement pre-mission crew training.

## J. Extravehicular Activities

1. Lunar Stay.

1.1 Terrain Illumination

The terrain illumination at the lunar landing site shall be suitable for the planned exploration.

1.2 LM Illumination.

It is required that the LM be visually inspected from several angles while on the lunar surface. Due to the high specularity of most of the LM surface, some combinations of LM-sun-viewing angles are to be avoided.

# 2. Contingency Transfer.

## 2.1 General.

In the event that the LM crew is unable to transfer from the LM to the CM in the normal manner, an EVA mode will be employed. In this mode the two astronauts in the LM will egress from the LM into space, then enter the CM. To facilitate contingency transfer, certain visual aids are required.

#### 2.2 Visual Aids.

A floodlight is required on the CSM exterior to illuminate the area on the CSM containing the EVA handles. Radioluminescent (RL) discs are also required to be appropriately placed on or near the handles as a further aid in locating the handles.

The visual aids, floodlight and RL discs must be visible to the helmeted crewman at distances of up to 25 feet.

# K. Rendezvous and Docking Visibility Requirements

# 1. LM Tracking.

A LM tracking light (flashing) shall be provided for CM sextant acquisition and tracking of the LM for backup guidance information.

2. CM Rendezvous Beacon Light.

A flashing beacon shall be provided on the CM for backup to rendezvous radar during the final phase of the rendezvous.

LM Docking Lights.

Docking lights shall be provided for visual orientation cues and gross attitude determination.

4. CM Running Lights.

Exterior lights shall provide visual acquisition and gross attitude information at 1000 feet and docking alignment information at 200 feet.

5. CM Docking Target.

A, docking target shall be provided on the CM to aid the LM in visually aligning to the CM.

6. Crewman Optical Alignment Sight (COAS), LM.

A crewman alignment sight is required in the LM to provide (using the CM docking target) relative attitude and indications of range and range rate to the LM pilot.

## 7. LM-CSM-Sun Geometry.

Due to the high specularity of most of the LM and CSM surfaces, some combinations of the LM-CSM-Sun angles are prohibited. These are the angles at which the brightness ratio between any adjacent vehicle surfaces visible to the crew of the active spacecraft is 500/1 or greater.

## 8. LM Docking Window and Reticle.

An overhead window shall be included above the commander. It will be used during docking to provide visibility of the CM docking target. A reticle shall be provided on the window for visually monitoring vehicle attitude, with the horizon as a reference, during lunar ascent.

#### 9. General.

The aids on each vehicle shall provide the crew member(s) in the other vehicle with the following visual cues for the full range of mission lighting environments:

- a. Acquisition and gross attitude determination at a minimum distance of 1,000 feet.
- b. Indication of relative attitude and alignment from a minimum distance of 200 feet.
- c. Range and range rate indication from a distance of 200 feet.
- d. Indication of fine alignment from a distance of approximately50 feet to the precontact alignment position.

#### L. Crew Personal Equipment

#### 1. Helmets.

The helmets, required for crew safety, must not prevent the performance of scheduled tasks due to excessive light attenuation, visual distortion, or other visibility degrading factors. Freedom of astronaut's head movement inside the helmet and minimum eye relief are required for using optical sighting instruments (SCT, SXT, AOT, COAS) while pressurized.

### 2. Extravehicular Visor Assembly (EVVA).

Protective visors are required to provide the crewman with visual, thermal, impact (inside LM, ingress, egress) and meteoroid protection on the lunar surface. Degradation of crewman visibility from these devices shall not prevent the satisfactory completion of scheduled tasks.

### 3. Crew Protective Clothing.

Crew clothing must not be so reflective as to degrade crew visual performance inside the spacecraft.

### 4. Miscellaneous.

# 4.1 Penlight.

Each crewman is required to have a small flashlight for portable lighting.

## 4.2 Sunglasses.

Each crewman is required to have a pair of sunglasses for eye protection.

# M. Photography

There are no additional lunar mission constraints or requirements to insure crew visibility with respect to photographic requirements.

## N. Television

There is no explicit requirement for television originating from the spacecraft during the lunar mission and there are no crew visibility requirements directly related to TV requirements.

# O. Earth Entry and Landing Phase Visibility Requirements

There are no natural lighting constraints on entry and landing. It is required that the crew be able to see the horizon through the commander's forward window as a rough check on proper entry attitude. Further, it is required that the crew visually confirm parachute deployment. The crew must be able to see inside the CM to perform their tasks preparatory to entry and landing.

# P. Degradation of Visibility

## 1. Hardware

Degradation of optical devices (windows, COAS, SCT, SXT, AOT, helmets, visors, lenses, etc.) from all causes, shall not be so great as to render the item useless prior to the last time it is required, or to prevent the completion of any scheduled task. Interior and exterior (including the RL discs on CM and LM handrails and the special light for illuminating the CM and CM/LM interface exterior for EVA in space) lighting sources must not be degraded so as to affect the performance of any function during the mission.

## 2. Operational Factors.

The geometric relationships between the spacecrafts and celestial bodies (stars, earth, moon, sun) shall insure adequate illumination so that all planned tasks can be accomplished as scheduled. Extravehicular activities shall be planned and equipment designed so as to insure illumination sufficient to perform all scheduled duties.

## 3. Crew Performance.

Insofar as is possible, crew activities must be scheduled so as to minimize any adverse effects on crew performance due to:

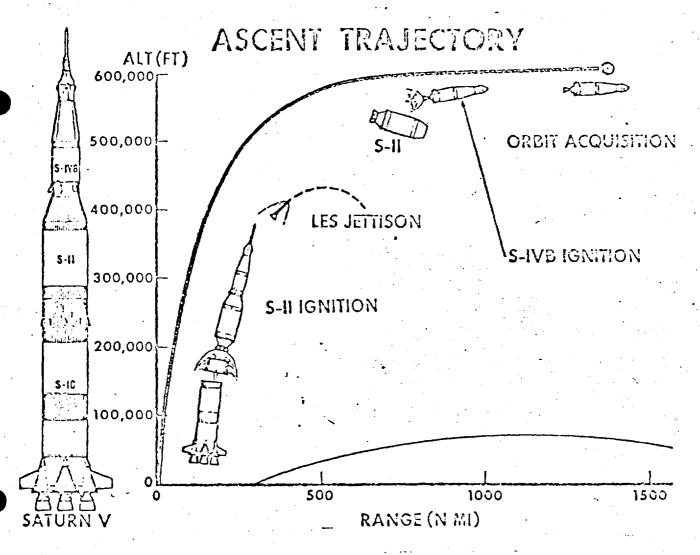
- a. Eye irritation from contaminants in the zero-G environment causing tearing, etc.
- b. Fatigue.
- c. Effect of ionizing radiation which may cause tissue damage.
- d. Optical illusions, perceptual biases, or any other factors which may degrade visual capability.
- e. A chance glance at the sun without proper eye protection.
- f. Excessive oxygen pressure, which affects visual capability.

. . . 

# 3. HARDWARE DESCRIPTIONS

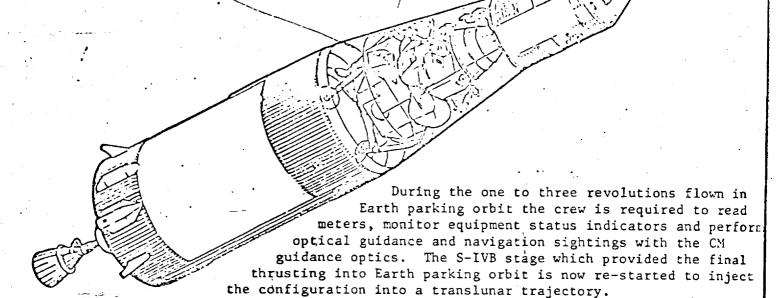
This section is devoted to describing the Apollo flight hardware which is directly related to flight crew visibility. Data on optical characteristics is organized by module and functional element. Data not available at the time of this report is indicated.

General - Consideration of crew visibility factors throughout the mission from prelaunch to splashdown requires a knowledge of the spacecraft configurations that obtain during the various mission phases. These configurations are summarized by the following sketches.

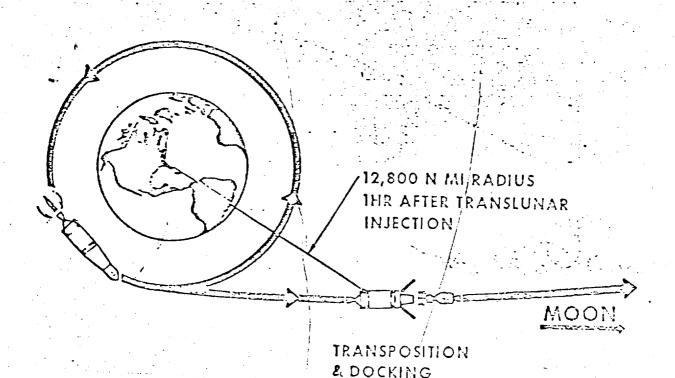


A natural lighting constraint exists at launch because of the necessity for manual control of the CSM attitude for thrusting in case of abort requiring SPS burning for control of landing point. The alignment of a reference mark on the CM window with the horizon maintains proper burn attitude. The clear plastic helmet shell worn by the crew during all thrusting maneuvers as a part of their pressure garments is a consideration in visual performance.

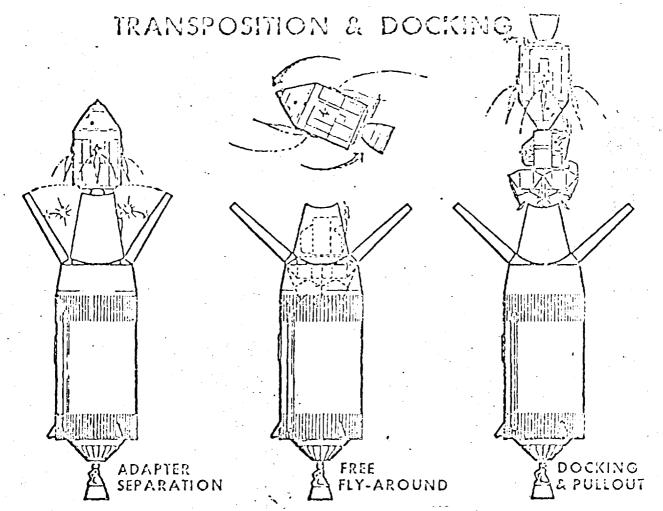
# APULLO SPACECRAFI/S-IVE EARTH ORBITAL CONFIGURATION



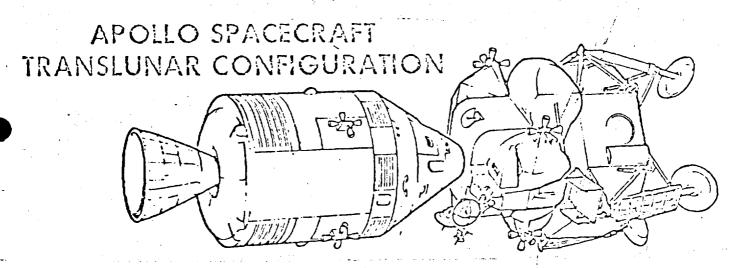
# TRANSLUNAR INJECTION & COAST



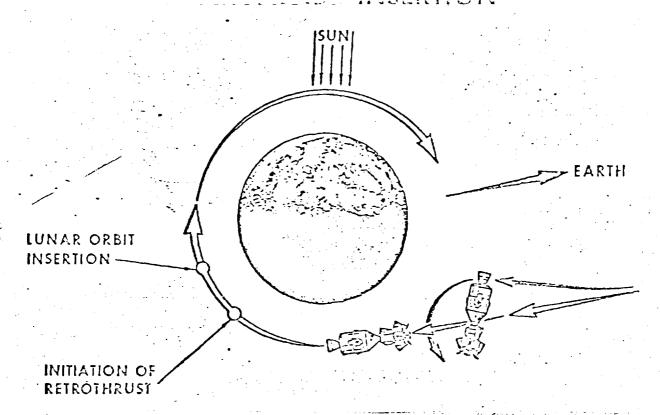
The process of transposition and docking, which occurs immediately after translunar injection, is conducted entirely by visual means.



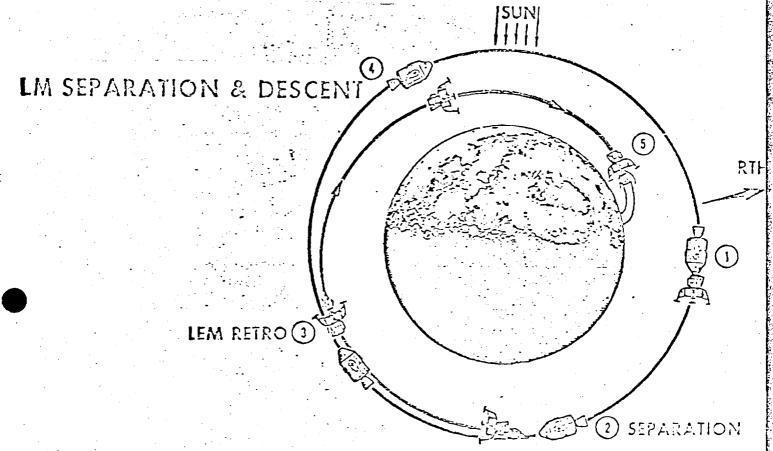
The CSM separates from the S-IVB LM adaptor and rotates 180°. The LM is exposed when its protective shroud is opened by pyrotechnic devices. The S-IVB now follows the CSM/LM at a distance which will insure minimum interference with optical guidance and navigation sightings due to sunlight reflected from the S-IVB.



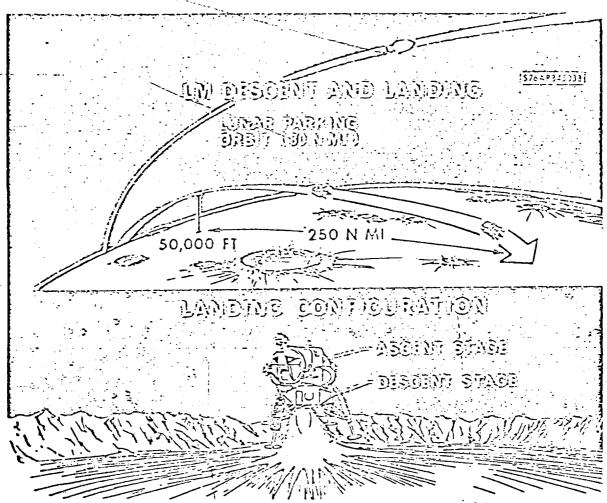
Most of the approximately three day lunar coast is spent in a passive thermal control mode. The vehicle rotates slowly (two to three revolutions per hour) to avoid excessive soak temperatures due to solar radiations and radiative cooling. This passive thermal control is interrupted by guidance and navigational sightings and up to three midcourse corrections. Crew dark adaptation for star sightings may be maintained by deployment of opaque window shades over the windows or by the wearing of sun glasses when the crewman's helmet shell is doffed.



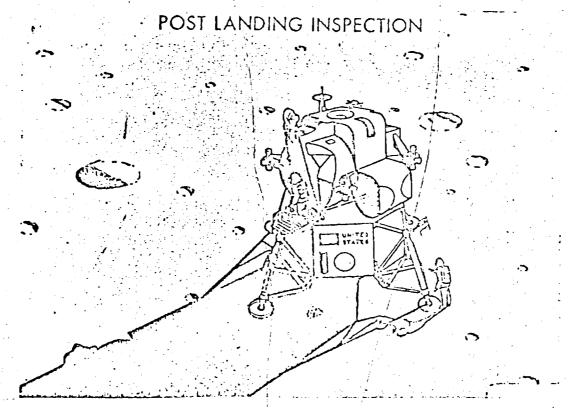
Upon arrival at the moon a braking maneuver is performed using the SM engine to place the vehicle in a 60 nautical mile lunar parking orbit.



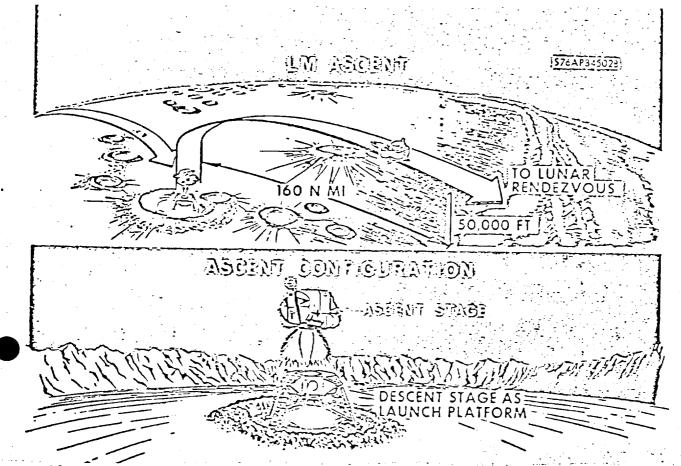
Two of the astronauts transfer from the CM through the docking tunnel of the LM. The LM crew prepares for LM descent (reading meters, unstowing equipment, etc.). After several revolutions about the moon the LM is separated from the CSM and star sightings are made to ready the LM guidance system. The CSM remains in the 60 nautical mile lunar orbit throughout the descent and stay of the LM



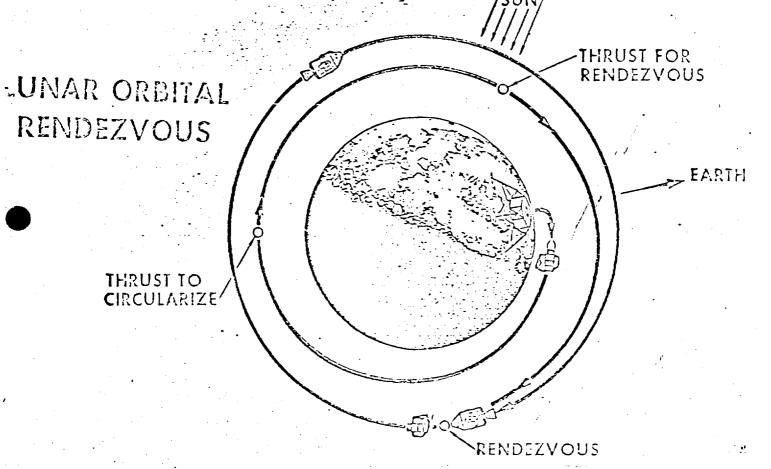
The lunar descent engine is used to place the LM in an eliptical orbit. At perilune descent engine thrusting is re-initiated to bring the LM in for a soft landing on the lunar surface.



After landing the crew performs surface excursions and deploys scientific equipment. Sunlight and supplemental battery powered penlights carried by each astronaut are the sources of illumination.



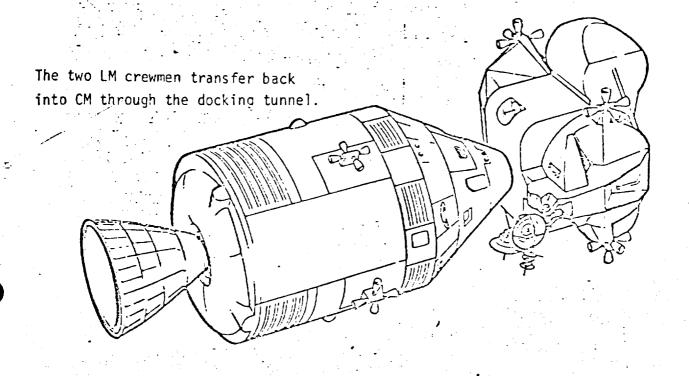
After completion of their duties the two crewmen re-enter the LM and prepare for lift-off (reading instrument panels, etc.). The expended descent engine is used as a launch platform, and the ascent engine provides power for lift-off and thrust into lunar orbit.



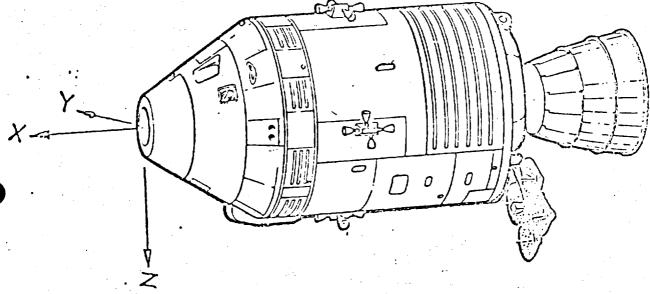
The LM performs an active rendezvous and docking with the CSM, the final phase of which is conducted visually in Earthlight.

-20-

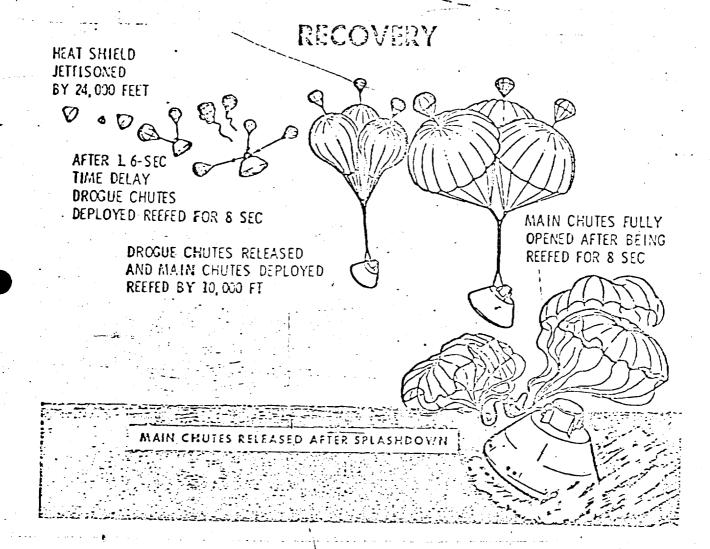
# APOLLO SPACECRAFT LOR CONFIGURATION



APOLLO TRANSEARTH CONFIGURATION



The two vehicles separate, and the CSM crew prepares for transearth injection by reading instruments, making star sightings, etc. The LM remains in lunar orbit. The majority of the time after attainment of a transearth trajectory by the CSM is spent in passive thermal control as during translunar coast. Again the slow rotation is interrupted by guidance and navigation sightings and up to three midcourse corrections.

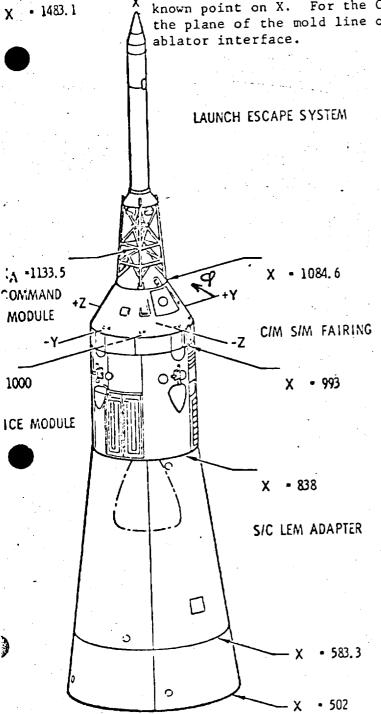


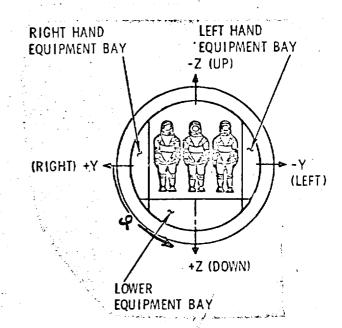
Upon arrival at the Earth the SM is jettisoned and the CM is oriented for re-entry into the Earth's atmosphere. The crew again aligns marks on the spacecraft window with the Earth's horizon in manually controlling the spacecraft attitude. Re-entry and splashdown occur; spacecraft location aids are deployed; and the spacecraft is recovered.

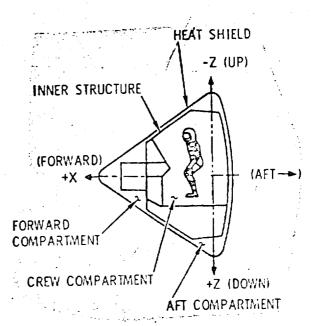
# 3.1 COMMAND AND SERVICE MODULE (CSM)

# 3.1.1 CSM Body Coordinates

The X-axis is the longitudinal axis of the vehicle. The Z-axis is normal to X and passes through a benchmark at the top of the Service Module (SM) fairing pointing in the same direction as the crew's feet point when they are restrained in their couches. The Y-axis completes a right-handed system. Roll position is measured from the +Y direction to the +Z direction. Locations of points on the CSM can be specified by a roll position and the distance of a plane perpendicular to X from a known point on X. For the CSM, this point is 1000 inches below the plane of the mold line of the heat shield main structure ablator interface.

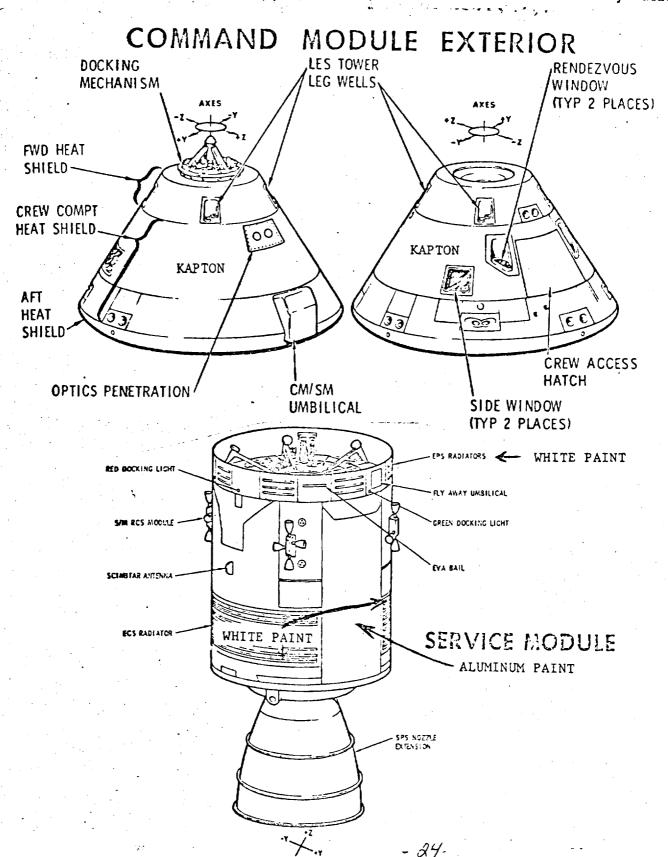






# 3.1.2 Exterior Surfaces

The CM exterior is SiO/Al/500g KAPTON except for the windows. For description of the windows see Section 3.1.6. The SM exterior is aluminum polyurethane paint except for the radiators which are painted white. See Appendix 1 for reflectivity data.

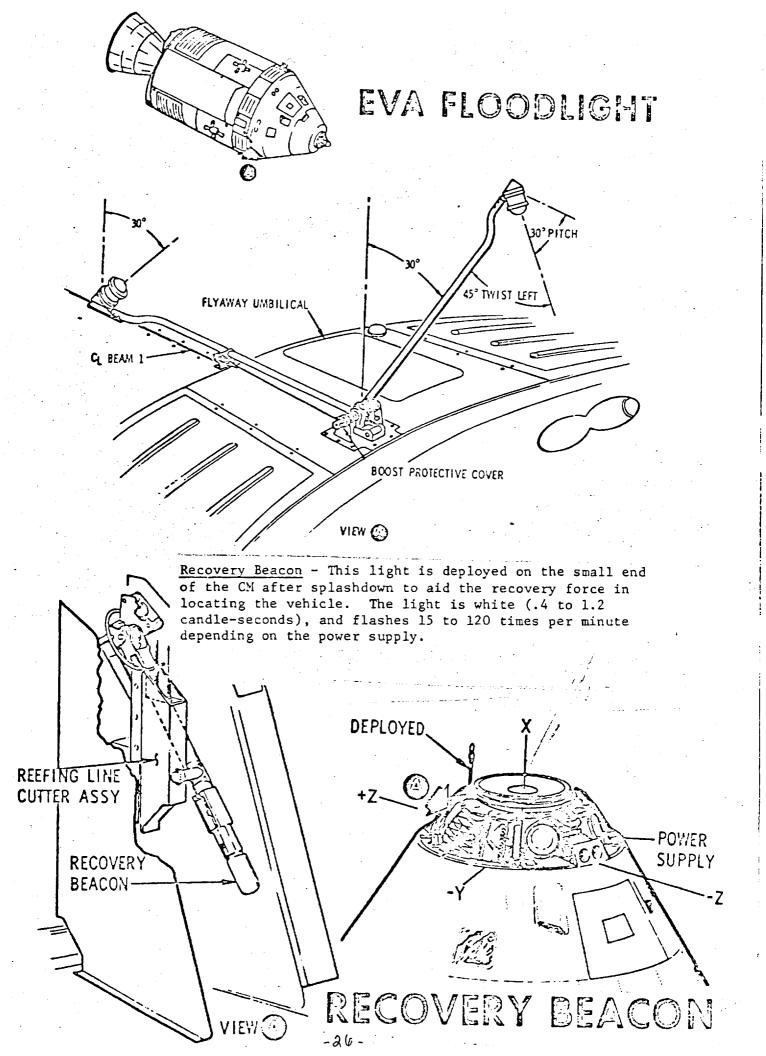


# 3.1.3 Exterior Lighting

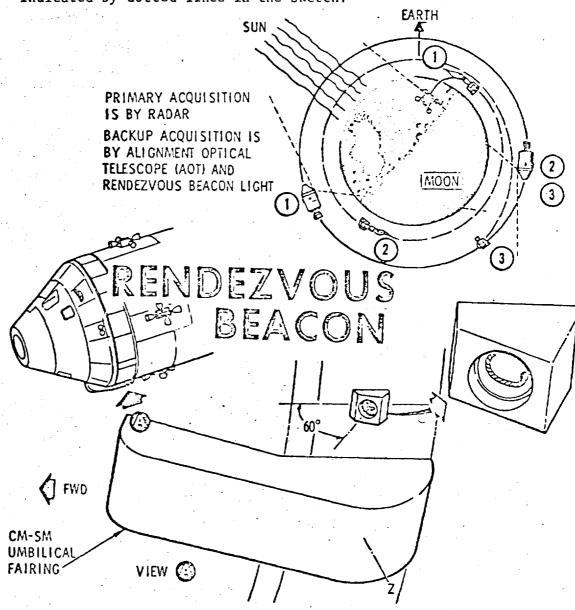
The following external lighting will exist on the CSM.

- 1 Exterior Spotlight
- 1 Rendezvous Beacon Light
- 8 Running Lights, 2 red, 2 green, 4 yellow
- 1 EVA Floodlight
- 81 RL Discs, 60 on docking ring, 21 on exterior handles
- 1 Recovery Beacon (Deployed during recovery phase only).

Exterior Spotlight - The exterior spotlight is mounted on the EVA compartment door near the forward end of the SM at approximately 180 degrees roll position. This light is a 5 VDC, 5000 beam candlepower white light used for illuminating the LM during CM active docking. The light illuminates the LM with .01 foot candles, or more, at a CSM/LM separation distance of 400 ft. The beam is a 10 degree cone. EXTERIOR SPÓTLIGHT VIEW 🕥

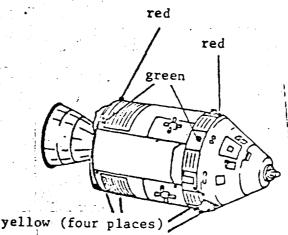


Rendezvous Beacon Light - This is a Xenon white flashing light mounted near the forward end of the SM at an approximate roll position of 78 degrees. The minimum intensity rating is 120 beam candle-sec minimum. The light flashes 55±5 times per minute with a 20 millisecond maximum pulse width. The cone of radiation is 120 degrees. One edge of the cone is nearly parallel to the x-axis of the CSM, as indicated by dotted lines in the sketch.



Running Lights - There are eight running lights for visual attitude reference mounted on the CSM, four on the forward end of the SM, four at the aft end of the SM. The colors, locations, intensities, and quantities are tabulated below:

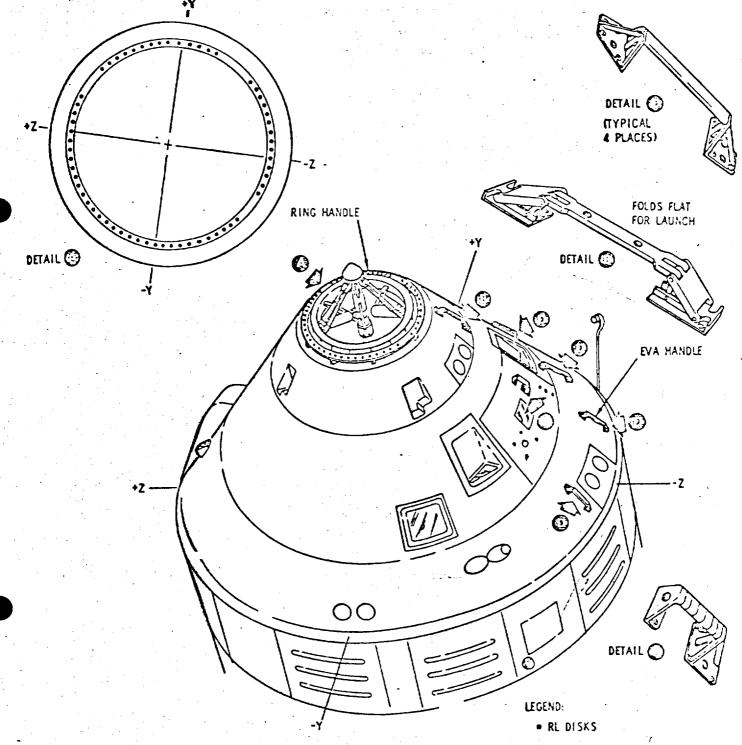
Color	Qty	Candlepower	Location on SM
Yellow	4	0.23	Bottom
Red	2	0.15	Left Side
Green	2	0.15	Right Side



Running Lights (Red, Green, Yellow)

EVA Floodlight - The EVA floodlight fixture is mounted on the CM between the right rendezvous and side windows, near 180 degrees roll location. The light is mounted on a 24 inch pole that is automatically extended after the space-draft has been inserted into earth orbit. The light is oriented to illuminate the CM side hatch, right-side EVA handrails, and LM EVA transfer handrails. The light provides 0.2 to 0.5 foot candles of white light at the SM/CM interface. The purposes of the EVA floodlight are to provide illumination of the CM exterior to aid the crew in performing EVA tasks, and to serve as a docking floodlight to aid in LM active docking.

Radioluminescent (RL) Discs - Eighty-one RL discs are mounted on the CM as visual aids to EVA and docking. Sixty discs are located on the docking ring, 21 on exterior handles. Each disc provides 0.6 ± 0.1 ft lamberts of green light.



EVA HANDLES AND RL DISKS

TABLE I .- ILLUMINATION COLOR AND BRIGHTHESS

•		-			
Component	Primary lighting	Transillumination color	Brightness at rated capacity	Brightness adjustment	Color under inclient illumination
		In	Internal		
ushbuttons — panel nomenclature displays and controls	Integral Ef. pri- mary, preferred	White,	0.5 : 0.2 ft-L	Continuous from O fc-L (0.01 minimum)	Control panels Gruy 36231 Pushbuttons Background: black 37038, gruy 36076 Characters: white 37875
aster alama	Integral (incan- descent)	Aviation red (per MIL-C25050A)	100 +50 ft-L	Fixed	Background: translucent gray 36076, white 37375 Churacters: black 37038
arning annunciators	Integral (incandescent)	Aviation red (per MJL-C25050A)	50 · 10 ft-L	Continuous from 1.5 t 0.5 ft-L	Background: translucent gray 36076, white 37375 Characters: black 37039
aution annunciators	Integral (incan- descent)	Aviation yellov (per MIK C25050A)	50 * 10 ft-L	Continuous from 1.5 * 0.5 ft-L	Background: translucent gray 35076, white 37375 Characters: black 37039
component caution	Integral (incan- descent)	Aviation yellow (per HIL- C25050A)	15 * 3 ft-L	Continuous from 0.05 * 0.02 ft-L	Hackground: tronslucent gray/white
Status annunciator	Integral (EL or incandescent)	Aviation white	10 * 3 ft-L	Continuous from 0.02 * 0.01 ft-L	Rackground: translucent grey 36076, white 37375 Legend: black 37036
Advisory annunciator	Integral (EL or incandescent)	Aviation white (green)	10 +2 ft-L	Continuous from 0.02 t 0.01 ft-L	Background: translucent gray 360%, white 37875 Legend: black 37033
Flags 2 position	Integral Eb	White background  X = 0.330 · 0.030  Black opuque  Striping ener-	0.5 + 0.2 ft-1	Continuats from 0 ft-t	Alternate black 37039 and white 37679 Striping coergized, gray 3631 Deenergized
			•		

TABLE 1.- ILLUMINATION COLOR AND BRIGHTHESS - Continued

Composient	Primary lighting method	Transillumination color	Brightness at rated capacity	Brightness adjustment	Color under Incident illumination
Meter (color coding of lighted displays and controls)					
) /	Silhouette or EL flood- light (inte- gral)				Black 37030, yellow 33538, red (rocket)
_ <del></del>	Integral EL	White X = Y = 0.330 * 0.030	0.5 * 0.2 ft-L	Continuous from 0 ft-L	Black 37038, white 37875 /
	Integral	White X = V.330 * 0.030	0.5 * 0.2 ft-L	Continuous from 0 ft-L	Black 37038, white 37875/
Time-shared labels and multipliers	Integral	Green, wavelength: 5000 to 5300 Å	8 ft-L minimum	Continuous from O ft-L	
Range murkings	Integral (incandescent)	Aviation green	20 * 5 ft-f.	Continuous from 0 ft-L	
Display malfunction Indicator lights	Integral (incan- descent)	Avintion red	20 · 5 ft-L	Continuous from 0.05 to 1.	Translucent gray/white
Circuit broaker	Flood	Unite $X = Y = 0.300 t$ 0.03	0.5 * 0.2 ft-L	Continuous from O ft-L	Background: black 37038 Charucters: white 37875
Alphanwaeric read-outs I	Integral EL	Green, dominant vavelength: 1900 to 5300 Å	7 to 18 ft-L	Contimous From 0.02 * 0.01 ft-L	Background: grmy 36076

TABLE I.- ILLUMINATION COLOR AND BRIGHTHESS - Continued

Component	Primary lighting method	Primary lighting Transillumination Brightness at method color rated capacity	Brightness at rated capacity	Brightness adjustment	Color under incident illumination
Self-luminous devices, RL switchtip	RL	Green, wavelength: At launch 5150 +250 & 0.05 +0.03 10.05 -0.00 Initial 0.1 * 0.03	At launch 0.05 +0.02 ft-L Initial 0.1 * 0.02 ft-L	Fixed	Pale green
flood- lighting	fluorescent	White, unfiltered 30 4 10 ft-L	30 * 10 ft-L	Continuous from O ft-L	
CM utility light	Portable, incan- descent	, incan- White, unfiltered 0.2 ft-c mini-t	0.2 ft-c mini- mum at 3 ft	Fixed	

#### 3.1.4 Interior Surfaces

Panels are gray (Main Display Console, display panels on forward bulkhead). Other surfaces are pale blue-gray. Both kinds of surfaces are diffuse. Estimated reflectivities are 10% for the gray surface, 50% for the lighter colored surface.

#### 3.1.5 Command Module Interior Lighting

The command module interior lighting system furnishes ambient light for activities in the couch and LEB areas; back-lighted panel lighting to read nomenclature, indicators, and switch positions; and lights for tunnel activities. Table I presents a summary description of interior lighting components, colors, brightnesses.

The lighting systems to comply with the above are the CM floodlight system, the electroluminescent integral/numerics lighting system, and tunnel lighting. Lighting for under the couches will be furnished by a portable light.

Floodlights - The floodlight system consists of six variable brightness fluorescent floodlight assemblies. The lights are used to light the Main Display Console left and right areas, and the Lower Equipment Bay area.

Electroluminescent Lighting (EL) - White EL lights are used to back-light panels to read nomenclature, indicators, and switch positions.

Tunnel Lighting - The tunnel lights furnish ambient light for CM tunnel activities. There are two light fixtures in the tunnel, each containing two incandescent lamps.

Portable Floodlight — The portable floodlight provides light for crew activities between the couches and the aft bulkhead. The assembly consists of a handheld incandescent floodlight and a 12-foot power cable with a connector. The floodlight is approximately 5 inches long, and made of aluminum. The lamp unit has four lamps electrically wired in parallel and physically separated into two sets.

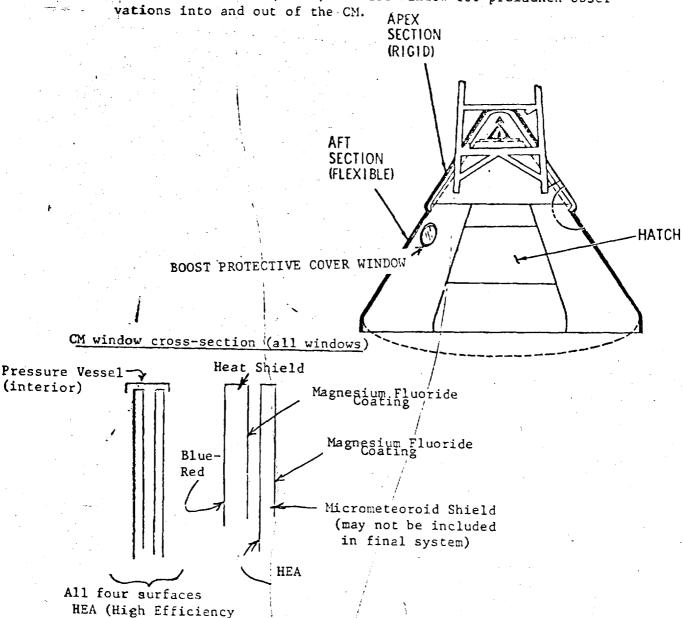
#### 3.1.6 Windows

The CM has four windows, two oblong-shaped forward windows, and two square-shaped side windows. The window dimensions, locations, pane thicknesses, are shown in figure 3.1.6-1. All windows have the same cross-section. For completeness, this figure includes the quartz micrometeoroid shield which current planning has eliminated. Optical transmission of the shield is unity for the entire visible spectrum, for practical purposes.

The spectral responses of the individual panes and the combined panes are presented in figures 3.1.6-2 (pressure window, two panes), 3.1.6-3 (thermal pane), 3.1.6-4 (micrometeoroid pane), and 3.1.6-5 (total window, four panes). The measurements were made on virgin samples and do not reflect degradation of any kind. The incident and tramsmitted light was normal to the window surfaces. Transmission through the system is linearly degraded by approximately 2% for each 15 degrees off-normal incidence angle up to about 45 degrees, then degrades more rapidly. The windows were coated as they will be on the flight hardware.

The commander's forward window (LH rendezvous window displays S/C attitude and horizon reference marks in accordance with the drawings presented as figures 3.1.6-6 and 3.1.6-7.

The Boost Protective Cover contains an 8" diameter clear window over the left-hand (CDR's) forward window for prelaunch observations into and out of the CM.



-34.

Antireflective)

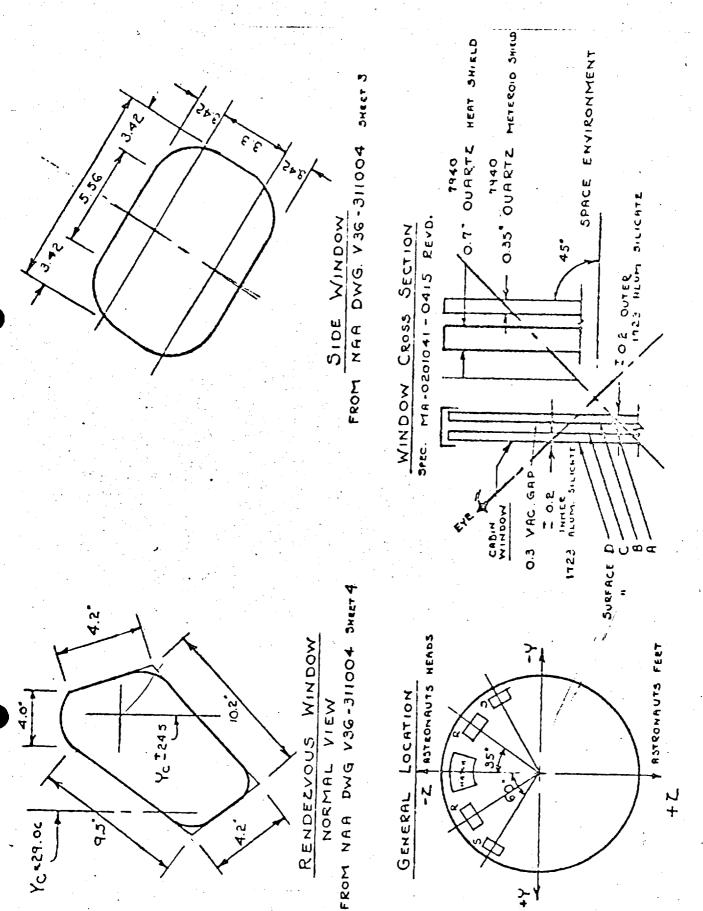
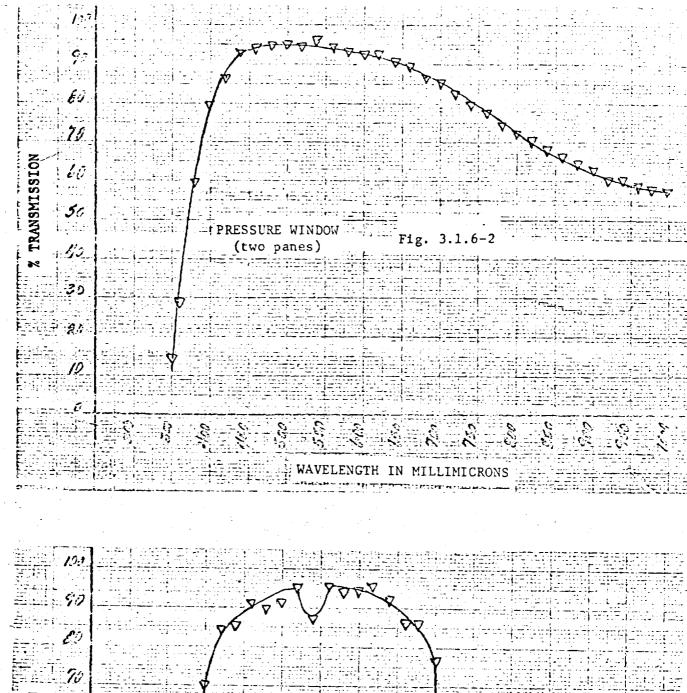
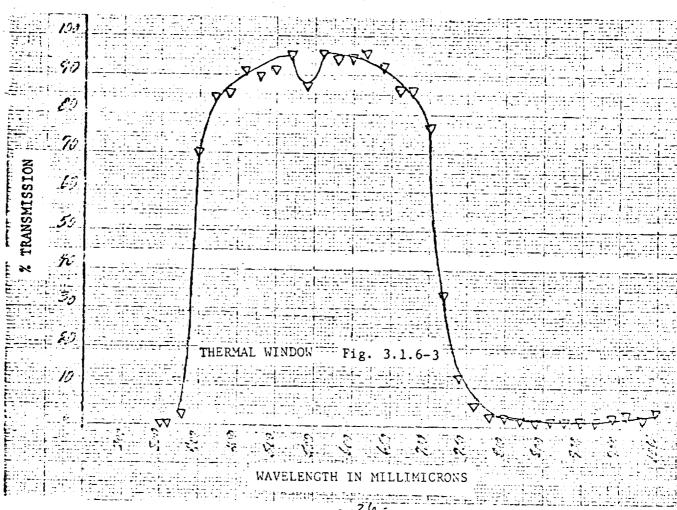
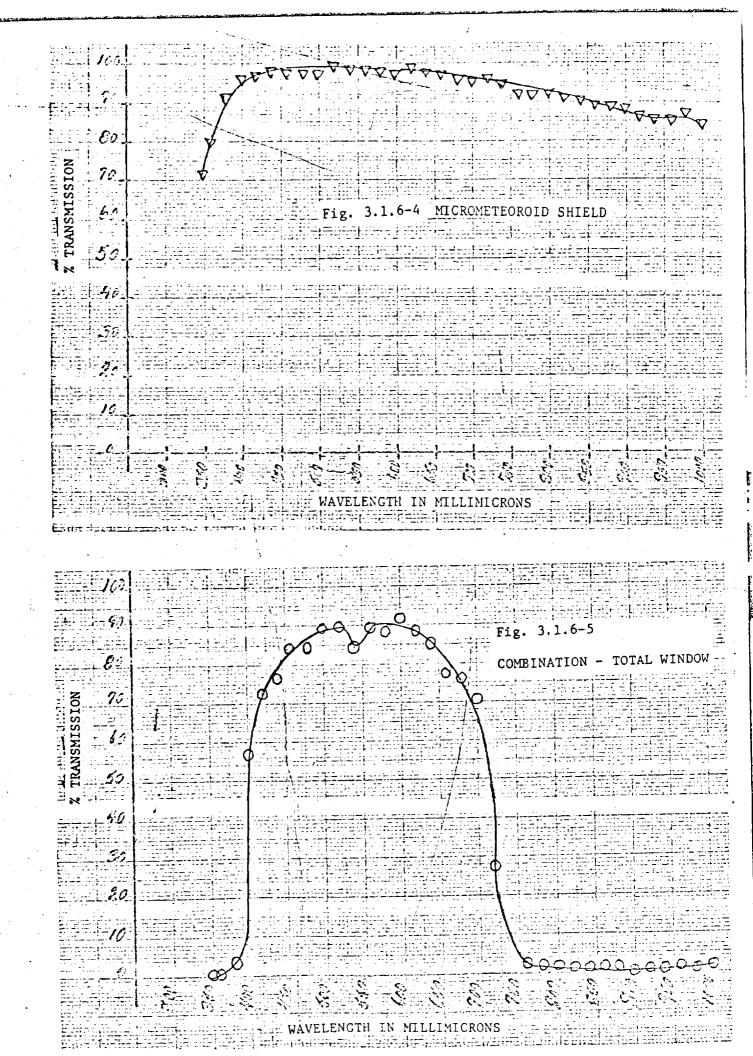
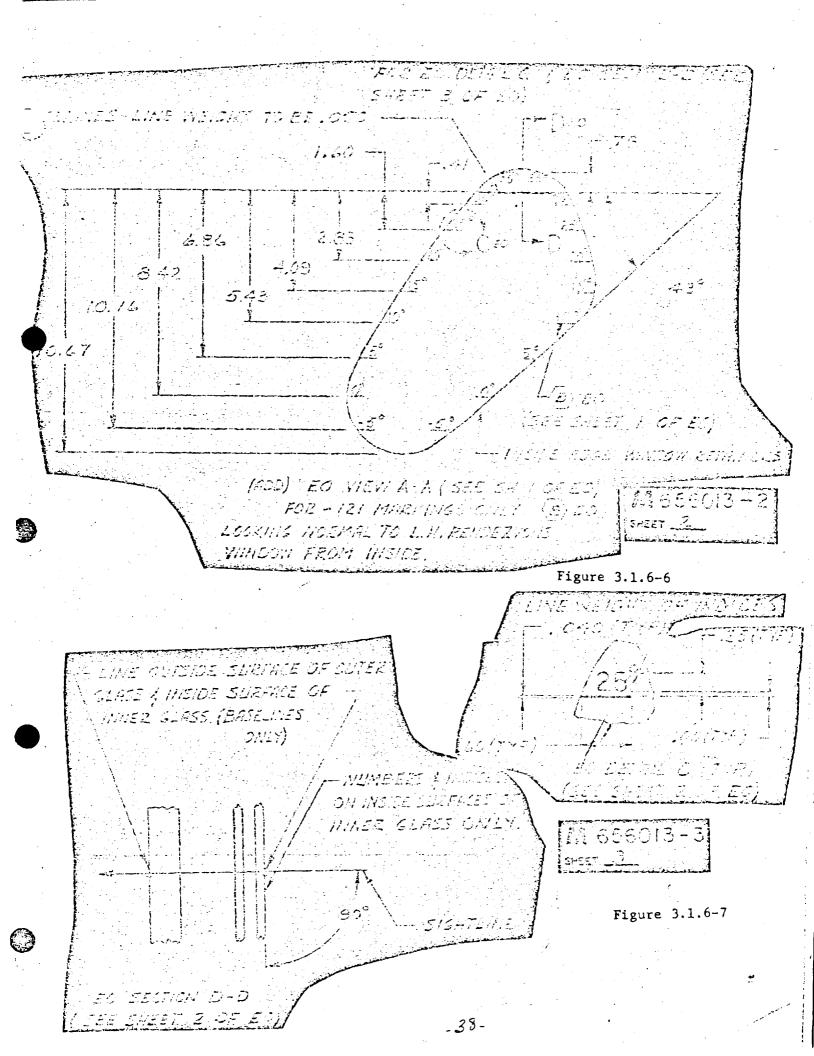


FIGURE 3.1.6-1





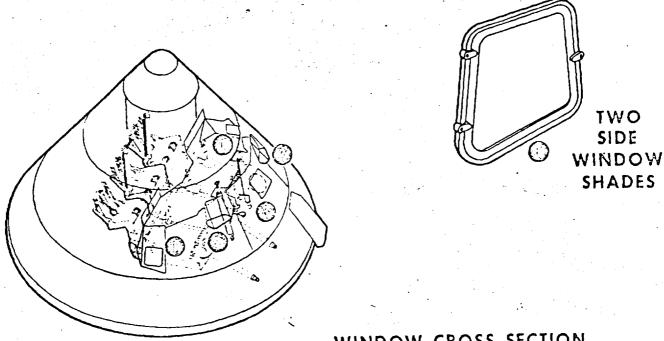




## 3.1.7 Window Shades

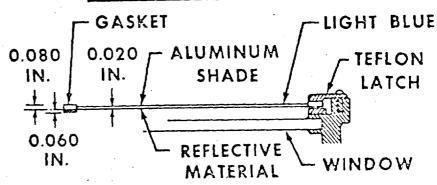
The CM has four windows: two triangular-shaped, forward; two square-shaped side windows. Periodically, the light coming through these windows has to be restricted. This is accomplished by window shades. See figure below.

The window shades are aluminum sheets held on by "wing" latches. The shades are 0.20" thick with a frame of 0.0080. The shade has a gasket on the "light" side which seats against the window. The shades are stowed in a stowage locker in the upper equipment bay.



# WINDOW CROSS SECTION



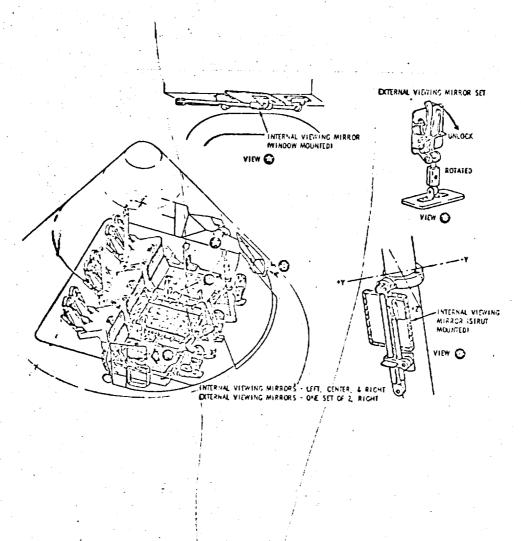


#### 3.1,8 Mirrors

There are two mirror subsystems: internal viewing mirrors and external viewing mirrors.

Internal Viewing Mirrors - When the astronaut is in the pressure suit pressurized, and on the couch, his field of vision is restricted by the helmet neckring in the footward direction. He can see only to the lower edge of the main display console (MDC), thus "blanking out" his stomach area where his restraint harness buckling and adjustment takes place. The function of the internal viewing mirrors is to aid the astronaut in buckling and adjustment of the restraint harness, and locating couch controls.

There are three mirrors, one for each couch position. The mirrors for the left and right astronaut are mounted on the side of the lighting and audio control console above the side viewing window and fold. The center astronaut's mirror is mounted on the left X-X head attenuator strut.



The mirror assembly consists of a mounting base, a two-segmented arm, and a mirror. The mirror is metal, rectangular (4 by 6 inch), flat, with a demagnification factor of 1:1. The two-segmented arm allows a reach of approximately 22 inches from the mount. The arms have swivel joints with a friction adjustment to position the mirrors to the desired orientation. The friction is adjusted with a torque set driver. The mirrors are locked in position by a clamp during boost and entry.

External Viewing Mirrors (CFE) - It is desirable to positively verify deployment of the parachutes during entry. With the couches in the 96-degree, or boost position, the left and right astronaut's view through the rendezvous window is restricted to +5 degrees to +42 degrees from the X-axis. One set of external viewing mirrors is installed in the CM right rendezvous window to allow the LM pilot to view the parachute while in the crew couch 96-degree position.

The set of mirrors consists of an upper mirror assembly and a lower mirror assembly. The upper mirror assembly is mounted on the side wall near the upper rim on the rendez-vous window frame. The lower mirror assembly is mounted on the rendezvous window housing near the lower rim of the window frame.

The mirror assembly consists of a mirror and a bracket. The bracket has a short arm with adjustable friction swivel joints that allow positioning of the mirror. The short arm has a lock to immobilize the mirror during landing. The mirrors will have a 1:1 magnification factor and are rectangular in shape.

#### 3.1.9 Crewman Optical Alignment Sight (COAS)

The primary function of the crewman optical alignment sight (COAS) is to provide range and range rate to the CM or LM pilot during the docking maneuver.

The sight provides the crewman with a fixed line-of-sight attitude reference image which, when viewed through the forward window, appears to be the same distance away as the target. This image is boresighted (by means of a sight mount) parallel to the centerline (X-axis of the CM) and perpendicular to the Y-Z plane. A secondary use of the COAS is for vehicle orientation by observation of a known star.

COAS Description (Figure 3.1.9-1) - The crewman optical alignment sight (COAS) is a collimator device, similar to the aircraft gunsight, weighing approximately 1-1/2 pounds, is 8 inches long and requires a 28-vdc power source. The COAS consists of a lamp with an intensity

control, reticle, barrel-shaped housing, mount, combiner assembly, and a power receptacle. The reticle consists of a 10-degree circle (figure 3.1.9-1), vertical and horizontal cross hairs with 1-degree marks, and an elevation scale (on the right side) of -10 to 0 to +31.5 degrees.

The COAS is stowed in a mount by the left side window at launch and entry, and other periods as the mission requires.

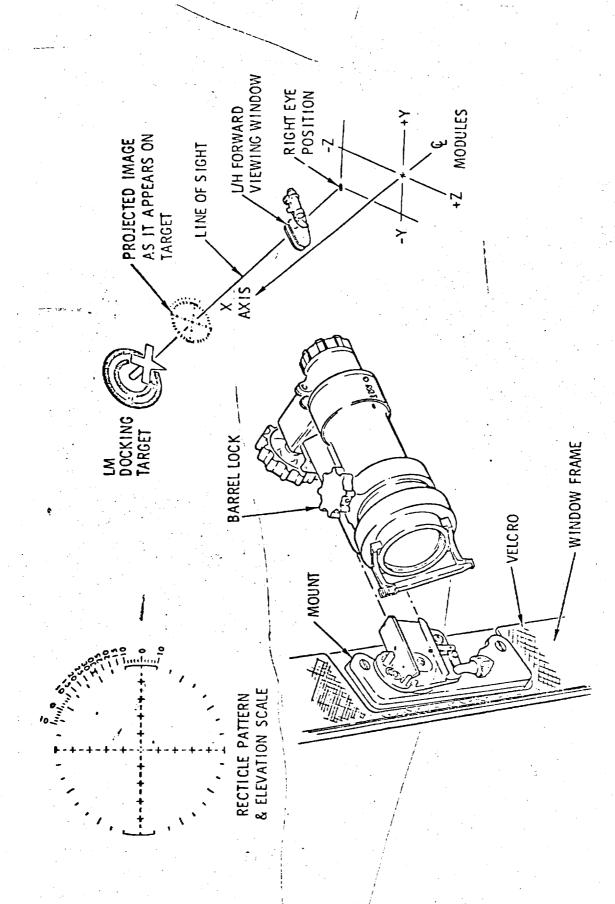
The optical system is collimated so that the parallax of the circular reticle dot is less than one mil per inch of eye movement with respect to an infinitely distant target. The center of the reticle pattern is visible when viewed from any point within a circle of up to 1.5 inches diameter. The parllax error of the reticle ring image is less than 1.5 mils per inch of eye movement with respect to an infinitely distant target.

When viewing a target through the trichroic combining glass, the illuminating lamp, installed behind the reticle, produces a reticle image that is discernible by the unaided eye against a background illumination of 10000 ft-L at a color temperature of 5000 to 5500 degrees Kelvin (or a minimum of 50 ft-L as measured by a photometer). The color content of the illumination has a wavelength of  $5250 \pm 250$  angstroms after being reflected from the trichroic combining glass. The reticle intensity can be dimmed to the point where a fourth magnitude star  $(4.86 \times 10^{-9} \text{ ft-L})$  plus or minus one magnitude  $(1.22 \times 10^{-8} \text{ to } 1.94 \times 10^{-9} \text{ ft-L})$  to be visible within the reticle image.

The COAS can be mounted on the right or left rendezvous window.

Additional Uses - While photographing activities or scenes outside the spacecraft with the 16mm sequence camera, the COAS is used to orient the spacecraft and aim the camera. The camera will be mounted on the right sidewall at a 90-degree angle to the X-axis, and will be shooting out the right rendezvous window, via a mirror assembly.

A constant angle on a star during a differential velocity maneuver can be maintained by use of the elevation scale. The barrel lock is lifted and turned so the barrel can be rotated, and will hold in an intermediate position by friction. The elevation will be read on the elevation scale using the horizontal "line" of the reticle as the index.



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Figure 3.1.9-1: Optical Alignment Sight System Configuration

## 3.1.10 LM Active Docking Target

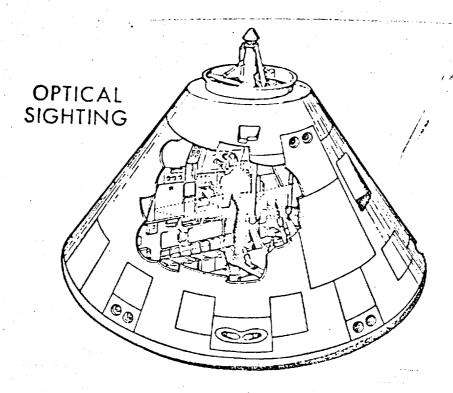
After lunar rendezvous and acquisition, as the LM approaches the CM, the CM orients the small end towards the LM. 50 feet, the LM rotates 90 degrees for the final approach, during which the LM Commander will sight through the overhead window, using the LM COAS for alignment. In nominal docking, relative indexing will align the LM overhead window to the CM right rendezvous window. The LM active docking target will be placed in the CM right rendezvous window to function as a guide to the LM Commander. As an additional guide, red "gross alignment stripes" are painted on the outside surface of the CM adjacent to the right rendezvous window.

LM ACTIVE

Description - The LM active docking target is a collapsible target of the same configuration as the LM docking target but approximately half the size. The base is 8 inches in diameter with green electroluminescent (EL) lamps and a black stripe pattern on the front. The stand-off reference has a red incandescent DOCKING TARGET lamp. The support struts fold for stowage and are held erect by locknuts.

## 3.1.11 Scanning Telescope (SCT) and Sextant (SXT)

The SCT and SXT enable the crew to make optical sightings on celestial objects and landmarks (earth and moon). These sightings are used to align the guidance inertial reference (IMU) and to update the spacecraft's position.



Telescope - The SCT is mounted beside the sextant to permit parallel lines-of-sight through an opening in the spacecraft opposite the side hatch. The unity power SCT with its 60° field of view is used for measuring angles to landmarks during earth orbit, and for acquisition during midcourse.

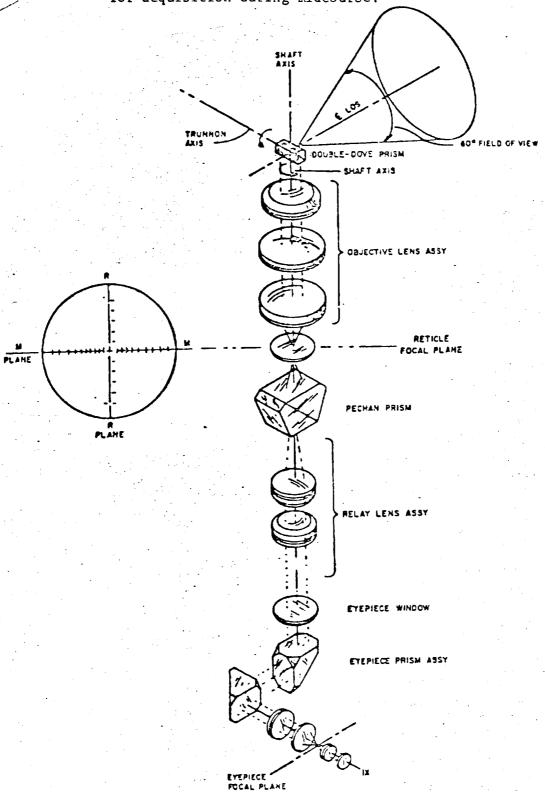


Figure 3.1.11-1 SCT Optical Schematic

Sextant - The 28 power sextant, with its 1.8° field of view and resolution of 10 seconds of arc, is more accurate for angle measurements than the SCT. It is used primarily for aligning the IMU to known star lines-of-sight. It also can be used to obtain backup navigation data by measuring angles between a landmark and a star during midcourse flight, and by tracking objects.

Guidance sightings (IMU alignments) require sightings on two stars (CM and LM). The pair of stars that are to be used for a guidance platform (IMU) alignment must be selected such that the angle between their lines-of-sight from the spacecraft is as large as possible without exceeding the trunnion angular capability of the sextant. If the angle is too large, the spacecraft would have to be reoriented in order to acquire the second star in the sextant field of view because of the trunnion limits. If the angle is too small, the uncertainty in final platform attitude will be excessive. An angle of 60 degrees between star lines-of-sight is the selection goal for an IMU alignment star pair.

Navigational sightings (spacecraft position measurements) require star/earth landmark pairs to be sighted with the sextant. The sextant has a "landmark lineof-sight" fixed to the spacecraft and a variable "star line-of-sight" fixed to the spacecraft and a variable "star line-of-sight" (index mirror angular position controlled by the shaft and trunnion). The landmark must first be sighted by orienting the spacecraft to align the "landmark line-of-sight" (which is fixed with respect to the spacecraft) toward the landmark. Then the star can be sighted by varying the sextant shaft and trunnion angles to position the sextant's index mirror perpendicular to the star/spacecraft lineof-sight. The shaft and trunnion angular freedom requires that the star selected for a star/landmark navigational sighting be within about 50 degrees. is evident from Figures 3.1.11-2/3, and 4.

Spectral responses of the SCT and the SXT (star line-of-sight and landmark line-of-sight) are not currently available. G & N Procurement Specification 2016207, Rev. H, dated 3-3-68 states that the luminous transmittance of the SCT must be 30% or more, that of the SXT star line of sight 25% or more, and that of the SXT landmark line

of sight 3.2% or more. The Spec. further requires that with the landmark line of sight filter installed, the ratio of the luminous transmittance of the SXT star star line of sight to that of the landmark line of sight must be at least twelve to one. These numbers are with respect to CIE illumination C.

The SCT and SXT star line-of-sight have no significant color filtering (approximately equal transmission of all visible wavelengths), but the SXT landmark line-of sight is filtered such that the field of view appears red-tinted.

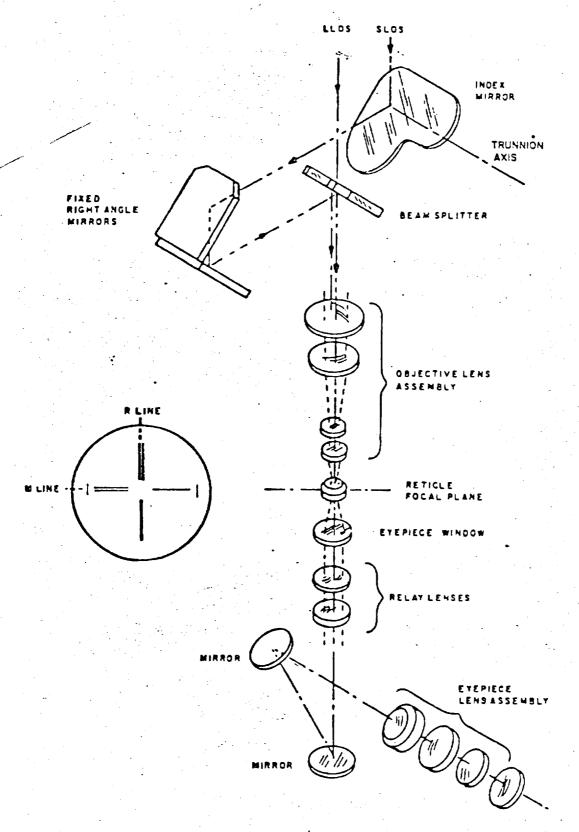


Figure 3.1.11-2 SXT Optical Schematic

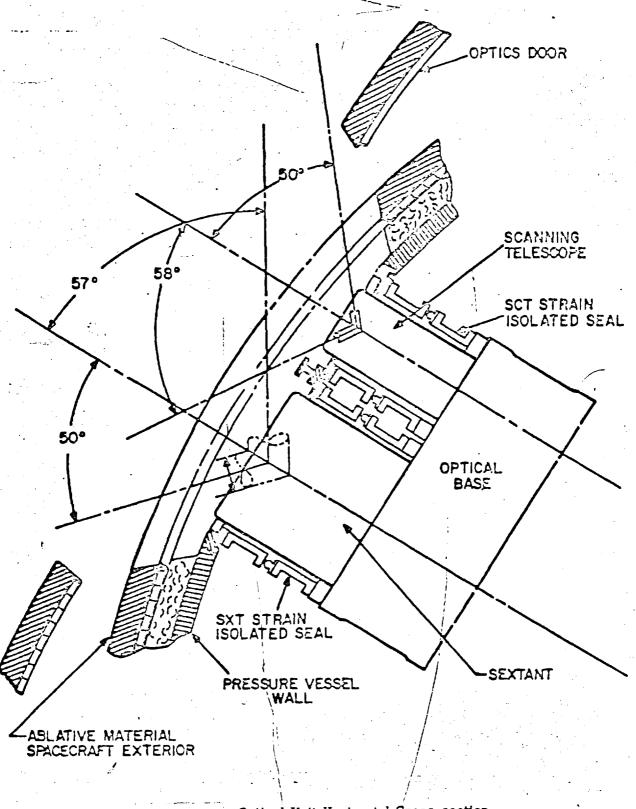
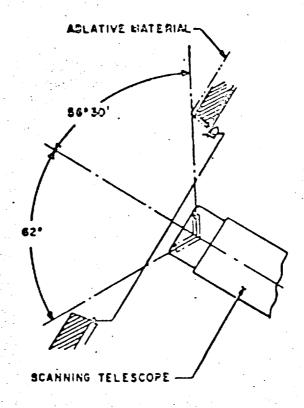


Figure 3.1.11-3 Optical Unit Horizontal Cross-section



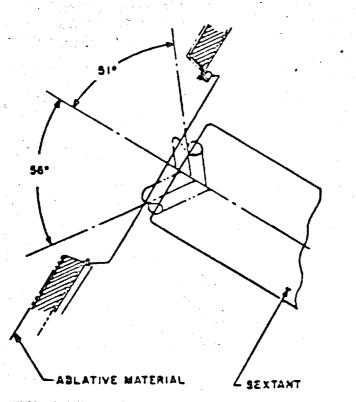


Figure 3.1.11-4 SXT and SCT Vertical Cross-section

## 3.1.12 <u>Cameras</u>

The photographic equipment to be loaded aboard the CM, includes:

'16 MM Data Acquisition Camera and Film Magazine - This is the same type of 16 mm camera as is used in the LM and is described in Section 3.2.15. 5 mm (extreme wide angle), 18 mm (moderate wide angle), and 75 mm (telephoto) focal length lenses are supplied in the CM.

Hasselblad Electric Camera and Film Magazine - Apollo Part No. SEB33100102: Weight 4.04 lb. This camera is the basic operational camera of the mainline Apollo and the Apollo Applications Programs and will replace the 70 mm Hasselblad 500 C P/N SEB33100029, on the third manned Apollo mission. The camera with a 200 exposure film magazine attached is shown in Figure 3.1.12-1. A motor drive mechanism powered by two sealed nickel-cadmium batteries advances the film to the next frame and cocks the shutter whenever the camera button is actuated. The electric drive makes possible more rapid exposures and reduces the astronaut's photographic workload. The camera can also be easily used as a remotely actuated unit by using a remote control cable attached to the accessory connector.

The 80 mm focal length lens furnished with the camera is similar to the one used on the 70 mm Hasselblad 500 c camera. The lens can be focused from three feet to infinity with a field of view of 37.9° on a side, has a diaphragm aperture range of f/2.8 to f/22 and is capable of shutter speeds of 1/500, 1/250, 1/125, 1/60, 1/30, 1/15, 1/8, 1/4, 1/2, 1 second, and time exposure. The aperture, shutter speed and distance scales are capable of being rotated by means of individual finger tabs. Unlike earlier space flight adapted versions of this lens, the commercial synchronizer contact and mechanism have been retained for use as a shutter actuation indicator for scientific data requirements. True X-synchronization is provided by this contact thus making the use of electronic flash possible.

The camera batteries, P/N SEB33100174, are sealed, epoxy covered nickel-cadmium cells each rated at 6.25 volts with 500 millampere-hour capacity. The two batteries provide enough energy for at least 2000 complete camera cycles under normal temperature conditions. They can be recharged many times in the laboratory, either in or out of the camera. At present no provisions exist for recharging these batteries in flight; however, the batteries can be easily replaced in flight for extended camera usage.

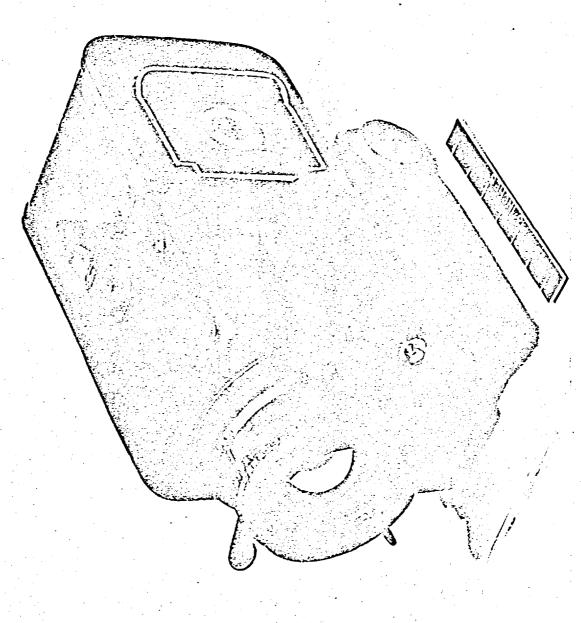
An accessory connector on the camera can be used for remote camera actuation, indication of camera operation, supplying power to the camera from an external source, and battery charging. The connector is a Deutsch, UR40-8-75; the mating plug is a Deutsch, UR46-8-7P. A unique application of this connector and the camera circuit is the electrical interconnection of two or more cameras for simultaneous actuation. This feature can be used for stereo photography with two cameras or for multi-band photography with a large array of cameras. Details of the electrical circuit and accessory connections may be obtained from Mission Operations Branch personnel.

The film magazines used with this camera are the same as those used with the LM super wide angle Hasselblad and are described in Section 3.2.15.

Haze Filter - This filter is designed to produce good color rendition on photographs of the earth by blocking light 3400 angstroms and shorter in wave length. The filter transmittance in the visible wavelengths is approximately 1.0; therefore, no exposure corrections are required.

<u>Red Filter</u> - This filter will increase contrast in terrain photographs made with black and white film.

Spotmeter—The spotmeter is a hand-held instrument used for obtaining exposure settings outside the spacecraft. It has a very narrow '(1°) field of view, permitting accurate exposure determination for distant objects against a very dark or bright background. The model now listed for CM loading is a manually operated unit such as was used on the Gemini flights. It is expected, however, that the new automatic model now listed for LM loading will be approved for CM usage before the manned lunar landing. A description of the automatic spotmeter appears in Section 3.2.15.



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## 3.2 LUNAR MODULE (LM)

## 3.2.1 General Description and Coordinate System

A view of the LM exterior and the positive directions of its body coordinate axes are presented in Figure 3.2.1-1. The origin of the coordinates is located 200 inches below the ascent stage base. The visibility-related features of the exterior include the windows (left and right triangular forward windows and a rectangular overhead docking window), the lights (docking lights and flashing tracking light), the docking target (the vertically protruding "T" shaped device in the upper right portion of the figure), and the geometry and coatings of the various external surfaces.

A view of the interior of the LM, looking forward, is presented as Figure 3.2.1-2. The visibility related features shown in this view include 4 of the flood lights (two overhead and two above panels 5 and 6, beneath the forward windows), the instrument and control panels, the windows, the glare shields, and the alignment optical telescope eyepiece. Also shown are the overhead receptacles where one or both of the two portable utility lights can be mounted.

#### 3.2.2 Exterior Surfaces

The LM exterior surfaces are shown in Figures 3.2.2-1, 3.2.2-2 and 3.2.2-3 (ascent stage), and 3.2.2-4 and 3.2.2-5 (descent stage). The surface coatings can be found listed in Table 3.2.2-1 under the numbers shown in the figures. All surfaces not designated by a number have the number "1" coating (except windows and motor nozzles).

## 3.2.3 Exterior Lighting

The positions of the exterior lights (docking and tracking) are shown in Figures 3.2.3-1, through 3.2.3-4. The types, colors and brightnesses are listed in Table 3.2.3-1. The tracking light flashes at a rate of 60±3 flashes per minute, with a maximum flash duration of 20 milliseconds.

## 3.2.4 <u>Interior Surfaces</u>

Colors - Instrument Panels have white markings on a medium gray (no. 36231 of FED-STD 595) background. Bezels are also no. 36231 gray. Most display faces have either black markings on a white background or white markings on a black background.

Contrast - Contrast between white and black combinations is at least 9 units and contrast between gray and white combinations is at least 1.7 units, measured in accordance with MIL-P-7788A.

Gloss - All interior surfaces (excluding glass) within the crew's normal field of view have a gloss not greater than 5 units as measured by ASTM method D523 as indicated in MIL-P-7788A.

Letters and Numerals: Letters and numerals applied to controls and displays are "FUTURA DEMI-BOLD" commercial style. Minimum letter height is .125 inches.

## 3.2.5 Interior Lighting

The interior components that are lighted, their methods of illumination, colors, brightness, and dimming capabilities are listed in Table 3.2.5-1.

Other information regarding interior lighting:

Floodlight Positions - The floodlights include

- 1) Overhead Lights One each above panels 1 and 2 These can be seen in Figure 3.2.1-2.
- 2) Forward Lights One each above panels 5 and 6 These can be seen in Figure 3.2.1-2.
- 3) Side Panel Lights A total of over 30 lights recessed above the rows of side panel controls and displays. These cannot be seen in Figure 3.2.1-2.

Illumination Controls - A 3-position maintain toggle switch on the Systems Engineer's lighting panel turns all floodlights on (including side panel floods) in the ALL position. In the OVHD/FWD position, only the overhead and forward floods light. In the OFF position, all of the floodlights are turned off.

- Dimming Controls Dimming shall be provided for the overhead and forward floodlights only. The side panel floodlights shall not dim, but may be turned off independently of the other floodlights by placing switch 16-S-6 in the OVHD/FWD position. A rotary control (16-R-4) shall regulate the intensity of the Systems Engineer's overhead and forward floodlights when switch 16-S-6 is in the ALL or OVHD/FWD position. A rotary control (16-R-1 on the Commander's lighting panel) shall regulate the intensity of the Commander's overhead and forward floodlights when switch 16-S-6 is in the ALL or OVHD/FWD position.
- 2) Docking Hatch Switch An upper hatch switch (16-S-11) shall be provided to automatically energize the overhead and forward floodlights or all floods (depending on the position of switch 16-S-6) when the hatch is opened. The intensity level will be established by the dimming control setting.
- 3) Portable Utility Light This is a small (about 3" X 2" X 1-1/2") two-lamp light which can either be hand held consecured by a clamp at various positions in the spacecraft. It is connected by a plug in power cable to a 28 VDC supply. The weight is about 5-1/4 oz. The brightness at the center of the two combined beams

at a distance of three feet is about 7-1/2 foot-candles. The lamps used are incandescent, with illumination color temperature of  $2850^{\circ}$  K  $\pm$   $200^{\circ}$ K.

## 3.2.6 Windows

There are three windows: two triangular forward viewing windows and one smaller rectangular window above the commander (used for docking).

Field of View - The commander's field of view is diagrammed in Figure 3.2.6-1. Figure 3.2.6-2 shows the increase in viewing angles through the overhead window due to considering binocular viewing rather than monocular.

Thicknesses and Coatings - The forward windows have two panes; the outer pane is made of Dow-Corning Vycor code 7913 glass and the inner of Dow-Corning Chemcor chemically strengthened code O312 glass. The thicknesses and coatings applied are as shown in Figure 3.2.6-3. The "blue-red" coating reflects very little radiation in the visible region of the spectrum, but more than 99% of ultraviolet radiation (below 400+ 15 millimicrons) and about 90% of the infrared radiation (from  $800\pm50$ millimicrons to 1.3 microns). The high efficiency antireflective (HEA) coating (alone) provides 99.5% transmittance per coated surface (the uncoated surface transmits 95.8%). The electrically conducting (EC) coating serves as a heat source for defogging the panels. To obtain uniform heat dissipation, the coat has a graduated thickness, resulting in a panel having a variegated color pattern. The net **ill**uminent C transmission falls in a range from 75% to 88% as the different color areas are scanned. The average total transmittance of both panels with all coatings applied is approximately 76-77%.

As can be seen in Figure 3.2.1-2, the forward windows are roughly triangular in shape. Their approximate viewing area dimensions are 22" X 22" X 25" (25" along the top edge).

The overhead docking window has two panels of the same thicknesses and with the same coatings as the forward windows. It is rectangular, approximately 12 3/8" X 5 1/8". There is a reticle on the window for the purpose of visually monitoring the lunar horizon upon pitchover during the LM ascent maneuver. Sighting the lunar horizon as an attitude reference, the crewman can use the reticle in controlling the vehicle pitch and roll attitude during launch from the lunar surface. There are two reticles, one on the outer surface of the inner panel and one on the inner surface of the outer panel. The inner reticle is red, the outer one green. The configuration is as in Figure 3.2.6-4.

## 3.2.7 Mirrors

There is one mirror in the LM. It is used to aid the crew in adjusting restraint harnesses and in donning parts of the EMU.

It can be mounted at three locations in the spacecraft: on panel 11, panel 16, or on the DSKY guard on panel 4. The mirror is roughly rectangular (about  $4-1/2" \times 3-1/2"$ ). It is metallic, with a smooth reflective front surface. The back of the mirror is chemically etched in a number of locations to reduce its weight.

#### 3.2.8 Window Shades

The LM has removable shades for all windows made of 5 mils of "ACLAR" uncoated on the cabin side and coated with vacuum deposited  $S_1O/Inconel$  on the window side. In full sunlight the low transmissibility of the shades in the visual spectrum (about 0.1%) results in a low cabin light level for using the alignment optical telescope or sleeping, yet provides some visibility through the windows.

#### 3.2.9 Glare Shields

Two glare shields are provided for the purposes of reducing lighting reflections from internal sources on the windows and direct impingement of sunlight upon control and display panels. They are located at the outside edges of panels 1 and 2 (i.e., between the windows and the forward panels). The size and construction is shown in Figure 3.2.9-1.

#### 3.2.10 Crewman Optical Alignment Sight (COAS)

Description - See Section 3.1.9

Usage in LM - The COAS is one of the docking aids used on the LM. Its primary purpose is to provide an optically projected line-of-sight as an accurate aiming reference for the docking maneuver. The LM Commander will use the projected image reference to align the LM with the CSM during closure for LM-active lunar orbital docking. The procedure is accomplished by controlling the LM attitude and translational motions so as to superimpose the reticle pattern on the CSM-mounted docking target within the required pre-contact alignment docking tolerances. An additional function of the COAS is to provide range and range rate cues when an object of known size (e.g., CSM) is viewed through the reticle. This is done by comparing the apparent size relationship between the object and the projected reticle image. An approximation of range rate requires timing the apparent change in object/reticle marking relationship.

The COAS is used to track the CSM during rendezvous and as a backup for taking star sightings in the event of an AOT failure. There are two mounting provisions for the COAS on the LM: one is above the brow of the Commander's forward window and the other position is at the inboard side of the overhead window. The forward position permits sighting along a line-of-sight parallel to the LM Z-axis, whereas, the overhead position provides an X-axis reference.

As a result of helmet interference with the sight in the overhead position, the sight has been positioned high in the LM cabin (center of the combining glass at X = 291.19). This location places the COAS at an eye distance of 10.6 inches for the 90th percentile individual and 16.5 inches for the 10th percentile individual. At these distances the visible instantaneous field of the reticle is restricted to 7°21' and 4°53', respectively. For this reason, it is recommended that all range estimates be made using a total of 4° or less of the reticle markings, when the COAS is mounted in the overhead position (reference Figure 3.1.0-1). The full reticle may be used with the COAS mounted in the forward window position; however, such a transfer in the operation may cause confusion. For this reason it is probably better to be consistent in limiting range and range rate estimation to the 4° diameter reticle markings for both forward and overhead window sightings.

Four primary targets will be used when tracking the CSM: (1) the CSM circular outline as seen when facing the spacecraft headon, (2) the docking ring (EVA ring hand rail, surrounding the docking tunnel),(3) the roll-alignment cross outside of the CSM docking window, and (4) the CSM-mounted, LM-active docking target located behind the CSM docking window. Table 3.2.10-1 lists the dimensions of the four CSM-mounted targets and their subtended angles at various viewing distances. There is some overlap in the effective range of these targets in all but the transition from the roll alignment cross to the LM-active target. In all other cases the point at which the aiming reference is changed from one target to another is left to the discretion of the astronaut.

At the closer distances (approximately 80 feet separation or nearer) the LM pitch-over maneuver will be made to properly orient the vehicles for pre-contact alignment. The COAS will be transferred from the forward window mount to the overhead mount just prior to pitch-over. An alternate method is to keep the COAS in the overhead position and use the Landing Point Designator (LPD) on the Commander's forward window to estimate range and range rate until the point of pitch-over.

### 3.2.11 Docking Target

The LM-mounted docking target is used with the CM-mounted COAS much as the CM-mounted target is used with the LM COAS as described above (3.2.10). The location of the LM target is shown in Figures 3.2.3-1 through 3.2.3-4. Figure 3.2.11-1 is a drawing of the essential features of the target. The diameter of the outer circle is about 18", and the distance between the "T" and background about 17". The self illuminating disks are green and radioluminescent. Their minimum brightness is specified as 0.5 ft Lambert at lift-off and 0.2 ft Lambert at any time during the mission. The black "T" and circle and white background provide good target visibility for docking with incident lighting.

## 3.2.12 Alignment Optical Telescope (AOT)

The AOT, illustrated in Figure 3.2.12-1, is a manually operated

periscopic instrument having an instantaneous  $60^{\circ}$  field of view and unity power. The coverage capability is provided by means of six shaft axis detent positions which permit rotation of the viewing prism to the center forward position, center rear position, and  $\pm 60^{\circ}$  from these positions. A seventh shaft axis detent permits rotation of the prism in order to protect it, while not in use, under the AOT hood.

The AOT is designed to function as a sextant in the following manner. A specially constructed reticle consisting of a shaft axis orientation line and an Archimedian spiral provides the capability for sequentially measuring shaft angles and trunnion angles with respect to a navigational star or lunar landmark. It may be seen from Figure 3.2.12-2 that this reticle, when rotated about the AOT optical centerline to superimposition of a target star on the shaft orientation line, establishes an angular reading of shaft (i.e., azimuth) with respect to the fixed reference position. This angle turned through ( $\emptyset$  in the illustration) can be read directly from a counter geared to the reticle drive mechanism. Subsequent rotation of the reticle until the target star is superimposed on the Archimedian spiral establishes an angle, fo, which is a measure of radial distance from the center of the field and thus directly proportional to trunnion angle. This measurement is also read directly from the AOT counter and is manually inserted into the computer after multiplication by a proportionality constant which relates counter angle to trunnion.

Primarily, the telescope is to be employed for inertial platform alignment while the LEM is situated on the moon. The procedural usage of the telescope for the required sightings is as follows. Having set the computer and inertial platform complex in the "FINE ALIGN" mode of operation, the navigator identifies a preselected star in the field of view, codes the shaft detent being used into the computer, and then rotates the reticle until the star is superimposed on the shaft orientation line. At this point he depresses the computer "MARK" button, and inserts the counter reading into the computer after multiplying by the proportionality constant. Utilizing the data from two such measurements, on separate navigational stars, the inertial platform may be aligned and an updated estimate of vehicle position may be computed. Figure 3.2.12-3 presents a functional block diagram of the alignment procedure as related to the overall G&N System.

As previously noted the AOT may be employed for refining position and velocity computations while the spacecraft is in Lunar orbital flight. For this phase of operation the LEM attitude drift is controlled roughly through the reaction control engines and the astronaut measures the sighting angle each time the target star crosses the AOT reticle (Figure 3.2.12-4). Such a measurement is accomplished by depressing the computer "MARK" button repeatedly as the star apparently moves back and forth across orthogonal reticle lines due to angular vehicle motion. The counter angle reading for this operation is inserted into the computer via the command keyboard as in the case for celestial sightings while on

the Lunar surface. The orthogonal reticle lines used for this measurement are not shown in the reticle drawing, Figure 3.2.12-2.

A schematic of the AOT optical system is presented in Figure 3.2.12-5. The essential components are the head prism, objective lens assembly, relay lens assembly, beryllium mirror assembly, and eyepiece assembly. Functional and structural descriptions of each assembly follow.

<u>Prism</u> - The purpose of the prism is to reflect a 60° segment of the celestial hemisphere into the telescope objective. Its internal reflections simply divert the image into the telescope, thus acting as a mirror in the system. Two surfaces of the prism are covered with an anti-reflection coating, i.e., the viewing surface and that side nearest the first objective lens. The hypotenuse, which acts as the mirror surface, is not coated nor is it silvered since the element functions by totally internal reflections.

Functionally the prism is fixed in elevation and movable about the shaft axis to any of the six viewing detent positions and one protective detent position as previously described. The prism is integrally mounted to the telescope inner tube and moves in conjunction with its rotation.

Objective - The objective lens assembly consists of six spherical elements and one aspherical field lens. Its purpose is to focus the image at the first focal plane on the eyepiece side of the field lens. Image magnification by the objective assembly is five power. This is counter-balanced by the eyepiece (also five power) such that the image viewed at the eyepiece exit pupil has unity magnification.

An anti-reflection coating is applied to the exposed side of each objective lens element as is the case for all lenses in the system. Additionally, a black coating is applied to the periphery of each objective element for the purpose of eliminating scattered light in the optical path. The single aspherical field lens serves to collect divergent rays from the image and present these to the relay assembly.

Relay - The optics for the relay lens assembly consists of six elements contained in two separate symmetrically constructed cells. The functional purpose is to collect image rays from the objective and focus them at the second focal plane coincident with the AOT reticle.

In order that the relay assembly may be adjusted during telescope fabrication it is constructed in two cells. By adjustment of the spacing between cells the overall power of the instrument is calibrated and image focusing on the second focal plane is accomplished. The aperture located between these cells functions as a field stop.

Mirror - A plano beryllium mirror is positioned at 45° to the AOT shaft axis. It serves to turn the light rays through 90° for imaging at the second focal plane. After reflection from the head prism and this beryllium mirror the image viewed at the eyepiece exit pupil is erect, non-reverted in the forward shaft detent position. As the head prism is rotated about the shaft axis to either of the five alternate detents the angle of its reflecting surface (prism hypotenuse) changes with respect to the beryllium mirror surface. As a result the field viewed appears to be tilted 60° right for the right side detent and 60° left for the left detent. Compensation for angles measured with the AOT reticle in the alternate detents is accomplished by manually transferring to the computer, via the keyboard, a code indicating the shaft detent being used for any particular sighting situation.

A plano-plano window is located directly above the beryllium mirror. It serves as a seal between the unpressurized telescope proper and the eyepiece section which is at ambient LM cabin pressure.

Eyepiece - The monocular eyepiece provides for viewing the star image and reticle pattern at an exit pupil roughly 1.5 in. behind the last lens element. The optical components are three doublets, an etched reticle element and a reticle cover. Functionally, the eyepiece magnifies the one fifth size star image presented at the focal plane and enlarges the reticle pattern to five times actual size.

Two eyepieces are included in the LM telescope design. The standard eyepiece (i.e., that is shown in the optical schematic) is for use with the spacesuit visor opened. A second long eye relief eyepiece, interchangeable with the first by means of a bayonet connection mechanism, is for use with development of a special dual purpose eyepiece which may be used with the space suit visor in the closed position.

# 3.2.13 Landing Point Designator (LPD)

The landing point designator is a visual aid that furnishes the LM pilot with a visual correlation between/computer output symbols defining the landing site to which the LM is being automatically guided during the final approach phase and the view through the window of the lunar terrain. It is in the form of reticles on the inner and outer commanders forward window as shown in Figure 3.2.13-1. In this view the entirety of the two reticles is superimposed; i.e., the view is from the point where the images of the larger, outer reticle and the smaller, inner reticle converge. This superimposition of reticle and lines establishes the line-ofsight angle between the LM and whatever appears on the surface behind the superimposed lines. The device is used as follows: The LM pilot calls out coordinates displayed on the DSKY to the commander which lefine, in terms of the reticle markings, the spot on the lunar surface to which the LM is being guided. The commander observes the site, using the reticles. If he thinks

the spot unacceptable, or sees an obviously better site within his redesignation capability, he commands the computer, using his hand controller, to aim the LM toward the more desirable site. The attitude changes can be made in increments of 2° of pilot yaw and 0.5° of pilot pitch. The above procedure is repeated until the computer-generated coordinates indicate an acceptable landing site.

## 3.2.14 Landing Site Recognition Aids

Although some form of landing site recognition aid is thought to be desirable, such aids do not as yet exist. Work is in progress to define the requirements for the aids.

## 3.2.15 <u>Cameras</u>

The photographic equipment to be loaded aboard the LM for the manned lunar landing mission according to the latest flight equipment allocation (30 Jan.1968) includes a 16 mm data acquisition camera, 18 mm lens, 16 mm data acquisition magazine, lunar surface super wide angle (SWA) camera, 70 mm film magazine, polarizing filter, and automatic 1° spotmeter. No photographic equipment is now scheduled to be transferred from the CSM to the LM. A television camera will also be carried aboard the LM.

16 MM Data Acquisition Camera (Part No. SEB33100100) - This camera is designed to perform in both the spacecraft environment and in the hard vacuum of space. The unit, designed and manufactured by J. A. Maurer, Inc., of Long Island City, New York, is small, can be handheld or bracket mounted, and can operate from spacecraft direct current power as well as a portable battery pack.

This camera is correctly titled as a data camera and is not a movie camera. Unlike commercial movie cameras, this unit is capable of shutter speeds which are completely independent of frame rate. Also, the automatic frame rates are slower than commercial models in an effort to obtain maximum use of film and still maintain the desired engineering data value.

A lever on the side is provided to control the shutter speeds of 1/60, 1/125, 1/250, 1/500, and 1/1000 second. A second control lever on the camera selects any one of the following operating modes: time exposure, 1 frame per second, 6 frames per second, 12 frames per second, and 24 frames per second. The camera can interchangeably accept lenses fitted with a c-mount/bayonet adapter. Those lenses used on the Gemini 16 mm sequence camera (namely, 5tm, 18mm, 25mm, 75mm, and 100mm) are also usable on this camera. Also a 10 mm and a 150 mm lens will be available soon, and zoom lenses and automatic exposure control lenses are under investigation. This camera provides four fiducial marks on each frame for use in data reduction.

The camera exceeds the resolution capabilities of all flight film presently in use. Unlike the original 16 mm camera,

this camera provides a visual indication of the operating mode. The operate light, which is a green light on the magazine side of the camera, blinks at the frame rate being used. The camera is also internally protected from a malfunction, which eliminates the need for the circuit breaker and light assembly used with the Gemini Camera. A replacement fuse is used for the main circuit protection against a catastrophic failure and an automatic load sensing circuit shuts down the camera automatically when a continuous overload is sensed, such as would be seen when a magazine jam occurs. The operation of the camera requires 28 #4 vdc at a maximum current load of less than 1 amp. The camera produces PCM telemetry, indicating shutter actuations, making it possible to determine which camera mode is being used. weight of the camera is 1.7 pounds and its physical size is approximately 3 1/2 inches high (including connections) by 6 inches long by 2 1/2 inches wide. The mounting provisions are identical to those used for the later Gemini cameras.

Any number of film magazines with capacities of 150 feet and 400 feet of S0368 type color film can be used with this camera. Since the camera is capable of running at 1 frame per second, 6 frames per second, 12 frames per second, and 24 frames per second, the run times at these respective rates for the 150 foot magazine are 100 minutes, 16.7 minutes, 8.3 minutes, and 4.1 minutes, and for 400 foot magazine 266.7 minutes, 44.4 minutes, 22.2 minutes, and 11.1 minutes. Mounted on the rear of each film magazine is a red end-of-film light which illuminates to indicate that approximately 6 feet of film remains in the magazine. The 150 foot magazine weighs approximately 13 ounces without film and attaches within the dimensions of the camera. The 400 foot magazine weighs approximately 24 ounces without film. Figures 3.2.15-1 through 3.2.15-3 show the various features of the camera and film magazines.

Lunar Surface Hasselblad SWA Camera (Part No. SEB33100081)-The camera (with a 200 exposure 70 mm film magazine) is shown in figure 3.2.15-4. This camera has been designed for operation by the crewmen on the lunar surface, inside either spacecraft, or during extravehicular activity (EVA). Several design and manufacturing improvements distinguish this camera from the earlier 70 mm Hasselblad superwide angle (SWA) camera, P/N SEB33100055, which it will replace on the third manned Apollo mission. The camera's controls have been strengthened and enlarged for increased reliability and ease of handling; an improved film magazine locking mechanism has been included; a large folding sight has replaced the optical ring sight to simplify pressure suit operation; and the optical and mechanical tolerances of the camera have been tightened. For the lunar surface geology photographic experiment an adjustable polarizing filter will be attached to the front of the lens and a system for placing fiducial alignment marks on the film frames will be added to the camera body. Information on these

specialized features should be obtained from Mission Operations Branch (NOB) personnel. All the above modifications of the commercial SWC camera were performed by Victor Hasselblad AB of Goteborg, Sweden, and their subcontractors, Carl Zeiss and Compur of West Germany.

The 38 mm focal length Biogon lens of this camera is particularly noted for its high quality wide angle pictures with extreme depth of field. As with its predecessor, the SWA, this lens is an integral part of the camera body and cannot be removed or exchanged for other lenses. The lens has a 91.1° diagonal angle of view (71.7° on a frame side), is focusable from 12 inches to infinity, has a diaphragm aperture range of f/4.5 to f/22; and is capable of shutter speeds of 1/500, 1/250, 1/125, 1/60, 1/30, 1/15, 1/8, 1/4, 1/2, 1 second, and time exposures. The aperture, shutter speed and distance scales are rotated independently by use of individual finger tabs.

The Hasselblad 70 mm film magazines, P/N SEB33100082, may be used with this camera. The magazines can be removed, exchanged and later replaced on the camera at any time. The improved magazine latching mechanism of this camera prohibits the use of the older standard and cassette magazines, P/N SEB33100030 and SEB33100068. The section titled Hasselblad 70 mm Film Magazine furnishes detailed information on the film magazines for this camera.

The important features are briefly described below.

Filter Ring - threaded removable ring for retaining Series VIII filters (63 mm diameter). This will be replaceable with a special polaroid filter retaining mechanism for the lunar surface experiment.

Front Sight, - a foldable post used in conjunction with the rear sight.

Rear Sight - a foldable cross-bar sight used with the front sight for aiming the camera at objects ten feet from the camera.

Focus Ring - varies the lens focus when rotated. Includes a tab for improved pressure suit operation and an engraved distance scale indicating lens focus from 12 inches to infinity with click stops at the 10 feet and infinity settings.

Aperture Ring - when rotated, varies the lens diaphragm aperture from f/4.5 to f/22 with click stops every half stop. A tab is provided for ease of operation.

Shutter Speed Ring - varies the lens shutter speed in full increments when rotated. An attached tab provides ease of operation.

Central Index - a white engraved line against which all lens focus, aperture and shutter speeds are set.

<u>Depth of Field Indicators</u> - two red, movable markers that automatically show the depth of focus as the lens focus and/or aperture are adjusted.

Shutter Release Button - an enlarged push button which mechanically releases the shutter.

<u>Cable Release Socket</u> - a socket in the shutter release button threaded to accept cable releases for remote actuation of the camera shutter.

Magazine Lock Handle - used for locking the film magazine to the camera. It has three operation positions - LOCKED, OPEN, and RELEASE.

<u>Crank Handle</u> - used to simultaneously advance film and cock the shutter. The crank handle is unfolded for operation and folded for stowage.

Tripod Mount - a standard 1/4" X 20 tripod mounting socket for use during testing, in bracket mounting and in connecting a tether for extravehicular operations.

70 MM Film Magazine - Hasselblad 70 mm Film Magazine, Apollo Part No. SEB33100082: Loaded Weight 1.40 lbs. This film magazine incorporates the new latching features required by the Hasselblad electric camera, P/N SEB33100102, and the lunar surface Hasselblad super wide camera, P/N SEB 33100081. A 200 exposure magazine (and the camera) are shown in figure 3.2.15-4.

Victor Hasselblad AB of Goteborg, Sweden, produces this magazine by modifying their commercial magazine 70./ In addition to insuring that the magazine operation and materials are compatible with the spacecraft and lunar surface environments, special adjustments of the film flattening mechanism are required to accommodate either standard or thin base films. The magazine is provided in two configurations to allow for this film thickness variation - the Dash No. 201 (marked "200" on the exterior) is for thin base films and the Dash No. 202 (marked "100" on the exterior) is for standard base films. The magazine for thin base films is capable of 200 frames of thin base black and white film or 160 frames of thin base color; the magazine for standard base film is capable of 100 exposures of either black and white or color. In both cases the film is 70 mm Type II, perforated, and darkroom loading and unloading is required. The other magazine features are briefly described below.

Frame Counter - indicates the number of frames exposed, with a maximum of 200 for the thin base version and 100 for the standard base version. A line and number mark every fifth

frame of the standard base magazine; a line marks every fifth and a number every tenth frame of the thin base magazine version.

Gross Film Indicator - clock-like pointer geared to the frame counter to provide a gross indication of the amount of film used or remaining. The pointer is directed upward at frame one and turns clockwise as the film is used. White dots around the pointer are spaced approximately every 13 frames for the standard base magazine and every 26 frames for the thin base version. A red mark located between ten and eleven o'clock indicates the last 10 frames for standard base and frames 180 to 200 for thin base black and white film.

Film Signal - shows white when the magazine is loaded and ready for use, red when the current frame has been exposed or when the film supply has been depleted. An automatic stop will prevent further exposures after the last frame by prohibiting the actuation of the camera in a manner very similar to that of having the dark slide fully inserted.

Dark Slide - protects the film from light while the magazine is removed from the camera or during lens exchange with the magazine on the camera. The dark slide must be fully inserted in the magazine before the magazine can be removed from the camera. With the slide fully inserted in a magazine on the camera, the camera cannot be actuated. The shutter release button can be depressed in this case, but neither the shutter nor the camera drive will be actuated.

Automatic 1° Spotmeter - This meter is a modified version of the "Autospot 1°" commercial light meter (still and movie camera model) produced by the Minolta Camera Co., Ltd. It is used as follows: The object to be photographed is sighted through an eyepiece and brought into focus by turning the lens barrel. The total field of view is 8°; the 1° area to which the instrument's cadmium sulphide cells are sensitive is outlined in the center of the field of view. When the subject is properly sighted, a button on the handle is depressed. The instrument then responds to the light in the 1° circle, driving scales which indicate the proper exposure settings. The scales are visible through the eyepiece and are illuminated. When the button is released, the scales lock in position, retaining the measurement for later use. If the subject covers more than the 1° field, several readings over differently illuminated parts of the subject should be used. The image appears bright and erect and is magnified by a factor of four. The meter can be focused from one meter to infinity.

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The modifications made to the commercial instrument for use in the Apollo Program include scale changes (a foot-lambert scale has been added and a movie frames-per-second scale deleted), the addition of a long-relief eyepiece for use with the helmet, and structural changes for reliable operation in the space and spacecraft cabin environments.

## Television Camera

In developing the LM TV camera, the Westinghouse Electric Corporation applied considerable emphasis to making the camera operation simple. Essentially all that is required of the astronaut to operate the camera is to select the proper lens from a set of four interchangeable units supplied; attach the lens to the camera and then connect a cable supplying primary power and returning the mixed video for transmission. Aiming is accomplished by sighting along the edge of the camera. There is only one switch, located on the top surface. This is used to switch operating modes. The camera can be operated at 10 frames per second (fps) and 320 lines for normal viewing of the astronauts' activities and scenes of general interest or at 0.625 fps and 1280 lines for scenes with scientific interest. In the 10 fps mode the camera can be hand held but in the slower scan mode it should be mounted. Circuits are provided to automatically control the gain of the camera and thereby compensate for varying scene brightness over a wide dynamic range to maintain a relatively constant output.

Resolution - Resolution of a TV camera system is dependent on the cascaded response of the lens, sensor, electronics and display. For the Apollo Lunar TV Camera System, the resolution is limited by the 500KC electronics bandwidth in the 10 fps mode and by the sensor in the .625 fps mode.

<u>Lenses</u> - The lens serves to image the scene on the sensor. Four lenses are available for the camera. Their parameters are listed in Table 3.2.15-1.

Sensor - The sensor used is a secondary electron conduction (SEC) tube. It contains an electrostatic image section, electrostatic focus-magnetic deflection reading section and SEC target. The target output may be considered a current source with signals in the order of 1 to 100 X  $10^{-9}$  amps.

<u>Video (Electronics)</u> - The video section amplifies the target signal, mixes in the SYNC and blank information and provides composite video output of 20 MA P/P. Equivalent noise of the video referred to the input is  $3 \times 10^{-10}$  amps for the video bandwidth of 2 CPS to 500 KC.

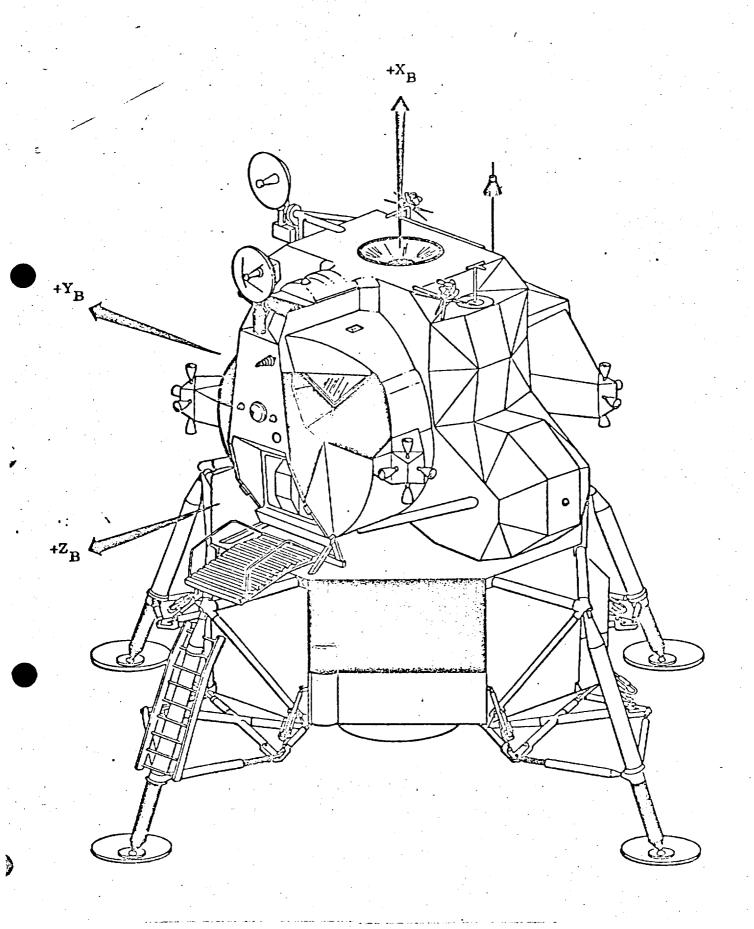
Thermal Control - Thermal control of the camera is expected to maintain the internal temperature between -20° C and +60° C. To insure reliable operation over this range, all circuits were designed to operate from -55° C to +125° C. This range, though broad, is not unreasonable since most military equipment and components meet this range of temperatur.

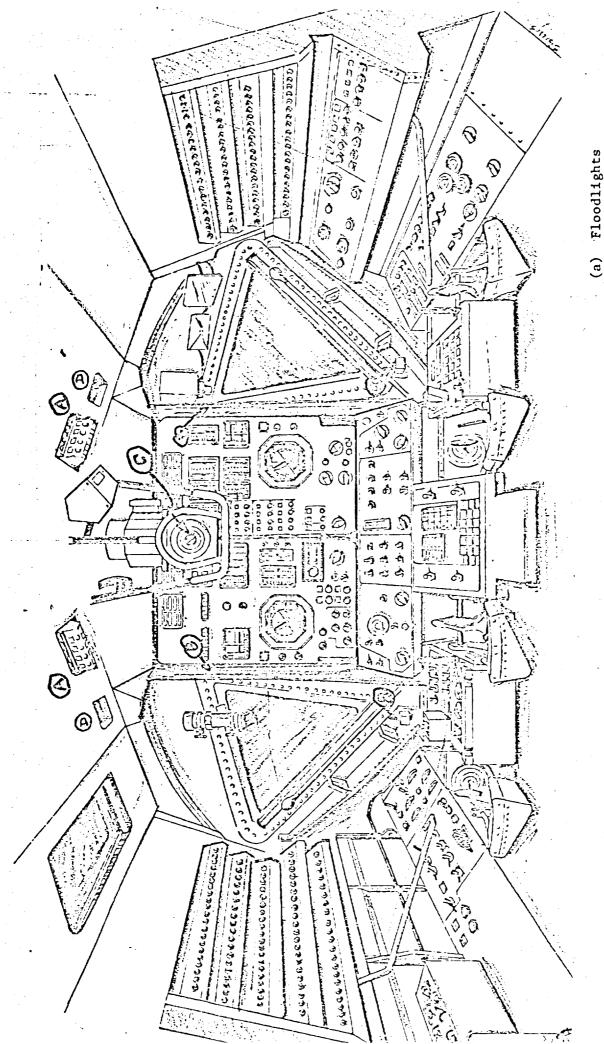
A study conducted to find the best method of thermal control, considering the range of environments to be encountered, size, weight and reliability, resulted in selection of a passing cooling technique. This method uses the optical properties of the surface finishes to radiate camera heat to space with minimum absorption of solar heat. After evaluation of a number of finishes with appropriate optical properties, white paint and silver plate were selected. Primers, curing cycles, etc., were developed to enable the finishes to maintain their optical properties in the spaceflight environments.

Connector and Cables - The camera requires a cable to provide power and to return the mixed video to the transmitter for both spacecraft and lunar surface operation. Making and breaking connector contacts in both environments is required. Since there were no standard connectors available that would fulfill the requirement, a unit was developed by Westinghouse.

A nine foot cable was designed for operating the camera inside the LM and from hatches for lunar surface views. The cable consists of the following:

- a. Two .0063 diameter 19 strand leads one for power and one for power ground. These are insulated with extruded polytetrafluorethylene (PTFE).
- b. One coax lead for video signal on center conductor and signal ground on outer braid.
- c. Double wrap Teflon jacket.
- d. Outer braided PTFE coated glass jacket Both ends of the cable are wired to a Westinghouse designed space connector. One end mates with the bulkhead receptacle and the other mates with the camera receptacle. At the camera end the connector is provided with a handle for hand held camera operation.





Floodlights

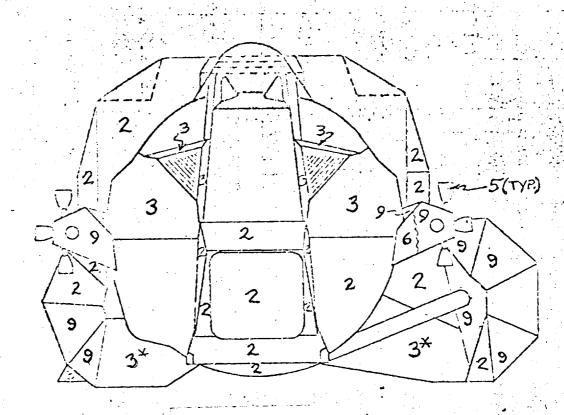
Glare Shields **(**2)

AOT Eyepfece <u>်</u>

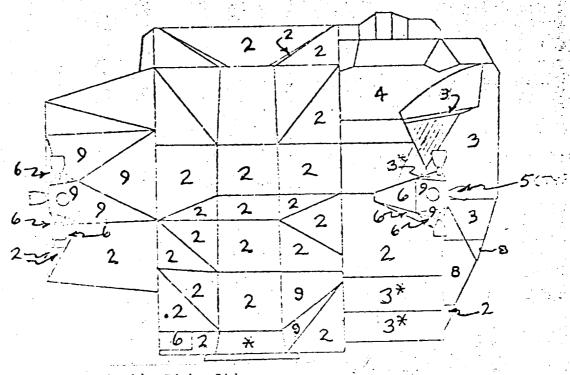
LM INTERIOR

FIGURE 3.2.1-2

Portable Utility Light Receptacles <del>P</del>



a) Front



b) Right Side

<sup>\*</sup> Revision C Changes FIGURE 3.2.2-1 LM ASCENT STAGE

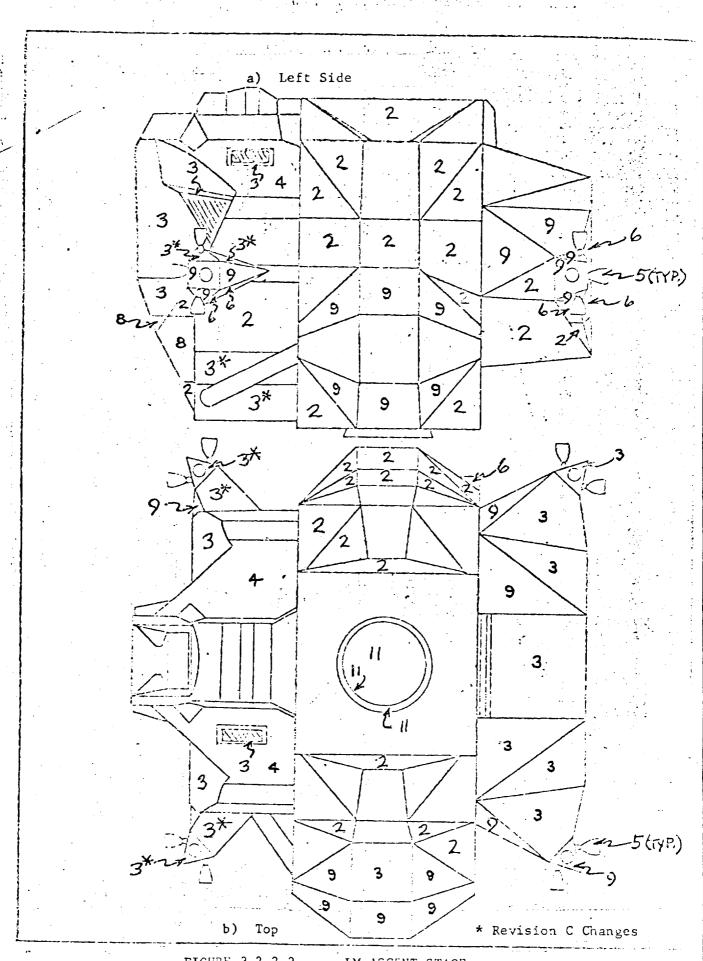


FIGURE 3.2.2-2

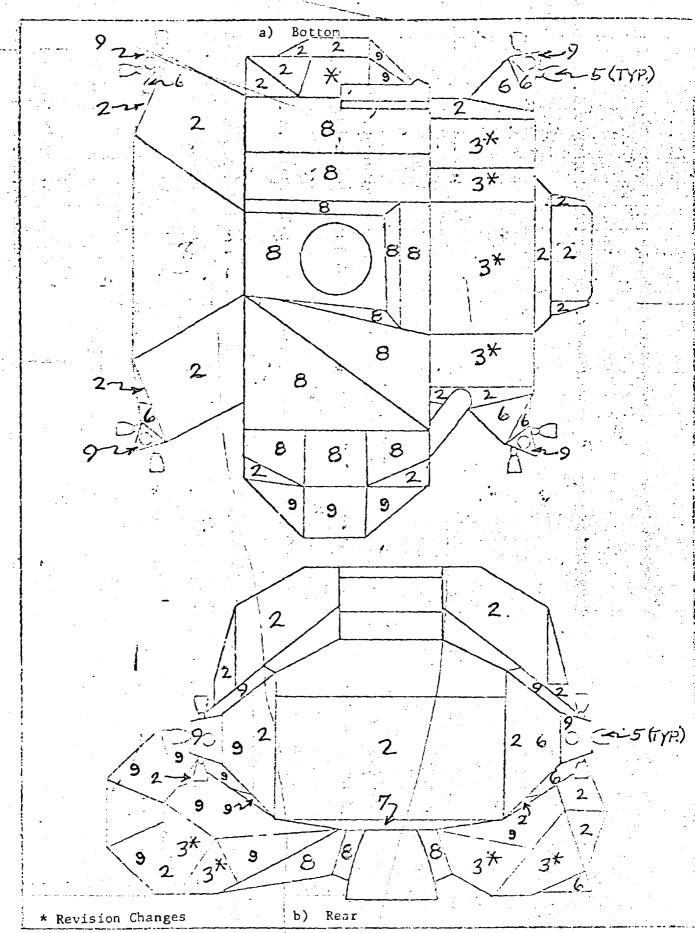
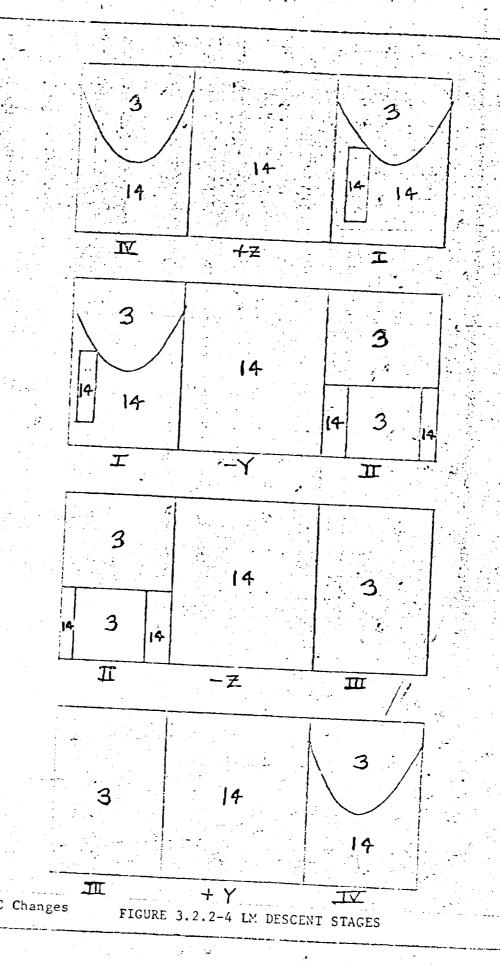
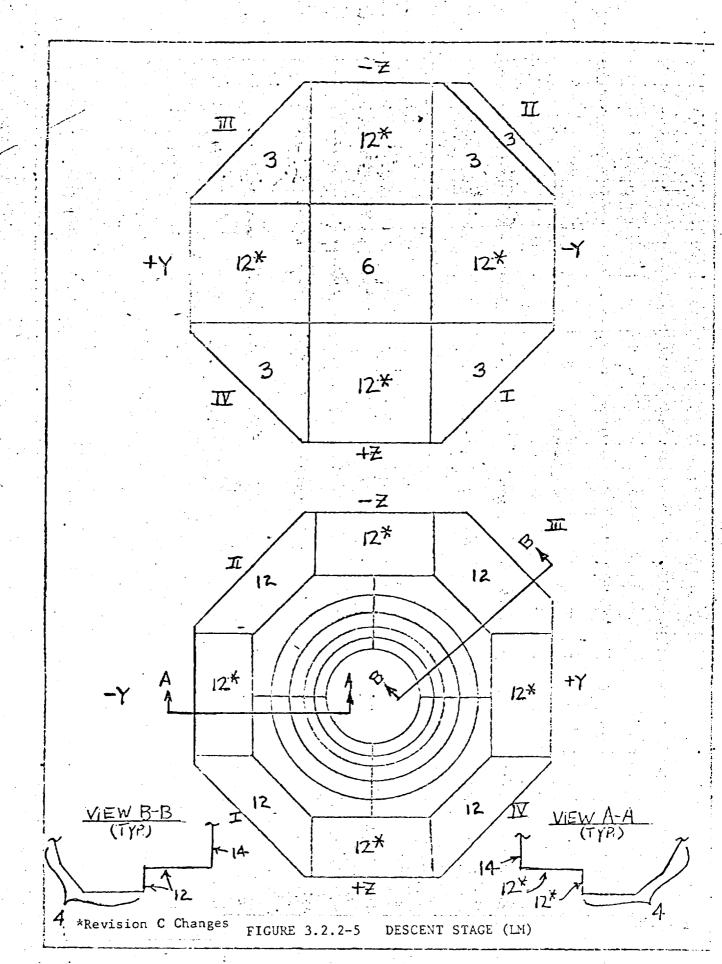
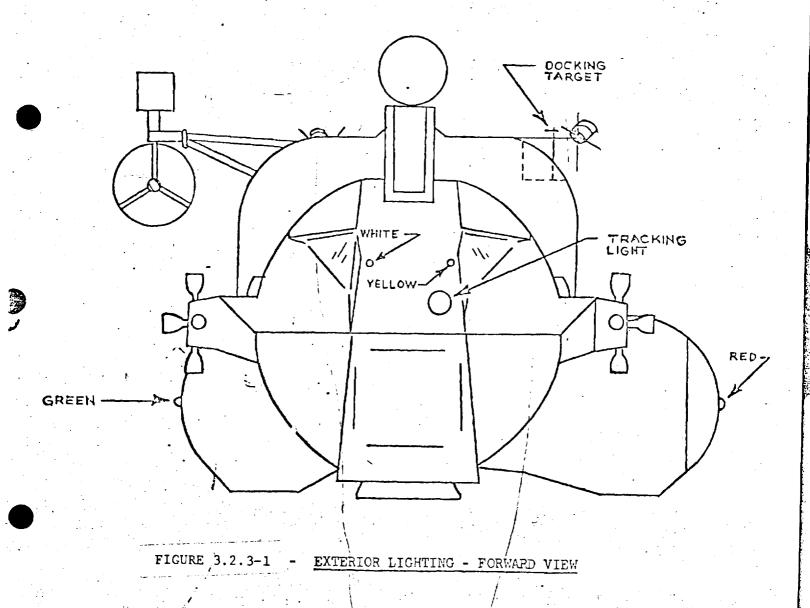


FIGURE 3.2.2-3 LM ASCENT STAGE







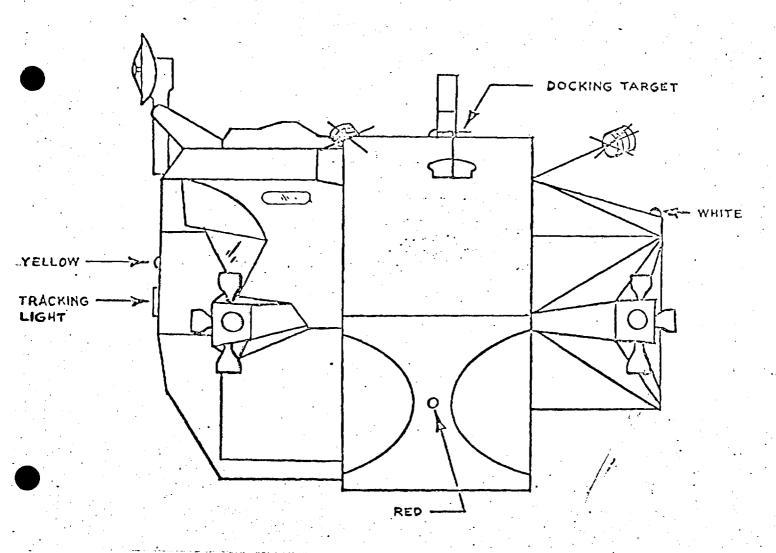


FIGURE 3.2.3-2 - EXTERIOR LIGHTING - PORT SIDE

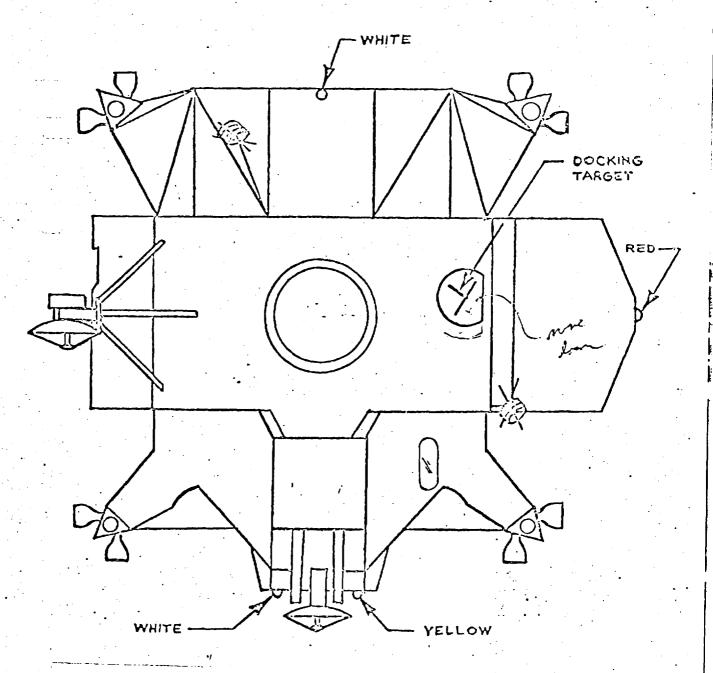
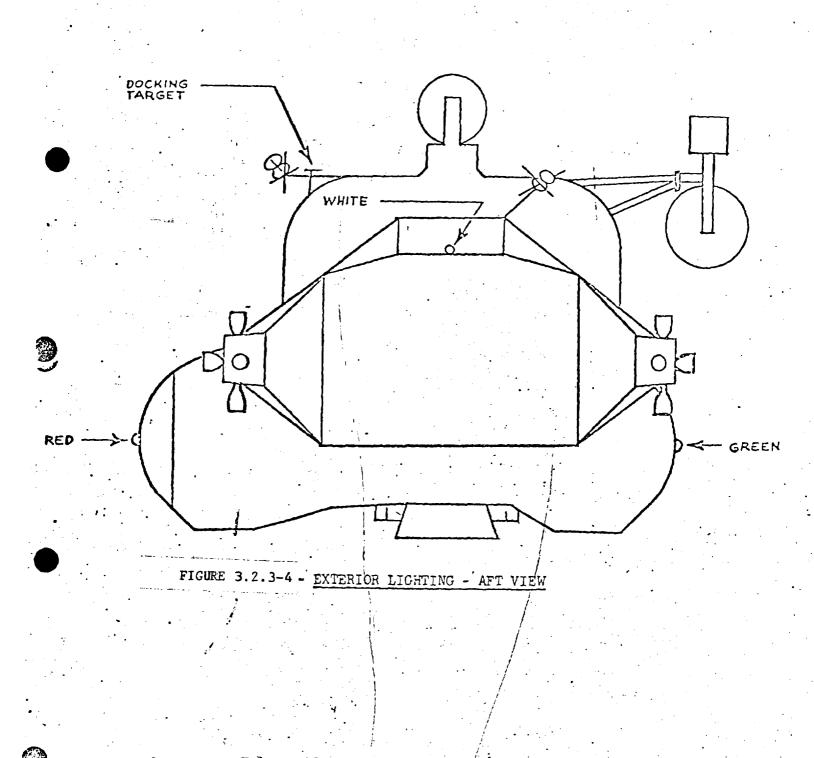
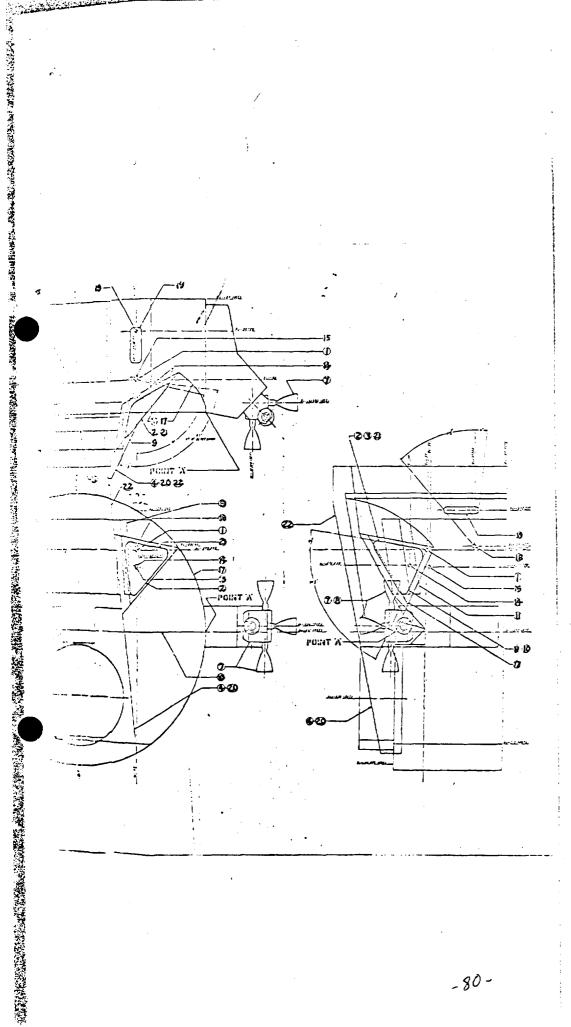
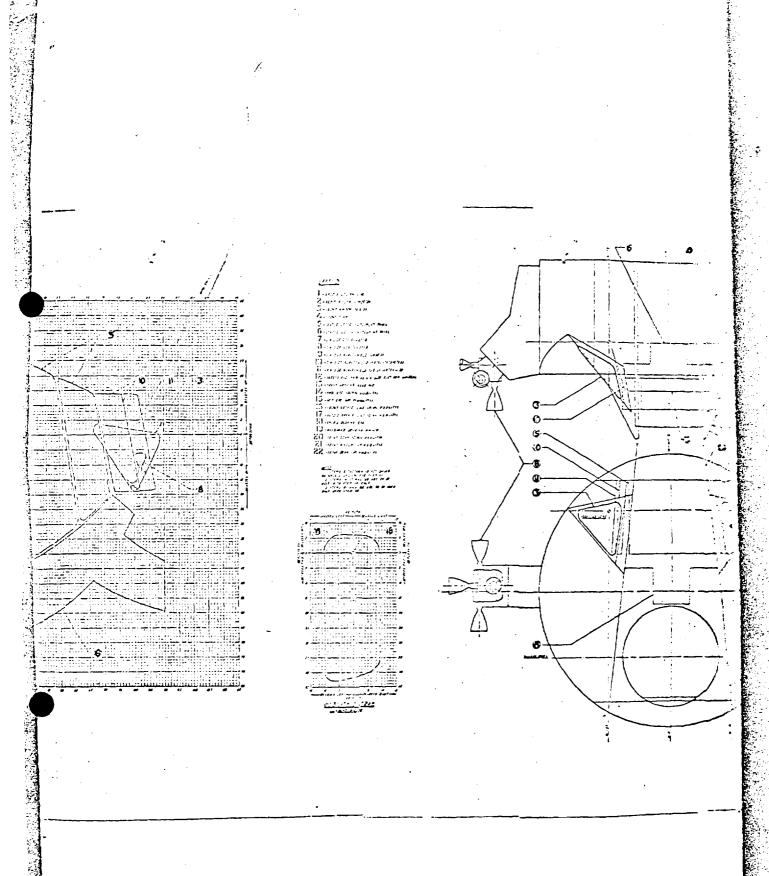
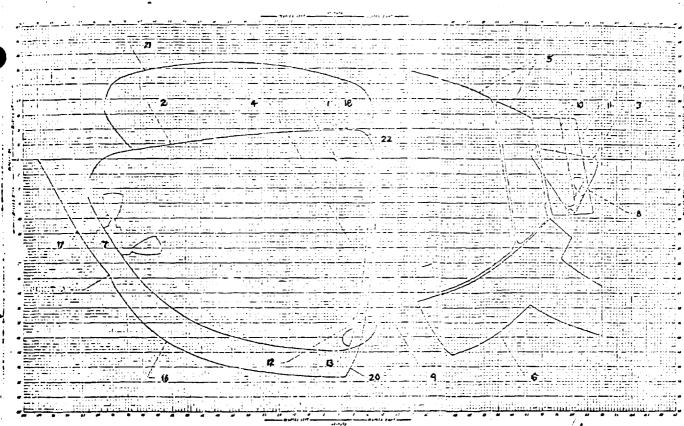


FIGURE 3.2.3-3 - EXTERIOR LIGHTING - TOP VIEW







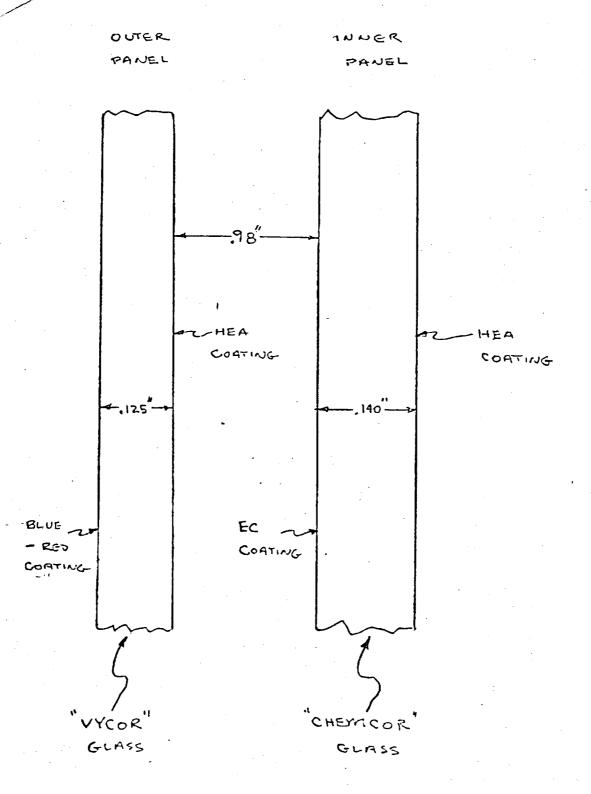


VORTALE SHOW

FIGURE 3.2.6-1 VISIBILITY THROUGH LM WINDOWS

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COMBINING GLASS -LIGHT FROM RETIELE " TARSET FROM TARSET COLLIMETING LENS - RETICLE 1 LAMP FIGURE 3.2.10-1 OPTICAL SCHEMATIC

-85-

- PANEL/WINDOW EDGE

FIGURE 3.2.9-1 LM GLARE SHIELD

Component	Primary Lighting Method	Trans-illumination Co
Control Famels and Pumbbuttons (Illuminated character type)	Integral (FL) (Primary)	White*  X = 0.330 ± 0.030  Y = 0.330 ± 0.030
	Flood (Incandescent) (Fackup)	White (unfiltered)
Circuit Breakers	Flood (EL)	White X = 0.300 ± 0.020 Y = 0.300 ± 0.020
EL Numeric Readouts	Integral (EL)	Green (Dominant wavele 4900-5300 Angstroms)
Lunar Contact Signal Light	Integral (Incandescent)	Blue_
Master Alarm	Integral (Incandescent)	Aviation Red
Caution Annunciators Warning Annunciators	Integral (Incandescent)	Aviation Yellow - Aviation Red .
Component Caution	Integral (Incandescent)	Aviation Yellow
Engine Start & Stop Pushbuttons	Integral (Incandescent)	Aviation Red
Engine Start & Stop posicion	and Integral (EL)	White
Status Indicators (DSKY&DEDA)	Integral (Incandescent)	Aviation White
Component Caution (DSKY)		Aviation Yellow
Self-luminous devices (Switch tips; Landing Point Designator, LFD)	Radioluminescence (e.g., Promethium 147)	Green (Dominant waveler 4900-5300 Amgstroms) (and Tellow for LF)

X and Y Measurements to be made in accordance with procedures in MIL-L-27160.

\*\* Initial value will be C.1 ± 0.02 foot Lamberts in order to achieve.05 ± .02 foot

\*\*\* Five digit numbers refer to colors per MIL-STD-595 (approximate visual match.)

\*\*\* Except for the C/W FWR (6 - DS - 34) which is fixed.

\*\*\*\* BUS FAULT //9h/ " " "

TABLE 3.2.5-1 - INVERIOR TELUM TOTAL, COLOR AND INTERFESS

			•	
ighting Method	Trans-illumination Colo	r	Brightness at Rated Capacity	Brightness
,) (Frimary)	White* X = 0.330 ± 0.030 Y = 0.330 ± 0.030		0.5 ± 0.2 foot Jamberts (75 v. 400 cps)	Continuous fr Lamberts.
ndescent) (Fackup)	White (unfiltered)		0.2 foot candles minimum (at 24 V.D.C.)	Continuous fro foot candics. others non-dim
	White X = 0.300 ± 0.020 Y = 0.300 ± 0.020		0.5 ± 0.2 foot Lamberts (75 v. 400 cps)	Continuous fr Lamberts.
)	Green (Dominant waveleng 4900-5300 Angstroms)	th	7.8 foot Lamberts minimum (115v.400cps)(DSKY=250v.800cps)	Continuous fr
ncandescent)	Blue		50 ± 10 foot Lamberts (5 V.D.C.) (5 lamps)	Fixed
ncandescent)	Aviation Red		150 ± 30 foot Lamberts (28 V.D.C.) (4 lamps)	Fixed (Push
ncandescent)	Aviation Yellow	-0-25350	50 ± 10 foot Lamberts (5 V.D.C.)	Continuous fr
ncandescent)	Aviation Yellow	per MIL	15 ± 3 foot Lamberts (5 V.D.C.)	Continuous fr foot Lamberts
ncandescent)	Aviation Red		15 + 3 foot Lamberts // (5 V.D.C.)	Continuous fr
) (記)	White		0.5 ± 0.2 foot Lamberts (75 v. 400cps)	Continuous fr
Incandescent)	Aviation White  Aviation Yellow		10 +8 foot Lamberts (5 V.D.C.)	Contin <del>oue</del> s fro
escence (e.g.,	Green (Domirant wavelengt 4900-5300 Angstroms) (and Tellov for LPD)	h	.05 ± 0.02* foot Lamberts	Fixed

accordance with procedures in MIL-L-27160.

Pot Lamberts in order to achieve.05 ± .02 foot Lamberts at time of launch.

per MIL-STD-595 (approximate visual match.)

Which is fixed.

## JOIL COTOR AND PERCEPTIOS

(75 v. 400 cps)  0.2 foot candles minimum (at 24 V.D.C.)  0.5 ± 0.2 foot Lamberts  75 v. 400 cps)	Drightness Adjustment  o.or. ± o.o/ Continuous from tero foot Lamberts.  Continuous from less than 0.1 Coot candles. (Panels 1-6; all others non-dimmable)  Continuous from zero foot Lamberts.  Continuous from zero foot	Color Under Incident Illumination  Control Fanels: Fray 36231***  Pushbuttons: Background: black 37038 Characters: white 37875  Background: black 37038 Characters: white 37875
(75 v. 400 cps)  (0.2 foot candles minimum (at 24 V.D.C.)  (at 24 V.D.C.)  (b)  (c)  (c)  (c)  (c)  (d)  (d)  (d)  (e)  (e)  (e)  (f)  (f)  (f)  (f)  (f	Continuous from tero foot Lamberts.  Continuous from less than 0.1 Coot candles. (Panels 1-6; all others non-dimmable)  Continuous from zero foot Lamberts.	Pushbuttons: Background: black 37038 Characters: white 37875  Background: black 37038
0.5 ± 0.2 foot Lamberts  75 v. 400 cps)	Coot candles. (Panels 1-6; all thers non-dimmable)  Continuous from zero foot Lamberts.	Background: black 37038
75 v. 400 cps)	Lambert .	
178 foot Temberts minimum	Continuous from zero foot	
(115v.400cps)(DSKY=250v.800cps)	Lambert#	Background: gray
50 ± 10 foot Lamberts (5 V.D.C.) (5 lamps)	Fixed	Background: non-specular gray
150 ± 30 foot Lamberts (28 V.D.C.) (4 lamps)	Fixed (Push to turn off)	Background: translucent gray/ white Legends: black
50 ± 10 foot Lamberts (5 V.D.C.)	Continuous from 1.5 ± 0.5 foot Lamberts ****	Background: translucent gray/ white Legends: black
15 * 3 foot Lamberts (5 V.D.C.)	Continuous from 0.05 ± .02 foot Lamberts ****	Background: translucent gray/ white Legends: black
15 + 3 foot Lamberts V.D.C.)	Continuous from .05 ± .02 foot Lamberts	Background : translucent gray/ white Legends: black
0.5 ± 0.2 foot lamberts (75 v. 400cps)	Continuous from zero foot Lamberts 0.02± 0,01	Background: translucent gray/ white Legends: black
10 +8 foot Lamberts (5 V.D.C.)	Contineues from zere foot Lamberts-	Background: translucent gray/ white Legends: black
.05 ± 0.02** foot Lamberts	Fixed	Pale Green Fele Yellow for LFD-inner-reticle.

ts at time of launch.

	,		
	Component	Primary Lighting Method	Trans-illumination Color
Flags	2-position	Integral (圧)	White bkgd.: X & Y = + .03 and black (opaque) striping - Energized.
	3-position	Integral (EL)	White bkgd.: C.I.E. Coordates X and Y = .330 ± .03 black (opaque)
·			Red
lighte	(color coding of ed controls and displays	.)	
	Pointers	Silhouette of EL flood	
	Indicia	Integral (EL)	. White: C.I.E. X and Y Coordinates = .330 ± .03
	Indicia Characters	Integral (EL) Integral (EL)	White: C.I.E. X and Y Coordinates = .330 ± .03 White: C.I.E. X and Y Coordinates = .330 ± .03
		Integral (EL)	Coordinates = .330 ± .03 White: C.I.E. X and Y Coordinates = .330 ± .03
	Characters Time-shared labels and	Integral (EL)	White: C.I.E. X and Y Coordinates = .330 ± .03  Green (Dominant waveleng)
Immed	Characters Time-shared labels and multipliers Range marking (Normal	Integral (EL) Integral (EL)	White: C.I.E. X and Y Coordinates = .330 ± .03  White: C.I.E. X and Y Coordinates = .330 ± .03  Green (Dominant waveleng 4900-5300A)

TABLE 3.2.5-1 - INTERIOR ILLUMINATION .....

	Primary Lighting Method	Trans-illumination Color	Brightness at takes
	Integral (丘)	White bkgd. : X & Y = .330 + .03 and black (opaque) striping - Energized.	0.5 ± 0.2 foot :
	Integral (EL)	White bkgd.: C.I.E. Coordinates X and Y = .330 ± .03 and black (opaque)	0.5 ± 0.2 foot Lames (75 v. 400 cps)
		Red	
oding of s and displays	) Silhouette of EL flood		
	Integral (EL)	. White: C.I.E. X and Y Coordinates = .330 ± .03	0.5 ± 0.2 foot Lamber (75 v. 400 cps)
·s	Integral (EL)	White: C.I.E. X and Y Coordinates = .330 ± .03	0.5 ± 0.2 foot lameer (75 v. 400 cps)
ed labels and	Integral (EL)	Green (Dominant wavelength 4900-5300A)	8 foot Ismberts minim (115 v. 400 cps)
cking (Normal	Integral (EL)	Green	+0 0.4 -0.1foot Lambert (75 v. 400 cps)
hergency is	Integral (EL)	Yellow	0.1 foot Lambert min: (75 v. 400 cps)
ion Indicator	Integral (Incombescent)	Aviation Red	20+5 foot Lamberts (5 V.D.C.)

# MINATION, COLOR AND BRIGHTHESS (CONTINUED)

Brightness at Rated Capacity	Brightness Adjustment	Color Under Incident Illumination
0.5 ± 0.2 foot Lambert (75 v. 400 cps)	Continuous from zero foot lambert	Alternate black (37038) and white (37875) striping (energized) Gray (36231) - (Deenergized)
0.5 ± 0.2 foot Lambert (75 v. 400 cps)	Continuous from zero foot Lambert	Red ("Velva Glow" by Padiant Color Co.) Letters: black (37038) on gray (36231) Gray (36231) - Deenergized Alternate black (37038) and white (37875) striping (energized)
		Black (37038) - yellow (33538) "Switzer" - Rocket Red or Fire Orange
0.5 ± 0.2 foot Lambert (75 v. 400 cps)	Continuous from zero foot Lambert	Black (37038)- white (37875)
0.5 ± 0.2 foot Lambert (75 v. 400 cps)	Continuous from zero foot Lambert	Black (37038)- white (37875)
foot Ismberts minimum (115 v. 400 cps)	Continuous from zero foot Iambert	NONE
+0 0.4 -01foot Lambert (75 v. 400 cps)	Continuous from zero foot Lambert	Green ("Velva Glow")
0.1 foot Lambert minimum (75 v. 400 cps)	Continuous from zero foot Iambert	Alternate yellow and black (33538/37038) with yellow 3X-thickness of black. Striping at 45 from vertical, rotated clockwise.
20+5 foot Lamberts (5 V.D.C.)	Continuous from 0.05±.02 foot Lambert4	Translucent gray/white

TABLE 3.2.10-1 -- COAS RANGING (LM-ACTIVE)

MISSION PHASE	CSM-MOUNTED AID CSM-Circular	TARGET SIZE	DISTANCE* (FEET)	TOTAL ANGLE SUBTENDED
Docking	outline	13 Ft.	745	1°
	•		372	2°
	· · · · · · · · · · · · · · · · · · ·		248	3°
	,		186	4°
	Docking ring	44 In.	210	1°
			105	2°
,			70	3°
			54	4°
	Roll align.			
•	cross	36 In.	172	1°
			86	2°
r		•	57	3°
	1	· ·	43	4°
	LM-active	0.7		
1	target	8 In.	38	1°
•			19	2°
	\		12.8	3°
Pre-contact alignment			9.9	3°49'

<sup>\*</sup> Distance from the nominal eye point of the LM COAS at X=291.19, -Y=20.94, Z=37.75, for the overhead window position.

LUNAR TV CAMERA

# LENS PARAMETERS

S E E	#/4	₹ E	Diagonal		•	Depth of	Peak	
Name	11.11	#_1	rield	Length	Weight	Focus	Focus	Scene Brightness
Wide Angle	f/4	T-4.8	800	1.31 in	.22#	201n-∞	401n	.15 - 92.2 ft Lamberts
Telephoto	£/4	T-60	9.30	4.95 tn	#26.	143ft-∞	287ft	22.7- 12,600 ft Lamberts
Lunar Day	£/4	T-60	350	1.53 in	.22#	llft-∞	23ft	22.7-12,600 ft Lamberts
Lunar Night	f/1.0	T-1.15	350	2.10 in	#77.	37ft-∞	74£c	.0079- 5.29 ft Lamberts
			-					

Based on a faceplate illumination range of .0015 to 1.0 footcandles.

Note: Scene Brightness is equal to the product of incident illumination times the reflectivity for diffuse scenes.

TABLE 3.2.15-1

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### 3.3 CREW PROTECTIVE CLOTHING

## 3.3.1 Intravehicular

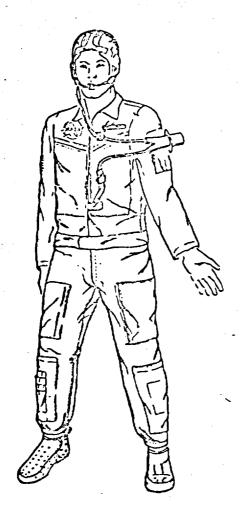
There are two outer garments which may be worn inside the CM (Figure 3.3.1-1):

Flight Coveralls - These provide the crewman warmth and stowage for miscellaneous personal equipment while in a shirt-sleeve environment. The material to be used will be teflon-coated white beta cloth, with a solar reflectance of about .73. These are not to be worn inside the LM.

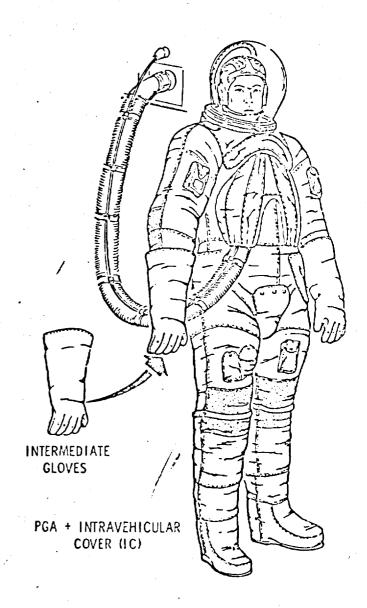
Pressure Garment Assembly (PGA) and Intravehicular Cover (IC) -The PGA provides a mobile life support chamber that can be pressurized separately from the inner structure in case of a leak or a puncture. The PGA consists of a helmet, gloves, torso and limb covers and requires an oxygen hose and electrical cable for oxygen and communication. For wear within the spacecraft, the PGA is covered with an intravehicular cover (IC), the outer garment as shown in Figure 3.3.1-1. The IC exterior is of the same coated beta cloth as used for the coveralls. Since the helmet is an important factor in suited crew visibility it merits further discussion. It consists of a molded polycarbonate plastic bubble with an opaque rear quarter (Figure 3.3.1-2). It secures to the torso neck ring with a slide lock. A slot channel at the rear of the neck ring receives oxygen from the torso and directs it to a one-half-inch-thick foam plastic manifold. The manifold lays on the aft quarter of the helmet, terminating at the top. Numerous slits in the manifold direct the oxygen across the face, purging the helmet of carbon dioxide. Optical properties of the latest helmets are yet to be obtained.

## 3.3.2 Extravehicular

During extravehicular activity (EVA), the crewman wears a PGA covered with a thermal-meteoroid protective garment, the exterior of which looks much like the intravehicular cover (Figure 3.3.2-1) and is made of the same type of coated white beta cloth. He also wears an extravehicular visor assembly (EVVA), extravehicular gloves and when on the lunar surface lunar overshoes. The EVVA is a three-piece polycarbonate structure composed of a shell which supports two adjustable visors (Figure 3.3.2-1). It fits over the pressure helmet assembly and is held in place by a strap and gorget. Its purpose is to provide a crewman with visual, thermal, impact, and micrometeoroid protection during extravehicular tasks. The inner visor is clear (with an infrared reflecting coating on the outer surface) and is used to provide impact and micrometeoroid protection during dark periods of extravehicular activity. The outer visor is gold coated and provides face (particularly eye) protection from the sun. The visors are raised and lowered by tabs arranged such that the outer visor cannot be used without the inner visor. A force of four pounds (maximum) is required to place either visor into any position within its range of travel. The visor is held in any position set by a friction device within the pivot mechanism. Data on EVVA optical performance has not yet been obtained.



FLIGHT COVERALS



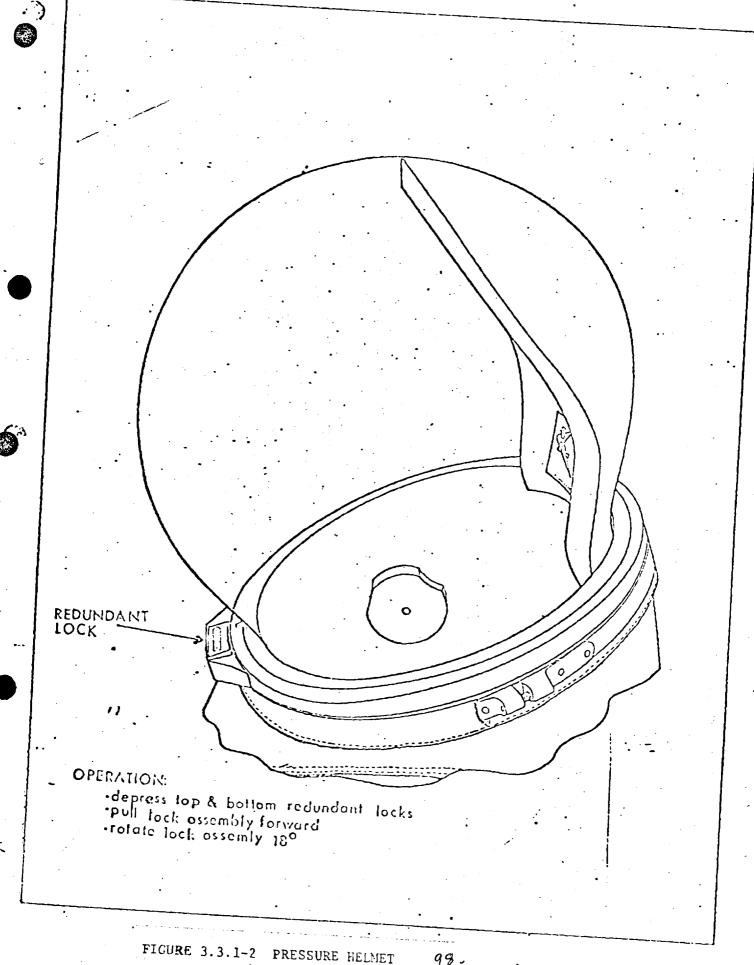
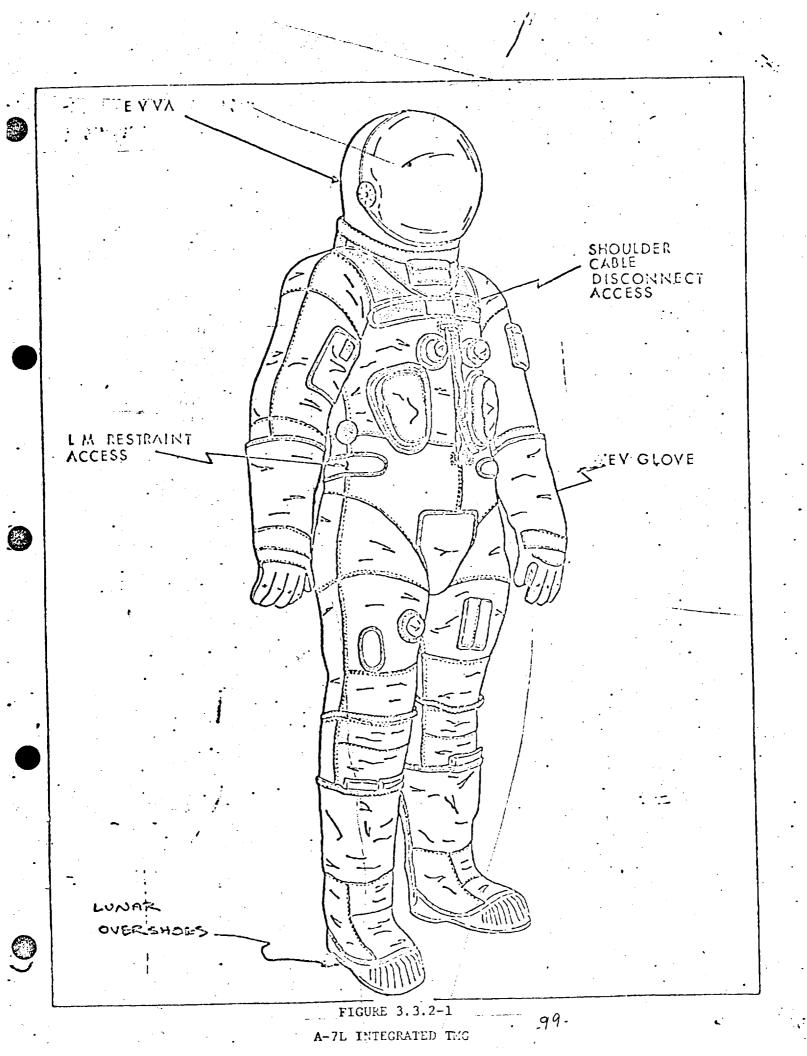


FIGURE 3.3.1-2 PRESSURE HELMET



#### 4. FACTORS AFFECTING VISIBILITY

## 4.1 WEIGHTLESSNESS (AND SPACECRAFT OPERATIONAL ENVIRONMENT)

Visual acuity tests were conducted in the Gemini program to determine the effects of the flights on astronaut visual performance. Pre-flight, in-flight, and post-flight tests showed no statistically significant change in visual capability of the Gemini V (8 day) and Gemini VII (14 day) crews. Throughout the flights the visual performance was tested one or more times each day by means of a self-contained in-flight vision tester. The test consisted of detection of the orientation of a series of high contrast (-1.0) and low contrast (-0.223) rectangles. The sensitivity of the test corresponded roughly to the ability to separate performance at 20/15 from that at 20/20. Statistical analysis of the results showed no significant changes in means or variances. The crews of both flights observed specially prepared targets on the ground near Laredo, Texas. In spite of some operational problems, which interfered with the planned sightings, a number of sightings were made and these gave results which were within the statistical range of the astronauts' preflight performance.

Reference: Gemini Mid-Program Conference, NASA SP-121, Manned Spacecraft Center, Houston, Texas. February 1966.

#### 4.2 UNFAVORABLE GEOMETRY

### Lunar Descent

View of Terrain through Window - The surface area seen during LM descent is shown for seven altitudes from 7000 to 1000 feet in Figure 4.3-1. This figure gives a perspective view of the surface for a viewing point at the normal design eye position and for a line of sight to the nominal landing area. The intersection of the line-of-sight from the LM to the nominal landing site makes an angle of about 16° elevation with the lunar surface (see Figure 4.3-2) during the period from high gate to low gate.

The shallow viewing angle during descent will result in an increased difficulty of landmark identification and site elevation due to the substantial foreshortening in the downrange-uprange direction. Most of the pictorial information on the landing areas is from vertical Orbitor photography; substantial differences in appearance of the terrain can be expected between the vertical and 16° viewing angles. The oblique Orbitor photographs provide a better display of surface appearance; however, the elevation angle of the line-of-sight for these is still on the order of 50°. In addition, the oblique photographs are generally at azimuth angles large compared to the LM approach azimuths and have limited resolution.

Sun Elevation Angle - The effect of sun elevation angle and viewing angle on surface visibility is discussed in detail in Section 4.3.2, and the photometric (reflectance) characteristics of the lunar surface are described in Section 5.5. In general, adequate visibility for the case of the sun behind the LM requires that the viewing angle (intersection of line-of-sight with the surface) be greater than the sun angle (intersection of sun-surface line). The angle between the sun-line and line-of-sight is the phase angle; visibility improves as the phase angle increases. A "washout" region exists around the point at which the line-of-sight and sun-line are equal. The "washout" region was inferred from Earth-based measurements and confirmed from Surveyor and Orbital data. Thus, the reflectance characteristics of the moon require the sun elevation angle at the landing site to be less than the line-of-sight angle, 16°.

The maximum and minimum acceptable values of sun elevation angle has been the subject of substantial study. The latest recommended range is from 6° to 12° which would replace the current requirement of from 7° to 20°. Because the sun angle range affects the launchwindow from Earth, it is an important mission consideration.

The minimum sun angle should be determined by two factors: (1) The amount of shadowing acceptable during landing, and (2) The amount of shadowing acceptable during lunar-orbit for landmark sighting. Fewer studies have been conducted on the lower sun limit as compared to the upper; however, 5° seems to be an acceptable lower limit for landing. Each lunar orbit results in

an increase of about 1° in sun elevation. For the present trajectory, as many as four lunar orbits may be planned which would result in an elevation angle of 1° if a 5° minimum was allowed at landing. This is too low for landmark sighting and, therefore, the lower sun limit during landing is not constrained by landing visibility as much as by orbital landmark sighting.

Present studies on the visibility and sun angle problems are being conducted at MSC, and by Bellcomm, General Electric, TRW, and Kodak, under contract to MSC. These studies are directed toward identification of landmarks for use during descent, further examination of sun angle limitations, surface shadowing, and requirements on terrain models for use with the LM Mission Simulator.

## 4.3 VISIBILITY DURING EVA - Lunar Surface

### 4.3.1 Surface Characteristics

Preliminary reports from the Surveyor missions provide data on the size and distribution of craters and surface fragmental material adjacent to the landing sites. The surface characteristics are remarkably similar at all the sites although these vary from a flat surface near a mare ridge to interiors of large (100 km) and small (10 m) craters. Brief summaries of some of the surface characteristics and plots of cumulative size-frequency distribution of small craters and of small fragments are included here.

### Surveyor I

"The lunar terrain within 1 km around the landing site varies from nearly flat to gently rolling and is pockmarked with craters ranging from a few centimeters to several hundred meters in diameter. The surface materials consist of blocks and angular fragments, ranging from a few millimeters to over 1 meter in diameter, set in a matrix of finer particles too small to be resolved.

The observed angular blocks and fragments occur over the surface area in a nearly random distribution and have a noticeable higher albedo or reflectance than the finergrained matrix material. The prominent block in the middle of the mosaic is approximately 40 cm wide and 18 cm high. These blocks and fragments littering the surface are composed of material somewhat different physically from the finegrained matrix, and probably represent strongly cohesive single pieces of rock.

A preliminary determination of size-frequency distribution of fragments indicate that one block about 0.5 m across can be expected to occur on each 100 m<sup>2</sup> of surface area. Angular fragments and blocks occupy approximately 8% of the surface area at the landing site. The volumetric median grain diameter of all fragmental material on the surface, including the fine-grained matrix, is probably less than 1 mm." (1)

### Surveyor III

"Data on the mechanical properties of the lunar surface material were obtained from examination of the depth of the footpad imprints, the straingage records, and computer simulation of the landing, as well as by the soil mechanics surface sampler. The surface sampler made 8 bearing tests and 14 impact tests on the lunar surface, and dug four trenches; i picked up three objects on the lunar surface. One of these, a small rock, was gripped in the surface sampler scoop, which exerted a pressure of at least 107 dynes/cm<sup>2</sup> (10<sup>2</sup> psi) on the rock without apparently crushing or breaking it.

In general, the character and properties of the lunar surface at the Surveyor III site seem very similar to those at the Surveyor I site. The position inside or outside a crater or in different more locations does not seem to make a gross difference in surface characteristics. similarity includes the mechanical properties of the soil. The static bearing strength, on widths of 2 cm (0.8 in) to 20 cm (8 in), is about  $2 \times 10^5$  to 5.5 x  $10^5$  dynes/cm<sup>2</sup> (3 to 8 psi), the cohesion  $10^3$  to  $10^4$  dynes/cm<sup>2</sup> ( $10^{-2}$  to  $10^{-1}$  psi) and the angle of internal friction roughly 35°. The elastic rigidity modulus of the top 20 cm (8 in) or so, as indicated by the frequency of vibration of the spacecraft on the surface, is about  $5 \times 10^6$  dynes/cm<sup>2</sup> (70 psi). This is much lower than is typical for loose sand, and may represent fine, loosely packed particles. The penetration of the footpads into the surface material during touchdown did not exceed 5 cm (2in), according to present measurements.

The distribution of craters and rock-like features near Surveyor III is not different than that observed by Surveyor I. Large blocks were more frequent around some of the 10 m (33 ft) to 15 m (49 ft) diameter craters near Surveyor III. Blocks up to 4 m (13 ft) long were visible from the spacecraft. Some of these were angular or flat; others were more rounded. Sizes of individual visible particles extended down to the  $1.0\ \mathrm{mm}\ (0.04\ \mathrm{in})$  limit of camera resolution; over 85%of the exposed surface consisted of unresolved finer material. The surface retained a clear imprint of the bottom of a footpad which had ridges of the order of 60 microns high. The surface material probably contains a considerable fraction of material smaller than 60 microns in diameter, and an appreciable fraction smaller than 10 microns. The fine matrix tends to pile up slightly on the uphill side of the larger blocks, suggesting that it slowly moves downhill." (2)

"Bright angular-to-rounded pieces of fragmental debris are the most conspicuous features in the Surveyor III pictures. The observed fragments which range in size from about 1 mm to 4 m in longest dimensions are scattered somewhat irregularly and, in most places, sparsely over most of the visible parts of the lunar surface. Except in two prominent strewn fields of course blocks, the resolvable fragments occupy no more than about 14% of the surface."

"All of the recognizable fragments are conspicuously brighter at high sun than the rest of the lunar surface. Although the brightness is, in part, dependent on the orientation of the surface of the fragments, it is clear that the fragments have a higher albedo, in some cases perhaps as much as 30% higher than the average albedo of the rest of the surface." (3)

### 4.3.2 Illumination Environment

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From the standpoint of astronaut visibility on the lunar surface the significant aspects of the illumination environment are:

Incident solar illumination
Lunar surface photometric function
Shadows
Effect of glare on visibility
Reflectances of LM, Pressure suit, ALSEP, other lunar surface
 equipment
Light transmission and optical characteristics of the helmet and
 EVVA

Performance criteria which must be considered include detection ranges of blocks and craters for the astronaut in LM and on the lunar surface, ability to inspect geological samples from a standing position and close up, ability to perceive fine detail required to deploy and activate the ALSEP and the protection of the eyes from excessive light, ultraviolet, and other radiation.

Detection ranges for several conditions of astronaut eye height (equivalent to standing on the surface, and on the LM) sun angle, slope and crater type (Figures 4.4.2-1,2,3) were computed by Goetz (6) of Bellcom. The surface was assumed to be a horizontal plane containing rimless craters, raised rim craters and blocks. The limit of detection was calculated for conditions of contrast equal to or greater than .01 and a limit of visual angular resolution of 0.5 milliradians. The study did not consider intermediate visibility gaps due to "washout" at zero phase angle, nor were the effects of glare considered. The calculations and figures thus represent optimum viewing conditions and for many expected mission conditions, are quite realistic.

Because of the low sun angles under consideration it will be difficult to eliminate glare as a major factor in most of the astronauts' activities on the lunar surface. According to Holliday (7) and others the effect of a glare source in the field of view can be equated to an overall veiling luminance which interfere with vision to the same degree. The effect is to decrease the apparent contrast and to raise the adaptation level of the eye. Application of the Holliday equation (see section 5.6) will show large decreases in detection ranges as the astronaut faces toward the direction of the sun.

It is possible to shield the eyes from the sun with a visor, but with a sun angle on the order of 10° a chance glance at the sun will be difficult to avoid in a number of instances. This will result in "flash blindness" which can require on the order of 2-20 sec to regain adequate vision into low luminance areas. Longer recovery times can occur in some instances. The recovery time depends on the magnitude and duration of the flash, the adaptation level of the eye, and the sensitivity required to perform the criterion task. Figure 4.4.2-4 (section 4.4.2) shows representative recovery time as a function of flash and target luminances. The data are from a very limited number of subjects and thus are useful only as a general guide.

# 4.3.3 Tasks during EVA - Lunar Surface

Inspection of LM. The astronaut(s) will inspect the LM from the lunar surface. In circling and viewing the LEM he will be exposed to a very wide range of luminance conditions. On the sun side his visibility of the LM will be affected by incident solar illumination, light reflected from the lunar surface, light reflected from the LM. Specular reflection is possible from a number of places on the LM exterior. Such reflections will be high luminance glare sources which can significantly interfere with detailed visual inspection.

In the shadow area of the LM there will be little or no illumination on the LM surfaces. Illumination can only come from reflection from the lunar surface (from the area not in the LM shadow).

It can be seen that visual inspection of the shadow side of the LM will be difficult or impossible without auxiliary illumination or possibly a controllable reflector which can be placed in the sunlit area.

Traversing Surface and Collecting Samples - The problems of obstructions and shadows have been mentioned in the section on Lunar Surface Characteristics. The astronaut must be able to safely walk on the lunar surface, avoid obstacles, and detect and collect samples. Samples picked off or chipped from the lunar surface are placed in containers for carrying back to the LM. The astronaut will take sightings to determine the locations of the samples and of other features of interest.

[Details of exploration and sighting tasks are not known in sufficient detail to comment further.]

The tasks difficulty will be strongly affected by suit, helmet, EVVA, and equipment characteristics.

Deployment of the ALSEP - Deployment of the ALSEP requires a number of detailed tasks which must be performed accurately. At several stages in the deployment process the astronaut is required to actuate latches and levers. Several experiments must be aligned and leveled with moderate accuracy (on the order of  $\pm$  5°). The telemetry antenna must be pointed at the earth with considerable accuracy.

The visual problem generally centers around the level of solar illumination, the high reflectance of ALSEP surfaces, the considerably lower reflectance and unique photometric characteristics of the lunar surface and the absence of light in shadow areas. The luminance and contrast levels will degrade visual performance.

In order that the astronaut may safely walk on the lunar surface under the constraints established by the pressure suit, PLSS, lunar gravity, and scientific equipment it is necessary that the surface be relatively free of obstacles and that those which exist are readily visible. The surveyor data indicate that areas do exist which are sufficiently free of rocks and craters to allow safe traverse.

Large rocks or a relatively high density of small rocks can create problems because of extensive shadowing. Figure 4.4-1 shows non-dimensional shadow length as a function of sun angles. For the low sun angles under consideration it can be seen that large or closely spaced rocks can cause extensive shadowing of an area. The lack of an atmosphere results in a complete lack of light scatter (and thus visibility) into shadow areas unless incident light is reflected into the shadows by other surfaces (lunar objects, space suit, reflectors, etc.). Shadow areas approximately equal to or larger than footprint could contain hidden rocks or holes large enough to cause the astronaut to stumble.

# 4.3.4 Distance Perception

"Perception of absolute and relative object distances depends on the relationships of several variables to distance from the observer. These variables include stereoscopic information, variation of object size with distance (aerial perspective), linear perspective, relative sizes of "known" objects, and interposition of objects.

A significant lunar effect on distance perception will be the variation in contrast and absolute luminance that occurs with changes in solar and viewing angles. Thus, the astronaut will not be able to use a constant size-illumination relationship for judging distance. Furthermore, as the characteristics of natural objects on the lunar surface do not change as a function of size, the apparent size of an object will not provide distance information. These conditions can be expected to severely degrade distance perception. Thus, the astronaut should not be required to estimate distances during EVA and his position should be monitored until his distance perception capability is tested.

- Rennilson, J.J., Holt, H.E., and Morris, E.C., "In Situ Measurements of the Photometric Properties of an Area on the Lunar Surface", PD 602-23, 1 September 1967, Jet Propulsion Laboratory, Pasadena, California.
- 2. Surveyor III: A Preliminary Report NASA SP-146 p. 1,2.
- 3. Surveyor III: A Preliminary Report NASA SP-146 p. 22,24.

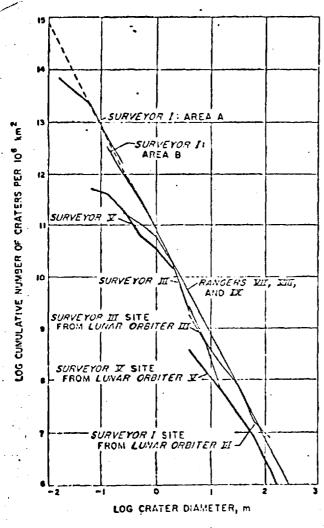


FIGURE 3-11.—Size-frequency distribution of small craters at the Surveyor V landing site compared with the size-frequency distribution of craters estimated for the Surveyor I and III landing sites, and the mean size-frequency distribution of small craters on the luming planes determined from Ranger VII, VIII, and IX pictures.

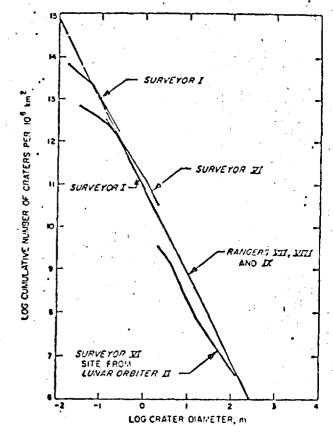


FIGURE 3-15.— Cumulative size-frequency distribution of small craters determined from Surveyor VI pictures and Lunar Orbiter II photographs compared with the cumulative size-frequency distribution of small eraters determined from Surveyor I pictures and on the mare planes determined from Rangers VII, VIII, and IN pictures.

Surveyor V: A Preliminary Report NASA SP-163, December 1967 p. 21 Surveyor VI: A Preliminary Report NASA SP-166, March 1968 p. 27

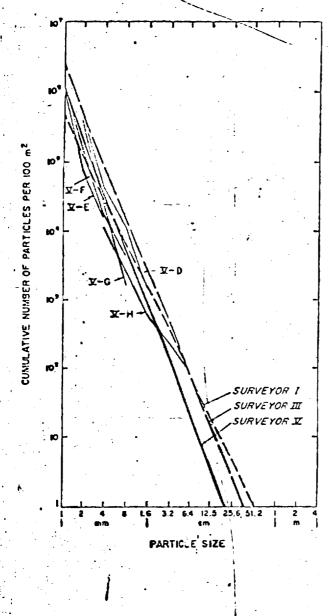
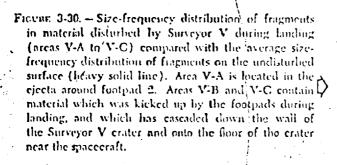
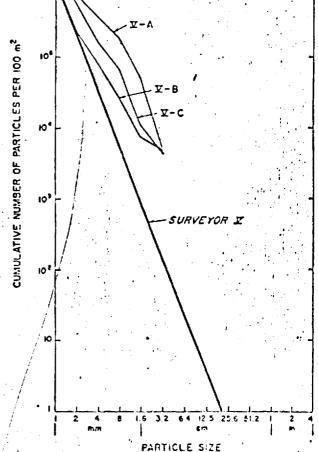


Figure 3-29. — Size-frequency distribution of fragments on the undisturbed surface around Surveyor V (solid line) compared with the average size-frequency distribution of fragments at the Surveyor I and III landing sites (dashed lines).





Surveyor V: A Preliminary Report NASA SP-163, December 1967 p. 21 10

4.3.5 Lunar Surface Illumination - Figures 4.3.2-5 and 6 are adapted from reference 4 and 3 respectively, to indicate representative lunar surface brightness as seen by the astronaut on the surface for 5° and 10° sun elevation angles. On these figures, the observer is located at the center of the semicircle with an assumed eye height of 5 ft. The semicircles represent distance from the observer. The heavy black lines (in Figure 4.3.2-5) represent lines of equal coefficients while in Figure 4.3.2-6 the coefficients are given at specific points. The surface brightness in ft-L is given by x 13,000 x local albedo. Local albedo for the lunar surface ranges from approximately 0.05 to 0.18. For example, using Figure 4.3.2-5 and neglecting glare effects, an observer looking 90° to the sun line at a point on the surface 20 ft away would see a surface brightness (for an assumed albedo of 0.100) of 0.10 x 13,000 x 0.10 or 130 ft-L. Looking more towards the sun along the 120° meridian (still neglecting glare) the surface brightness would be reduced to approximately 65 ft-L. Since the extravehicular visor is to have approximately a 10% transmittance in the visible spectrum, the light reaching the eye would be further reduced by a factor of 10. Look angles can vary from almost 90° (looking straight down) to almost zero (looking at the horizon). A 45° look angle may be considered reasonable for walking. Considerations of glare, shadows, and lunar reflectivity data thus rule out traverses from LEM at any angles near the sun azimuth angle. Using the referenced figures surface reflectance data were calculated for a flat surface with an albedo of 0.1, 3 azimuth angles (45, 90, 135) and 2 look angles (45° and 5.7) and are shown below:

5° Sun

Look Angle	Azimuth Angle					
	45°	90°	135°			
.45°	71.5	58.5	39.0			
5.7	510	195	65			

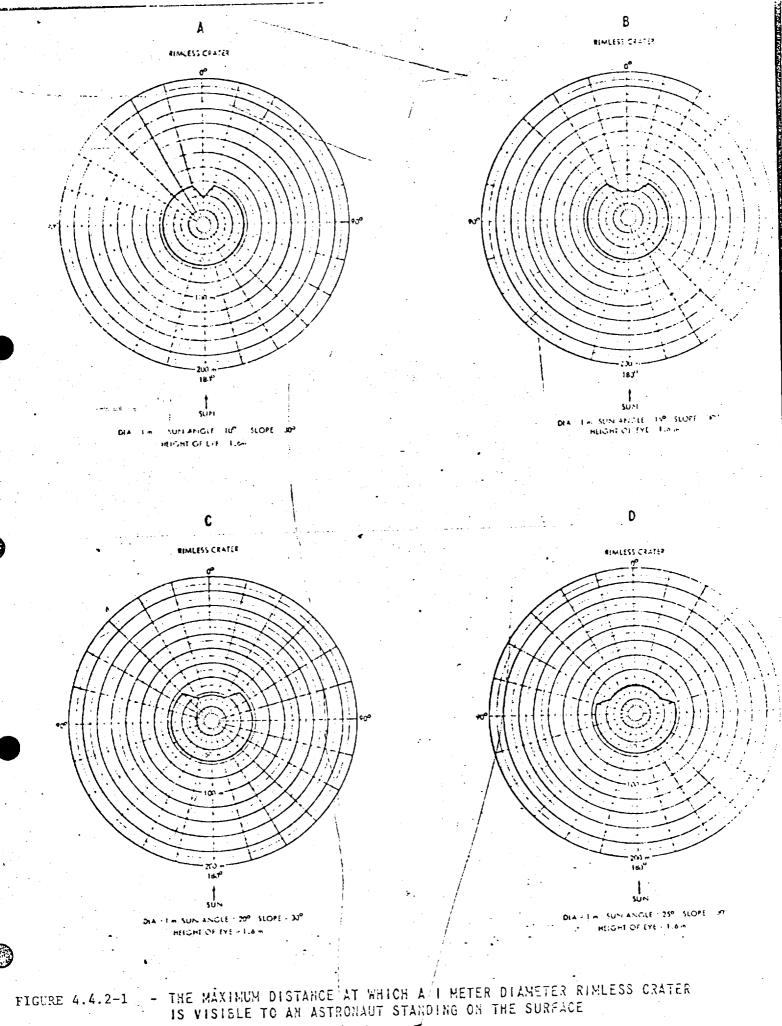
Values ere in ft-L

10° Sun

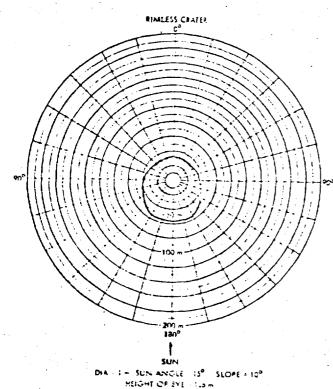
Look Angle	Azimuth Angle						
	45°	90°	135°				
45°	143	112	58.5				
5.7	510	234	91				
L	<del>/-/</del>	<del>}</del>	<del></del>				

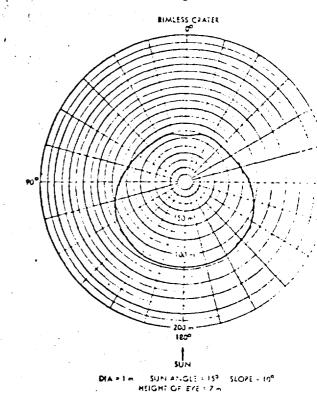
Veiling luminance due to glare from the sun for the 45° look angle and 135° azimuth was calculated, according to the Holliday equation, to be approximately 139 ft-L. It is obvious that serious interference with visibility can exist over a fairly large range of look and traverse angles. It appears that the traverse angles for the astronaut on the lunar surface must be well within 45° of a perpendicular to the sun line.

The Bellcom data (6) on lunar surface visibility should therefore be expanded and corrected for glare effects to more completely define the visual conditions. The calculations should also take into account the characteristics of the EVVA and helmet assemblies.



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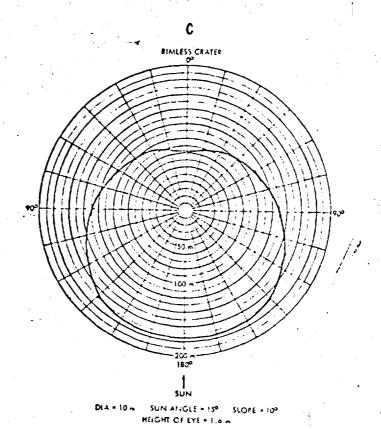
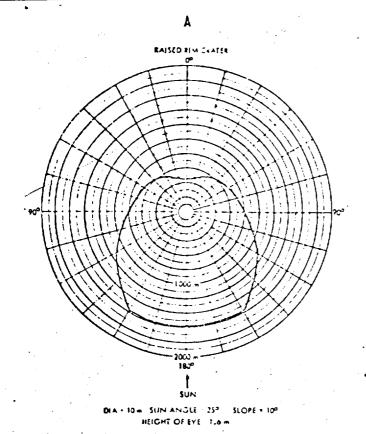


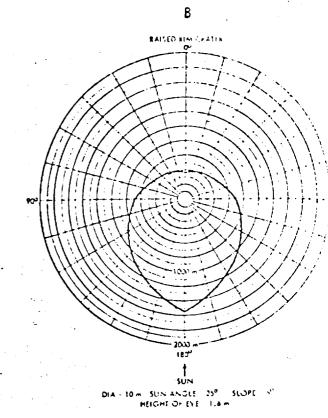
FIGURE 4.3.2-2 - A,3, COMPARISON OF THE VISIBILITY OF A 1 METER DIAMETER RIMLESS & CRATER FROM THE SURFACE AND FROM THE LM ROOF.

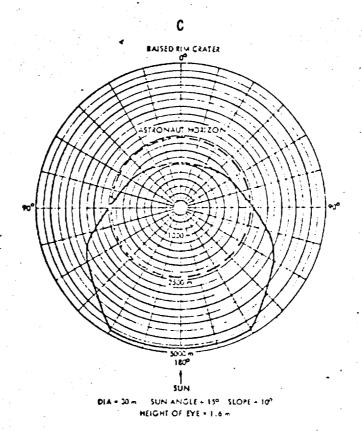
C, VISIBILITY OF A 10 METER DIAMETER RIMLESS CRATER FROM THE SURFACE

- 1/6-



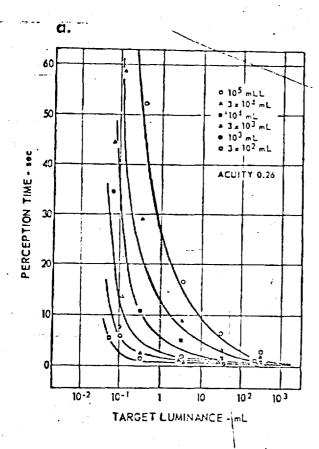
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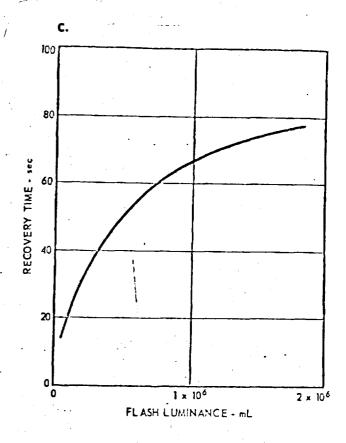


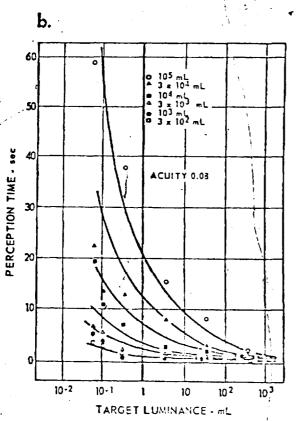


-117-

FIGURE 4.3.2-3 - THE MAXIMUM DISTANCE AT WHICH RAISED RIN CRATERS OF DIFFERENT SIZES AND SLOPES ARE VISIBLE FROM THE SUPERIOR







Flash blindness is the transient loss of vision for objects of low luminous intensity following an exposure to brief but intense general illumination. Figures a and b at left illustrate the times needed to perceive targets requiring two levels of visual acuity--0.25 for the upper curves, and 0.08 for the lower. Short "adapting" flashes were used, having various intensities as indicated by keying of the individual curves. Figure c shows the effect of 0.1 second flashes of much higher intensity on the ability of the eye to detect a large target, which subtended an angle of 17 min and which had a luminance of 0.7 mL. The brighter the flash, the longer was the recovery time.

Sources: Metcalf and Horn [17] and Brown [5].

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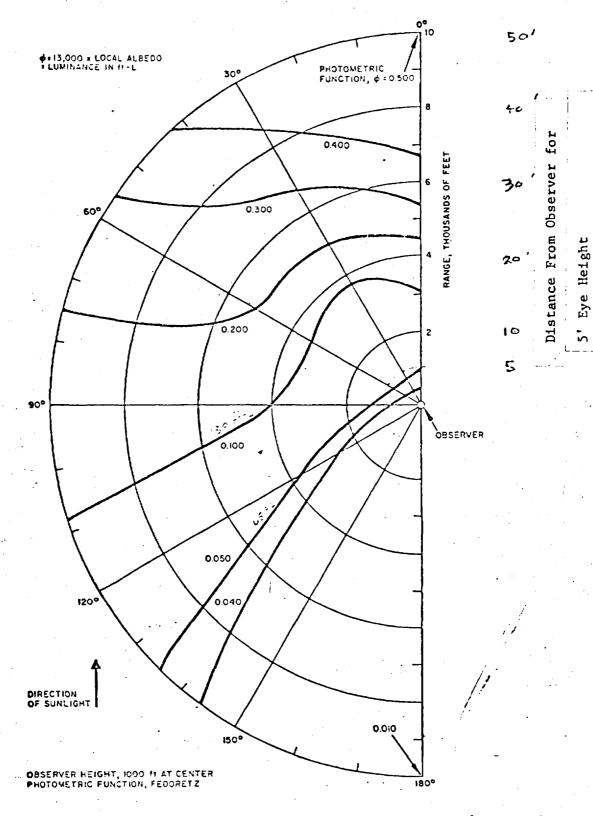
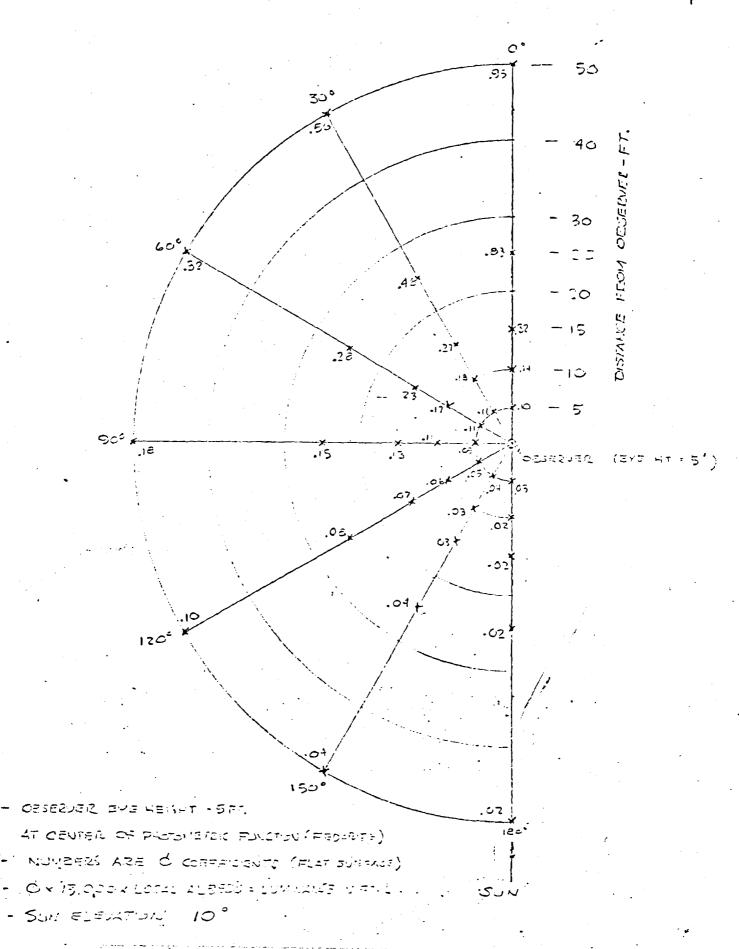


FIGURE 4.3.2-5 - Background Brightness Value Expressed in Photometric Function Values Range at 5 Degrees Sun Elevation



- GENERAL REFERENCE DATA
  - 5.1 Natural Lighting
  - 5.1.1 Stellar Illumination and Magnitude

The illumination from a 1st magnitude star at the earth's surface is

$$8.2 \times 10^{-8} lweens/ft2$$

$$8.8 \times 10^{-7} \text{ lumers/m}^2$$

In space the value is about 30% greater or

11.7 x 
$$10^{-8}$$
 lumens/ft<sup>2</sup>

$$12.5 \times 10^{-7} \text{ lumens/m}^{-2}$$

One stellar magnitude represents a ratio of illumination of 1: \$\sqrt{100}\$ or 1: 2.5119. Using the illumination of a 1st magnitude star as a standard, the illumination produced by a source of magnitude m, is

$$E_{m} = \frac{(2.5119)^{1-m}}{8.2 \times 10^{5}} \qquad lumens/ft^{2}$$

$$= \frac{(2.5119)^{1-m}}{8.8 \times 10^{7}} \qquad lumens/ft^{2}$$

$$E_{m} = \frac{(2.5119)^{1-m}}{11.7 \times 10^{3}} \qquad lumens/ft^{2}$$

$$= \frac{(2.5119)^{1-m}}{12.5 \times 10^{7}} \qquad lumens/ft^{2}$$

Solving the above for m in terms of E gives,

$$m = -2.5 \log E_m - 16.62 (E_m = lumens/ft^2)$$

= -2.5 log 
$$E_{m}$$
 - 14.25 ( $E_{m}$  = lumens/ $m^{2}$ )

earth's surface

earth's surface

in space

$$m = -2.5 \log E_m - 16.25 (E_m = lumens/ft^2)$$
  
= -2.5 log E<sub>m</sub> - 13.83 (E<sub>m</sub> = lumens/meter<sup>2</sup>) in space

Thus, a difference in magnitude of about -0.4 exists between inside and outside the atmosphere.

If the luminous intensity, I, of a source is known, the illumination produced by it at a distance R will be

$$E_R = \frac{I}{R^2}$$

where I is in candles, and  $E_{R}$  is in the same units as R. The magnitude of a source as a function of distance will be

$$m = -2.5 \log \frac{I}{R^2}$$
 -16.25 where R is in feet  
= -2.5 log  $\frac{I}{2}$  -13.83 where R is in meters

Values of m for various celestial sources are given in Table 1.

Table 1
Visual Stellar Magnitude for Major Celestial Sources

Source		•		Magnitude			
•	•• •	•		Earth Surface	In Space		
Sun		•		- 26.72	- 27.12		
Moon				- 12.55	- 12.95		
Venus*		•		- 4.07	- 4.47		
Jupiter			•	- 2.23	- 2.63		
Mars				- 1.85	- 2.25		
Mercury*				0.16	-0.24		

at elongation

## 5.1.2 Solar Illusination

The spectral energy distribution of solar radiation incident on the Earth's atmosphere is shown in Figure 1 and values of spectral irradiance (incident energy flux per unit area per unit wavelength) are given in Table 2. These values apply when the Earth is at its mean distance from the sun. The data are from Johnson.

The solar constant is the total solar irradiance at the top of the Earth's atmosphere and has the value  $0.140~{\rm watt/cm}^2$ . It is the integral of the curve in Figure 1. The luminous energy due to solar irradiance is given by the expression

(1) 
$$\phi_{s} = K_{m} \int H(\lambda) V(\lambda) d\lambda$$

where  $\phi_s$  = solar luminous flux (lumens/unit area)

 $H(\lambda)$  = energy density (watts/unit area unit wavelength)

 $V(\lambda)$  = relative luminous efficiency (visual)

The value of  $\phi_s$  was calculated from the data in Table 2 using values of  $K(\lambda)$  from 0.35 $\mu$  to 0.75 $\mu$  in steps of 0.01 $\mu$ . The result was 13.71 lumens/cm² or 12,745 lumens/ft² (footcandles). This value is slightly greater than that used by Hardy which was 13.5 lumens/cm². The difference is minor considering seasonal variation in solar radiation and lack of an agreed upon weighting for the basic data.

### Solar Luminance

The average luminance of the sun is given by

 $L = \phi_s$ /average solid angle =  $\frac{lumens}{unit area \cdot steraiian}$ 

-123 - or caniles/unit area

The sun subtends an engle of about 32 arc min at the mean distance, giving a solid angle of

$$\Omega = \left(\frac{32}{60 \times 57.3}\right)^2 \cdot \frac{\pi}{4} = .682 \times 10^{-4} \text{ steradian}$$

and

$$L = \frac{13.71}{.682 \times 10^{-4}} = 2.01 \times 10^5 \text{ candles/cm}^2$$

# Luminance of the Surlit Earth

Assuming  $\phi_s = 13.71$  lumens/cm<sup>2</sup> and an average Earth alcedo of 0.4, the luminance of the Earth is 1.16 candles/cm<sup>2</sup> (see Section 5.3). A list of typical local albedos is given in Table 3.

To be supplied: graphs of Earthshine and Moonshine as a function of phase.

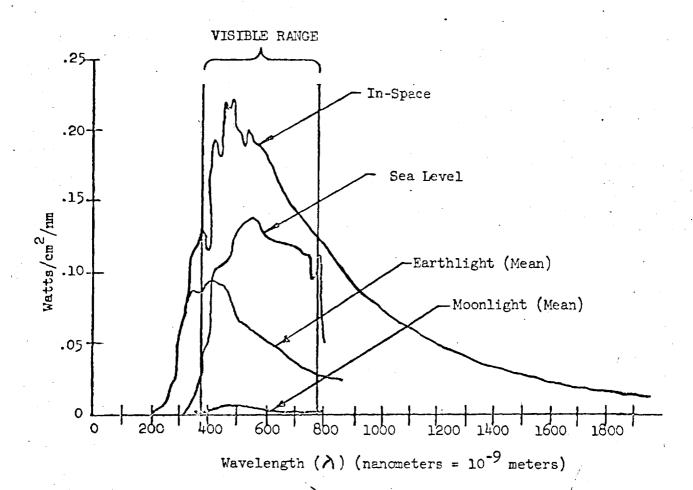


Figure 1 Solar Spectral Energy Distribution
(From "Satellite Environment Handbook," by F. S. Johnson)

# Table 3

Forests	0.07
Grass	0.15
Bushes	0.10
Sand	0.25
New Snow	0.70
Old Snow	0.55
Ice	0.55 to 0.70
Lakes and Water	0.07
Ocean	0.065 - 0.070
Clouds:	
Low	0.69
Middle	0.48
High	0.21
Cumuliform	0.70

(From H. G. Houghton's "On The Annual Heat Balance of The Northern Hemisphere," Journal of Meteorology, Feb. 1954)

# 5.1.3 Luminance Calculations

## Sphere Illuminated by a Point Source

The expressions for the intensity of a sphere illuminated by a point source are

Specular surface:  $I = \frac{r^2}{4}$ , E

Diffuse surface:  $I = \frac{2 r^2}{3\pi} (\sin 0 + (\pi - \theta) \cos 0) E$ 

where r = sphere radius, E = illumination, and  $\theta$  = phase angle between sphere and line of sight.

Note that the intensity of the specular sphere is independent of phase angle. The two types are equally intense when viewed at 83.7 degrees.

# Illumination et a Point S

The illumination at a point due to a point source is given by:

$$E = I/R^2$$

where E = illumination, I = source intensity and <math>R = range. The illumination at a point due to a uniformly illuminated, diffuse sphere is

$$E_R^{\int} = \frac{L r^2}{R^2}$$

where L = sphere luminance (ft-L), r = sphere diameter, and R = distance to center of sphere.

Note that  $E_R$  obeys an inverse-square law for a source of intensity L . The assumption of uniform illumination is fairly reasonable for the Earth if viewed at zero phase angle, due to atmospheric scatter.

# Flat Disc Illuminated by a Point Source

For a perfectly diffuse or Lambert disc of reflectance  $\rho$ , the intensity of a surface element  $\Delta$  A, illuminated by a point source at angle,  $\emptyset$ , and viewed from angle  $\Theta$  will be (see Figure 2):

$$\Delta I = \frac{\rho E}{\pi} \Delta A \cos \beta \cos \theta$$

where E = illumination from source in lumens/ft<sup>2</sup> and I = intensity in candles. The total intensity of the disc will be:

$$I_D(\emptyset, \theta) = A \Delta I = \rho Er^2 \cos \theta \cos \theta$$

where I is in candles, r = radius of disc. Note that intensity is defined only for viewing distances large compared to the size of the source.

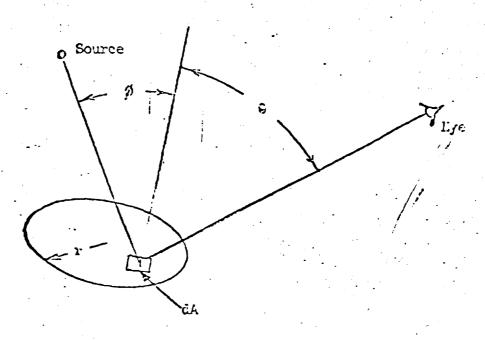


Figure 2

Calculation of Intensity of a Flat Disc

Table 2
SOLAR-IDRADIANCE DATA

SOLAR-SPECTRAL-TERADIANCE DATA-0.22 TO 7.0 MICRORS

		<u> </u>									<u> </u>
<b></b> .	$H_{\lambda}$	P,	A -	H,	P,	1	$H_{\mathbf{x}}$	2,	λ -	$H_{\lambda}$	· P <sub>X</sub>
(*)	(w/cm²#)		(نه)	(w/cn/#)	(S)	(=)	(w/cm14)		(-)	(w/cm/a)	
0.22	0.0030	0.03	0.375	0.120	3.54	0.57	0.127	33.2	1.9	0.01274	
0.225	0.00.2	0.03	0.40	0.154	9.03	0.575	0.107	23.9	2.0	0.01079	
0.23	0.0032	0.03	0.405	0.103	9.65	G.53	0.137	\$4.5	2.1	0.00017	91.50
0.235	0.0054	0.67	0.41	0.194	1û.3	0.535	0.185	35.2	2.2	0.00785	95.2)
0.24	0.0353	0.69		0.192	11.0	0.59	0.131	33.9	2.3	0.00373	95.71
									١		
0.245		6.11			11.7	0.525		25.5	2.4		
0.25					12.4	0.60	0.131	37.2	2.5	0.0350	
0.255		0.16			13.0	0.61	0.177	33.4	2.4		
0.25	0.013		0.435		13.7	0.62	0.174	39.7	2.7	0.00000	
0.255	0.020	0.27	0.∻∔	0.203	14.4	0.63	0.170	40.9	2.3	0.00313	97,47
0.27	0.025	0.34	0.4-15	0.215	15.1	0.64	0.163	42.1	2.9	- 0.00003	97.72
0.275			C.+5		15.9	0.65	0.162	45.3		0.00013	97.50
0.23	0.024	0.51			16.7	0.55	0.159	4.5	3.1		\$2,03
0.235		0.62			17.5	0.67	0.155	45.5			93.24
0.29	0.052	0.77			13.2	0.63	0.151	-3.7		0.03191	93.39
V.27	0,002	<b></b>	0.102	0.2.5		0.00	0.451		5.5	0.02171	,,,,,
0.295		0.53			19.0	0.69	0.143	47.3		0.03171	
0.30	0.031	1.23	0.475		19.3	0.70	0.144	43.0	3.5	0.03153	90.63
0.305	0.057	1.43	0.43		20.6	0.71	0.141	49.3	3.6	0.00139	93.74
0.31	0.076	1.59	0.435	0.203	21.3	0.72	0.137	ઇ૪	3.7	0.00125	\$3.83
0.315	0.032	1.97	0.49	0.159	22.0	0.73	0.134	51.3	3.8	0.00114	93.91
								• •	!		A) 00
0.32	0.035	2.26	_		22.8	0.74	0.123	52.7	3.9		
0.323		2.60	0.50		23.5	0.75	0.127	53.7	4.0	0.00005	99.05
0.33	0.115	3.02	0.535		24.2	6.20	0.1127	57.9	4.1	0.00037	
0.335		3.40	,		24.9	0.85	0.1003	61.7	4.2	0.00000	50.18
0.34	0.111	3.83	0.515	0.189	25.6	0.90	0.805	65.1	4.3	0.00073	57.23
0.345	0.117	4.21	0.52	0.157	26.3	0 6:	0,0003	డు.1	414	6.00037	\$2.29
0.35	0.113	4.63	0.525		25.9	1.0	0.0025	დ.1 70.9	4.5	0.00031	99.33
0.35		ಕ.ಬ 5.04	0.53		25.9 27.6	1.1	0.0723	75.7		0.00005	\$2.33
0.35	0.116	3.47	0.535		23.3	1.1	0.0303	79.6	7.5	0.00005	\$7.35
0.35	-	_								0.000351	
0.333	0.129	5.89	0.54	0.193	29.0	1.3	0.0005	82.9	ે.ઽ	0.00043	59.45
0.37	0.133	6.36	0.545	0.193	<b>2</b> 9.8	1.4	0.0328	85.5	4.9	0,00014	99.43
0.373	0.132	6.84	0.55	0.195	30.5	1.5	0.0257	87.6	5.0	0.00042	99.51
0.33	0.123	7.29	0.555	0.192	31.2	1.6	0.0220	\$9.4	6.0	0.00021	\$9.74
0.133		7.72	0.55	0.190	31.3	1.7	0.0132	ಣ.ಚ	7.0	0.00012	\$2.00
0.37	0.112	8.13	0.555		32.5	1.8	0.0152	92.03			
						<u> </u>			<u> </u>		

Johnson (1954), reproduced with parmission of American Meteoralogical Society.  ${}^{\bullet}\lambda$  is wavelength;  $H_{\lambda}$  is spectral irrediance; and  $P_{\lambda}$  is the paramitage of the solar constant associated with wavelengths shorter than  $\lambda$ .

(From "Satellite Environment Handbook," by F. S. Johnson)

### 5.2 VISUAL REFERENCE DATA

# 5.2.1 Photometric Units

Many different terms and systems of units are used to treat the measurement of light and perception. Often the same term is used to refer to different quantities, and, conversely, different terms are used to refer to the same quantity. The lack of uniqueness, in addition to everyday connotations of much visual terminology, often confuses the reader not familiar with photometry, physiology and perceptual psychology. The purpose of this section is to briefly describe such terminology and the relevant visual principles. No attempt is made to derive photometric units in detail or to completely discuss visual perception.

## 5.2.1.1 Radiant Flux

The visual system responds to radiant energy in the wavelength band from about 400 to 700 millimicrons ( $m\mu$ ). The total amount of radiant flux in any given wavelength band is generally specified in terms of watts. Radiant flux is the amount of radiant energy striking a surface per unit time.

The spectral density of radiant flux is the amount of radiant flux per unit wavelength for a given source. For example, in the measurement of the spectral output of a lamp, the measuring instrument will accept a finite band of wavelengths, say 10 m $\mu$  wide. Thus, for that acceptance band the radiant flux,  $P_{\lambda}$  measured for a center wavelength,  $\lambda$ , must be divided by 10 if the spectral density is to be stated in terms of one millimicron wavelength units (watts/ $m\mu$ ).

## 5.2.1.2 Luminous Flux

Equal emounts of radiant flux of different wavelength compositions will not, in general, appear equally bright. For example, a wavelength of 550 mm (green under normal conditions) will appear brighter than a wavelength of 450 mm (blue under normal conditions) of equal energy. Obviously, in order to design lighting systems, it is convenient to be able to predict the relative brightness of different sources, without the requirement of testing each one.

Such a procedure was developed during the 1920's and 1930's and is now standard in the lighting field. Essential to the procedure are the assumptions that:

o All wavelengths can be assigned weights which give the relative amounts of radiant flux required to equate any two wavelengths in brightness.

o The relative brightnesses of two sources of different wavelengths compositions can be found by integrating the product of the weighting function and spectral density function and comparing the resultant sum.

The weighting function is termed the relative luminous efficiency function  $(V_{\lambda})$ . The quantity obtained from the above integration is termed luminous flux, i.e., it is radiant flux weighted according to the response of the visual system. That is,

$$(1-1) \qquad \emptyset = K_{m} \int P_{\lambda} V_{\lambda} d\lambda$$

where

 $\phi$  = luminous flux in lumens

 $P_{\lambda}$  d<sub> $\lambda$ </sub> is the radiant flux between  $\lambda$  and  $\lambda + d\lambda$  i.e., flux density in watts/wavelength

 ${f v}_{m \lambda}$  is the relative luminous efficiency function

 $K_{\underline{m}} = constant$  to convert from watts to lumens

= 680 lumens/watt, for daylight vision (see below).

Two  $V_{\lambda}$  functions are specified as standards. The reason for two is that the eye changes its spectral response characteristics as a function of illumination level, thus the relative brightness of two sources will also depend on the illumination level. One  $V_{\lambda}$  function is used for high levels of illumination (e.g., daylight) and the other for low levels (e.g., starlight). The  $V_{\lambda}$  functions corresponding to high levels is referred to as the photopic curve and the function corresponding to low levels as the scotopic curve. These are shown and

The change in spectral response is due to the change from the cone receptors to the rod receptors as the illumination level is lowered. A continuous sequence of V, curves can be obtained in the transition range from high to low levels termed the mesopic range. The comes are densest in the central area of the retina and provide greater resolution but less sensitivity than do the rods, which are densest in the periphery of the retina. The comes also provide color discrimination whereas the rods only allow a light-dark discrimination.

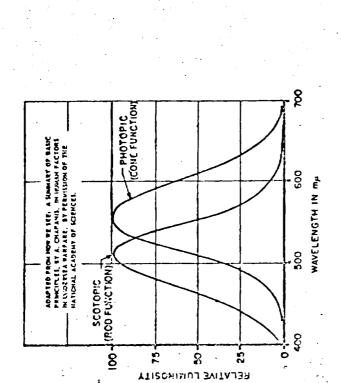
described in Figure 5.2-1\*\*

The unit of luminous energy as defined by Equation 1-1 is termed the lumen. The lumen is a measure of the brightness producing capacity of a radiant source. Under normal viewing conditions two sources of equal luminous flux will be judged equally bright. The original purpose of a measure which allows one to equate different light sources is thus accomplished. However, perceived brightness and luminous flux are not, in general, simply related. It is useful, therefore, to discuss the difference between brightness and luminous flux.

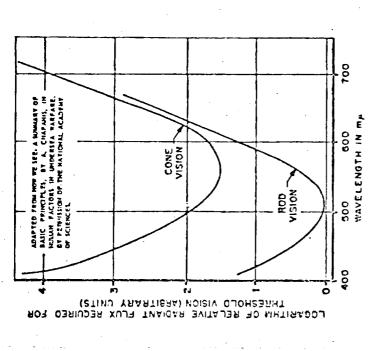
## 5.2.1.3 Luminous Flux Versus Brightness

It is important to note what has not been accomplished in the determination of luminous flux. First, quantitative statements predicting the amount of perceived brightness differences between two sources cannot be made from a knowledge of their corresponding luminous fluxes. For instance, in general a two-lumen source will not appear twice as bright, that is, will not be judged as twice as bright, as a one-lumen source. Second, two sources of the same luminous flux may not, in fact, appear equally bright unless certain conditions are satisfied. The most important of the conditions is that the two sources under comparison must be focused on retinal areas of equal sensitivity and that the adaptation level of each area must be the same (adaptation level refers to the sensitivity of the eye and is related to the history of light exposure). Obviously, the matching experiments from which the standard curves were obtained satisfied such conditions. An exception to these conditions can be easily demonstrated. Close one eye for five or ten minutes

A schematic illustration of the manner in which the V, function was obtained is: Choose a given narrow bandwidth radiant energy source of wavelength  $\lambda_1$  and radiant flux  $\beta_1$ . Coserve a second source of wavelength  $\lambda_2$  and radiant flux  $\beta_2$ , and adjust it until  $\lambda_2$  appears equally bright as  $\lambda_1$ . Assign  $\lambda_2$  a weight of  $\beta_1/\beta_2$ . Continue in this manner throughout the visible portion of the spectrum. Finally, normalize the weights so that the most effective wavelength has a weight of 1.0 and all others have smaller values. The resulting curve is the relative luminous efficiency function. The unit of luminous flux, the lumen, is defined as 0.00147 watt at a wavelength of 555 mm. The basic photometric standard, from which the above value was determined, is the luminance (defined below) of a black body at the temperature of solidification of platinum.



Relative luminosity functions  $(V_{\lambda})$  for photopic and scotopic vision. Maxima of curves equated at relative luminosity of 100.



Relative amounts of radiant flux required to stimulate rods and cones. Relative distance between curves is accurate, flux units are arbitrary.

Figure 5.2-1. Rod and Cone Sensitivity Functions (Figures taken from Reference 4, p. 106-107.)

in a brightly illuminated room. Then alternate between your two eyes. The scene appears brighter with the dark adapted eye than it does with the eye that was kept open.

Another example of an exception is to surround an area of constant luminous flux with an area of variable flux. The central area will darken as the surround flux is increased.

Thus, a difference in brightness can occur between two sources of equal luminous flux. Luminous flux is obtained from a weighting function based on a standard observing condition (hence sometimes termed "objective"); whereas brightness is obtained from judgments of an observer in a given situation (hence, sometimes termed "subjective") and is a complex function of the illumination history and other factors, as well as of the luminous flux present at a given time. Luminous flux is a useful measure for the specification of lighting levels. If the visual response (perceived brightness) of an observer is desired in a given situation then factors other than luminous flux may need to be considered.

Brightness as a function of adaptation level and other conditions has been studied, but the determination of brightness in an arbitrary viewing situation remains a difficult problem. The distinction between brightness and luminous flux is often confused both in everyday use and in the technical and scientific literature. The term brightness is most commonly used incorrectly where a luminous flux measure is appropriate. A set of brightness functions is illustrated in Figure 5.2-2.

# 5.2.2 Photometric Quantities

Several kinds of measures (photometric quantities) are derived from the basic definition of luminous flux. In principle, these measures are analogous to radiometric quantities, the only difference being that luminous flux replaces radiant flux. In practice, however, various

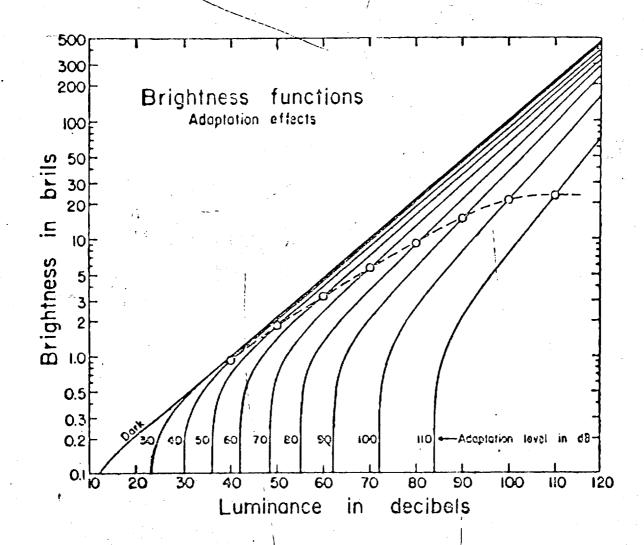


Figure 5.2-2. Brightness Functions for Various Levels of Adaptation. Each curve represents a brightness (brils) versus luminance function at a given adaptation level. The data were obtained from subjects' ratings of the brightness of a 5° circular target which was exposed for 2 seconds after the extinction of a 58° adaptation field. The dashed line is the equilibrium brightness, i.e., the judged brightness of the test spot after the eye is allowed to adapt to the target luminance. Note that the equilibrium, brightness function covers a smaller dynamic range than the non-equilibrium functions. Graph reproduced from Stevens, J. C. and Stevens S. S. "Brightness Function: Effects of Adaptation," J. Opt. Soc. Amer. 1963, 53, 375-385. (O dB = 10-10 lambert, 1 ft-L = 70.3 db. 1 bril = brightness seen under above conditions for target luminance of 40 dB re 10-10 lambert, or 1 micro-Lambert.)

photometric quantities are in use. Furthermore, several photometric units may exist for each quantity, including metric and non-metric. The choice of a particular unit or photometric system in a given application has largely depended on the idiosynchrocies of the particular investigator. Much confusion has resulted.

The basic photometric quantities and their most common units are described in this section. A set of metric units has been accepted as standard by the International Commission on Illumination (CIE) and appear in Reference (1). The relationships among the different units and possible sources of confusion are described below.

## 5.2.2.1 Luminous Intensity (I)

Luminous Intensity (I) is analogous to radiant intensity and is the amount of luminous energy emitted from a point source per unit solid angle, i.e.,  $I = \frac{d\phi}{d\omega}$ , where  $\phi = \text{luminous flux and } \omega$  is solid angle.\*

The unit is the candle (cd) which is equal to one lumen/steradian.

For example, a typical 100 watt household lamp emits a total flux of 1700 lumens. If this flux is evenly distributed over a sphere surrounding the lamp, then its luminous intensity is:

 $I = 1700/4\pi = 135 \text{ lm/steradian or } 135 \text{ cd.}$ 

 $\omega = A/R^2$ 

One steradian is the solid angle subtended at the center of a sphere by an area of arbitrary shape on the surface of the sphere, equal to the square of the radius of the sphere. Since the total area of a spherical surface is  $4\pi R^2$ , the total solid angle about a point is  $4\pi$  steradians.

In general, if  $\omega$  represents the solid angle subtended at a point by an area A on the surface of a sphere of radius R, then  $\omega$  (in steradians) is equal to the area A divided by the square of the radius R, i.e.,

## 5.2.2.2 Illumination (E)

Illumination (E) is the amount of luminous energy incident on a surface. Several units are used with the most common being the foot-candle which equals one lumen/ft<sup>2</sup>. Note that the term foot-candle is a misnomer (2) as the hyphen in scientific terminology is generally used to refer to a multiplicative quantity such as erg-sec.; in the case of a foot-candle no such relationship is intended. The internationally approved unit is the lux (lx) which equals one lumen/meter<sup>2</sup>. Illumination is formally defined as  $E = \frac{d\phi}{dA}$  where  $\phi = \frac{d\phi}{dA}$  where  $\phi = \frac{d\phi}{dA}$  and  $\phi = \frac{d\phi}{dA}$  are surface area.

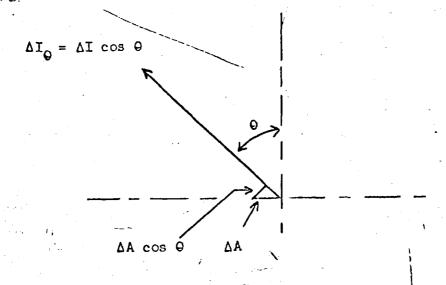
In the case of the above lamp, consider a 1.0 ft<sup>2</sup> plane surface 10 feet distant. The solid angle subtended by the surface is approximately  $\omega = A/R^2 = 1/10^2 = .01$  steradian. Thus, the number of lumens incident on the area is 135 lm/steradian x .01 steradian = 1.35 lm. As the area is 1.0 ft<sup>2</sup>, the illumination E = 1.35 lm/ft<sup>2</sup> or 1.35 ft-c. Measured in lm/m<sup>2</sup>, E = 14.5 lux.

# 5.2.2.3 Luminance (L)

Luminance (L) is a somewhat confusing term, in part because of the existence of two measures. One measure refers to the total flux emitted by a surface (luminous emittance); the other involves the directional reflectance characteristics of a surface (luminance). In general, luminance and luminous emittance apply to area sources which cannot be treated as point sources.

Luminance is defined in the following manner: Consider a small element of surface,  $\Delta A$ , which can be considered a point source\* (below). In

For an area to be a point source, it is sufficient that the sensor be at a distance from the source so that the inverse square low holds between illumination and distance. That is,  $E=I/r^2$ , where E=illumination, I=intensity, r=distance



a given viewing direction, 0, denote the intensity of that element by  $\Delta I_0$ . If the element is viewed at an angle 0 from the normal, the projected area will be  $\Delta A \cos \theta$ . Luminance is defined as intensity per unit of projected area or

$$(1-2) L_{\Theta} = \frac{d(\Delta I_{\Theta})}{dA \cos \Theta}$$

In other words, it is the amount of luminous flux per unit solid angle in the viewing direction per unit projected area. If the intensity is measured in candles, the luminance is in candles/cm<sup>2</sup>, candles/m<sup>2</sup>, candles/ft<sup>2</sup>, etc., depending on the area unit. The standard metric unit is the nit (nt) which equals one cd/m<sup>2</sup>. Luminance is analogous to the radiometric term, radiance.

In order to determine the luminance of the surface in the example above, it is necessary to know its directional reflectance characteristics. This problem will be deferred briefly.

The other measure of luminance, luminous emittence, is the Lambert which is expressed in terms of total luminance flux emitted (or reflected) per unit area (lm/unit area). Thus the Lambert unit is not luminance in the sense of luminous intensity per unit projected area (cd/unit projected area).

However total luminance emittance per unit area (Lambert) can be easily related to luminous intensity per unit projected area (cd/unit area) by integrating the latter quantity over a hemisphere. In particular, for a perfectly diffuse surface a simple relationship exists between cd/unit projected area and lumens/unit area. That is

 $M = \pi L$ 

where M = luminous emittance, L = luminance.

Thus, a perfectly diffuse surface with a luminance of  $1 \text{ cd/m}^2$  has a luminous emittance of  $\pi \ell \text{m/m}^2$ . One footlambert (ft-L) is defined as the luminous emittance of a perfectly diffuse surface emitting  $1 \text{ lm/ft}^2$  or with a luminance of  $\frac{1}{\pi} \text{ cd/ft}^2$ .

Referring to the above example, if a diffuse surface with a reflectance of 1.0 is assumed, the surface then has a luminous emittence  $M = 1.35 \text{ lm/ft}^2$  or 1.35 ft-L. Its luminance,  $L = 1/\pi 1.35 \text{ cd/ft}^2 = 0.43 \text{ cd/ft}^2$ . In terms of  $\text{cd/m}^2$ , L = 4.6 nits.

The footlambert is a convenient unit because, as implied by the example, a perfectly diffuse surface with a reflectance of 1.0 and illuminated with one  $lm/ft^2$  (one foot-candle) also has a luminous emittance of one  $lm/ft^2$  (one footlambert). (As noted, the same surface has a luminance of  $\frac{1}{\pi}$  cd/ft<sup>2</sup>.) Thus, the illumination in foot-candles need only be multiplied by the reflectance of the surface to get the luminance emittance in footlamberts. Unfortunately, the term luminance is used in an ambiguous manner which ignores its alternative interpretations. The following confusions are typical:

A surface for which  $I_0 = I_0 \cos \theta$ , where  $I_0 = intensity$  in the direction  $\theta$  (measured from normal),  $I_0 = intensity$  for  $\theta = 0$ . See Section 1.2.4.

- o The footlambert is commonly referred to as a luminance unit, when it is actually a unit of luminous emittance. The simple relationship between the two  $(M = \pi L)$  only holds for perfectly diffuse surfaces. That point is discussed further below.
- o The names given the various units are misleading. One instance given above was that of the foot-candle. A similar situation exists for the Lambert unit. For instance,

one Lambert = 
$$\frac{1}{\pi}$$
 candle/cm<sup>2</sup>  
one meterlambert =  $\frac{1}{\pi}$  candle/m<sup>2</sup>  
one footlambert =  $\frac{1}{\pi}$  candle/ft<sup>2</sup>

Obviously, the Lambert should be called the centimeterlambert.

The lack of consistency is compounded with regard to another common Lambert unit, the millilambert. The millilambert (mL) is  $10^{-3}$  Lambert and only accidently is nearly equal to a footlambert (.929 mL = 1.0 ft-L).

## 5.2.2.4 Perfectly Diffuse (Lambert) Surface.

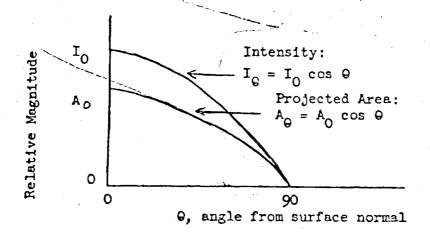
C

The simple relationship given above between luminous emittance and luminance holds for a surface which emits luminous flux according to the equation

$$I_{Q} = I_{Q} \cos \theta$$

where  $I_{\theta}$  = intensity at angle  $\theta$  from normal  $I_{\theta}$  = intensity at normal.

The intensity is maximum when the surface is viewed normally and zero when viewed tangentially. The locus of intensity vectors is a circle in two dimensions and a sphere in three dimensions. However, luminance in intensity per unit projected area and projected area both decrease as the cosine of  $\Theta$ . The relationships are shown in the Figure below.



Thus, for the Lambert surface, the ratio of intensity to projected area (or luminance) is a ratio of two cosine terms and is therefore constant:

(1-5)
$$\frac{\text{Intensity}}{\text{Projected Area}} = \frac{I_0 \cos \theta}{A_0 \cos \theta} = \frac{I_0}{A_0}$$

The constancy of the luminance of a Lambert surface as viewing angle varies is a further convenience of the Lambert quantity. That is, when the luminous emittance (lumens/ $m^2$ ) of a Lambert surface is known, the luminance (cd/ $m^2$ ) can be determined, and, further, is equal for all viewing angles. Thus viewing direction can be ignored and the two measures are easily related, although not equivalent numerically.

To continue with the example, assume the surface described above is viewed at  $\frac{1}{4}$  45° angle from a distance which is large compared to the size of the surface. Then it can be considered a point source. Its intensity is given by  $I = L \cdot A \cdot \cos \theta = \frac{4.24}{cd/ft^2} \times 1.0 \text{ ft}^2 \times .707 = 3 \text{ cd}$ .

Very few surfaces are good approximations to a Lambert surface although many diffuse surfaces are reasonable approximations (flat paint, velvet, blotting paper). Most photometers measure luminance (cd/unit projected area) rather than luminous emittance (lumen/unit area), even though they may be calibrated in the latter system. Thus, when a measurement of luminance at a given angle is taken on a non-diffuse surface and expressed

in Lamberts, one cannot predict what the luminance will be for a different angle. In that case, the interpretation of the Lambert value is that it is the luminous emittance that would be obtained for a diffuse surface with the indicated luminance.

It is common practice to state luminance values in Lambert units for non-diffuse surfaces. If the conditions of measurement are specified, no great harm is done, however, that procedure can result in confusion. It is suggested that some clarification can be achieved by dropping unnecessary terms such as footcandles and Lamberts and state quantities in terms of the basic units, i.e., lumens/ft<sup>2</sup>, cd/ft<sup>2</sup>, etc. Additional clarification would require analysis of the basis of photometric units and agreement as to their use. A useful conversion chart is given in Table 5.2-1.

TABLE 5.2-1

. ت

# Conversion Factors for Photometric Units

(Value in Unit in Left Hand Column Times the Conversion Eactor Equals the Value in Unit Shown at the Top of the Column.)

													•	
	C/ <b>E</b>	C/000	C/==	Sellb (E)	C/In	c/س	J	1	ન	1	1	Appetilb (II)	71	Photoge.
Candles per Bquare		10 X 10	1 × 10*	1.111 × 10°	6.452 × 10°	9.790 X 104	3.142 × 10°	3.142 × 10 <sup>4</sup>	3.142 × 10*	3.143 × 10 <sup>41</sup>	3.1G × 10*	I.61 × 10*	9.810 × 10°	7.83 × 19
Candias per Bquare Cantinistic (C.I.E. 8(15)	ri ×	. 1	1 × 19	1:11	6.433	0.290 × 10°	3.fg	3.142 × 10°	3.1C × 10°	3.143 × 10°	3.142 × 10µ	3.421 × 10+	2.019 X 10*	7.854 × 10°
Candles per Square	×	×	-	1.111 × 102	6.462 × 101	9.200 X 107	3.142 × 10~	3.142 × 10 <sup>-1</sup>	3.142 × 10"	3.142 × 10 <sup>4</sup>	3.1¢ × 10•	3.491	2.819 X 10-1	7.84 × 101
Holnar Candles per Equate Centimoter (Bulb (H))	9.0 X 19.0	9.0 X 101 9.0	90 X 0%	·	6.808	8.341 × 101	3.828	2.828 × 10°	2. 628 × 10°	2.E3 X 19	2.823 × 10 <sup>11</sup>	3.142 X 104	2.627 × 10*	7.063 × 10°
Canding per (Iquare Inch 1.10) × 10" 1.120 × 10"	1.189 X 10*	1.126 × 10 <sup>-1</sup>	1.550 × 10°	1.72 × 10-1	. 1	1.440 × 10°	4.869 × 10-1	4.869 × 10"	4.869 × 10 <sup>4</sup>	4.8c9 × 10*	4.8c3 × 10 <sup>11</sup>	2.411 × 10	4.524 × 10#	1.217 × 10°
Capellos per Squara Foot 1.978 X 19** 1.978 X 10**	1.678 × 10-1	1.078 X 10-1	1.078 × 10	1.105 X 10**	6.944 × 10-1	<b>a-1</b>	3.382 × 10~	3.382	3.192 × 10*	3.353 X 10°	3.382 × 10°	01 X 827.E	3.143	3.6
Lauberta (Equimbat Centrator Candisa, Apparent Lumana por Squara Cantimator)		9) X 많) .t 1-0) X 21.t 1-0) X 많) .t	3.15 × 19	3.537 X 10-1	2.054	2.967 × 10*	-	X 108	\$1 X	81 X	161 ×	1.111 X 194	9.250 × 10s	2.500 × 10°
Milliamberto	3.183 × 10**	3.15 × 10 × 3.15 × 10 × 3.18	3.188	3.537 × 107	2.054 × 10-1	2.957 X 10-1	101 X 10-1	-	1 × 10°	1 X 10	80 X	1.111 × 10	1 X 0CZ 0	2.500
Mireclam barta	1.153 X 10-4	3.183 × 10-1	3.153 X 10** 3.153 X 10**	3.837 X 10-1	2.054 × 10~	2.957 × 10-4	*0 ×	- X 10-		1 X 10	1 × 10	1.111 X 107	9.230 X 10~	2.300 X 10~
Ville Morolamberta (Elgo-Milliamberta)	1.183 × 10 u	3.183 X 10°1	1.18 × 10 v 3.18 × 10 v 9.18 × 10 v	3.337 × 10-10/2.054	× 10.	2.967 × 10-7	۲۵: × ۱	× F	× 101 ×		7 × 14	1.111 × 10-4	2.50 × 197	1.80 × 10-1
Micro-Microlamberts	3.153 X 10-#	1.153 X 10-1	1.153 X 10-4 1.153 X 10-1 3.183 X 10-1	3.537 × 10-u	2.054 × 10-11	2.957 × 1071	61-01 X 1	1 X 10+	1 X 10-	• 01 X	ш	1.111 X 10*	9.203 X 10~10.3.	1.500 X 10-
Apositib (Hednar Lumines per Bquare Foot)	2.884 X 10°1	1.864 X 107	2.584 X 10 <sup>-1</sup> 2.564 X 10 <sup>-4</sup> 2.884 X 10 <sup>-1</sup> 3.183	3.163 X 10-1	1.848 × 10*	2.661 × 10-1	9.0 × 10-	9.0 X 10-1	9.0 X 10	9.0 X 10	0.0 X 10		5.360 X 10-1	1.349
Foot Lamberts (Equiv- siant Poot Caulius: Aircamt Poot Can- clus; Apparent Lu- reans per Oquare Foot)		3. C3 X 10-1 3. C3 X 10-1 3. C3	32.28	3.807 × 10**	2.210 × 10*	3.15 × 10 ·	. 078 × 10**	1.076	1.076 × 10°	1.078 X 10*	1.076 × 108	1.186 X 10	_	1.601
Photons	1.m × 10*	1.m × 10 × 10 × 10 × 1.m	1.33	1.414 × 10-4	9.213 × 10-4	1.183 X 10 <sup>-1</sup> 4.099	€.000 × 10~4	X 10"4 4.000 X 10"4 4.000 X 10"	ı	4.000 X 10 <sup>4</sup>	4.000 × 10°	01 X H4.	3.716 × 10"	1

<sup>•</sup> In converting measures of brightness into photons, it is necessary to multiply the conversion factor by the aquare of the pupil diameter in millimeters.

In converting photons to measures of brightness, it is possessery to divide the conversion factor by the aquare of the pupil diameter in millimeters.

\* BURNER BY BERNER L

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#### 5.3 LUNAR REFLECTANCE PROPERTIES

Earth terrain acts approximately as a diffuse reflector and, therefore, with some exceptions exhibits nearly constant luminance for a wide range of sun and viewing angles. The lunar surface, however, acts like a retroreflector, i.e., a substantial proportion of the reflected light is directed back along the angle of incidence. The general shapes of lunar and Earth reflectance curves are shown in Figure 5.5-1.

The function that relates relative reflectance to viewing angle and solar incidence angle varies for different areas of the moon. The present discussion is restricted to maria areas and to two commonly used reflectance functions called photometric functions that have been determined for those areas from Earth based measurements. of these functions were derived from published data by JPL personnel for use in the Ranger program and have been used in Apollo visibility studies. The first function, based on data collected by Fedoritz (9), was described in 1962 by Herriman, et al (10) and is generally called the Fedoritz function. The second function, based on data collected by N. N. Sytinskaya and V. V. Sharanov (11) was described by Willingham (12) in 1964 and called the Lunar Reflectivity Model (LRM). development of the LRM model was initiated as the Fedoritz data exhibited a large data scatter for small phase angles and contained several sources of possible errors. For instance, Sytinskaya and Sharanov used direct photoelectric photometry whereas Fedoritz used photographic photometry. The latter technique may introduce several problems of interpretation not present in the former. Data from Surveyor have confirmed the Earth measurements to within  $\pm 20\%$  (JPL PD 602-23). Additional analysis of Surveyor data is in progress.

The Fedoritz and LRM functions are given in Figures 5.3-2 and 5.3-3 respectively. The vertical axis is the relative reflectance normalized to that at zero phase angle (at zero phase reflectance equals 1.0). The angle  $\alpha$  is plotted on the horizontal axis; it is the angle between the viewing direction and the projection of the surface normal on the plane containing the viewing angle and solar angle. The parameter is the phase angle g. The angles and sign conventions are also shown in Figures 5.3-2 and 3. The angle  $\alpha$  is positive if it lies between the solar vector and the surface normal (or projection of surface normal). Otherwise, it is negative, i.e., if it lies on the other side of the normal from the solar angle or beneath the solar angle.

For a fixed phase angle, a change in surface tilt is equivalent to a change in  $\alpha$ . Thus, the photometric functions can be used to determine the change in reflected light as a surface is tilted relative to the background, simply by interpreting  $\alpha$  as slope.

For example, assume a sun angle of 20° above the horizontal, a viewing angle of 30° above the horizontal and a coplanar situation. A g of 10° and an  $\alpha$  of 60° result. Refer to that point on Figure 5.3-3 which indicates a reflectance of .44. If a portion of the horizontal surface is now tilted 10° towards the observer,  $\alpha$  is reduced to 60° - 10° = 50° and the new reflectance value is 0.50. Note that g remains constant. The contrast against the background for the tilted portions is (.50 - .44)/ .44 = .136. Note that if the tilt were away from the observer,  $\alpha$  changes

to +70° and the contrast is (.31 - .44)/.44 = -.296. The minus sign indicates the tilted area is darker than the background. Thus contrast is not, in general, symmetrical for slopes away and toward the observer. It is not possible to draw generalized contrast contour lines because of the dependence of contrast on the direction of surface slopes as well as the magnitude of slope.

However, to give an indication of the variation in contrast as the viewing conditions change, equal contrast contours were plotted for a flat 10° forward sloping area against a horizontal background. These are shown in Figure 5.3-4 (Fedoritz) and Figure 5.3-5 (LRM). These contrast values cannot be interpreted as visibility values unless object size and shadowing are also considered.

An additional illustration of the shape of the reflectance function was given as a polar plot in Figure 5.3-1. The relative reflectance is given as a function of viewing angle for three sun angles, 0°, 45° and 10° from the normal. The data are based on the LRM. The locus of points corresponding to a 180° range of viewing angles is plotted on the LRM photometric function in Figure 5.3-4 for each sun angle. Note that two plots are necessary for the 10° and 45° sun angle conditions, one for viewing above the sun angle and one for viewing below the sun angle. Only the points for viewing above 10° solar angle fall in the relatively high contrast region.

Note also from Figure 5.3-1 that the peak luminance is the same for all sun angles when the phase angle is zero. This is merely a different way of illustrating the fact that the amount of light reflected from the surface is independent of  $\alpha$  at zero phase, as shown by the horizontal line for g=0 in Figures 5.3-2 and 5.3-3. Thus, at zero phase no contrast is contributed by surface slope. The result is a "washed-out" region. The size of this region is not clearly delineated but seems to include viewing angles at least a few degrees below the solar incidence angle. Analysis of Orbitor data to define the extent of the wash-out region are in progress at NASA/MSC.

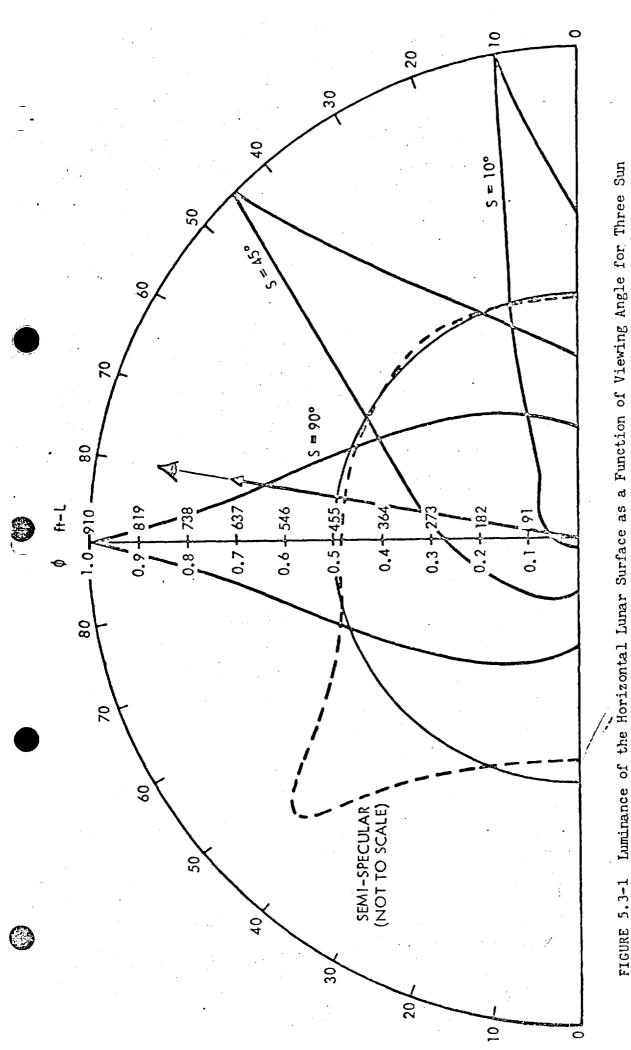
The albedo of different areas on the lunar surface is shown in Table below. Variation is apparently small within a given area. Thus, variation in total reflectance does not contribute substantially to contrast of lunar objects. Contrast is produced almost entirely as a result of the angular variations described above and by shadows.

# Lunar Albedo Values (From Ref. 10)

<u>Feature</u>	Albedo
Dark plain (maria)	0.0.65
Brighter plains (paludes)	0.091
Mountain regions (terrae)	0.105
Crater floors	0.112
Bright rays	0.131

A comparison of the two photometric functions of Figures 5.3-2 and 5.3-3 indicate that they differ mostly in the slopes for low phase angles and negative  $\alpha$ . The Fedoritz function predicts higher contrast in this region than does the LRM. In fact, the LRM shows zero constant for negative and for phase angles from 0° to 20° or 30°. This region would contain, for example, a sun elevation of 40° and an elevation viewing angle of 15° ( $\alpha = -75$ °, g = 25°). For that condition the two functions predict different contrasts for, say, a 10° forward slope  $(\alpha = -65^{\circ}, g = 25^{\circ})$ : Fedoritz = (.635 - .62)/.635 = .0237; LRM = 0 (see Figures 5.3-2 and 5.3-3). For both g and  $\alpha$  values outside of the above regions, the difference between the two functions is not appreciable for purposes of estimating visibility. Note that contrast increases as phase angle increases for both + and  $-\alpha$ . However, except for very large phase angles the contrast for  $-\alpha$  is substantially lower than that for  $+\alpha$ . That fact is the basis for the recommendations that viewing angles always be greater than the sun incidence angle, i.e., that  $\alpha$  always be positive.

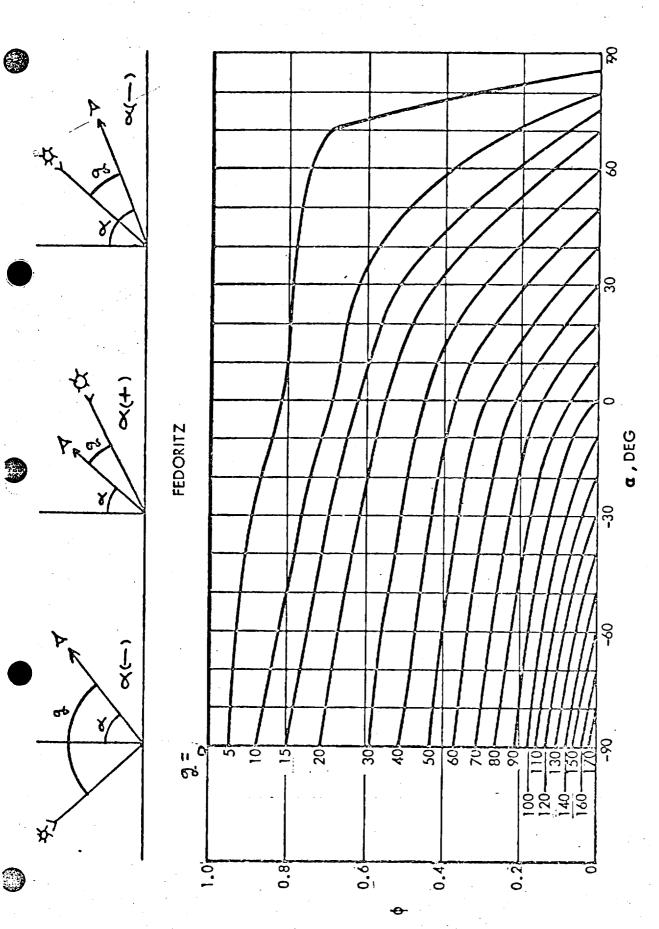
Finally, note that the discussion of the photometric function is only applicable to contrast due to slope differences. Shadows are important to detection at low sun angles as they may have a large area and always have a contrast of -1.0 (assuming no backscatter into shadow area from surround).



priate viewing direction and the reflectance function. For example, for S = 00 and view-Surface luminance is given by the intercept of the approing angle = 800, L = 600 ft-L. The reflectance function of a semi-specular material as Luminance of the Horizontal Lunar Surface as a Function of Viewing Angle for Three Sun typical of Earth terrain is shown by the dashed curve for comparison. Solar Illumimation = 13,000 lumens/ft<sup>2</sup> Lunar Reflectivity Model Lunar Albedo = 0.07 Angles:  $S = 10^{\circ}$ ,  $45^{\circ}$  and  $90^{\circ}$ .

-149-

\$\phi\$ = Relative Reflectance

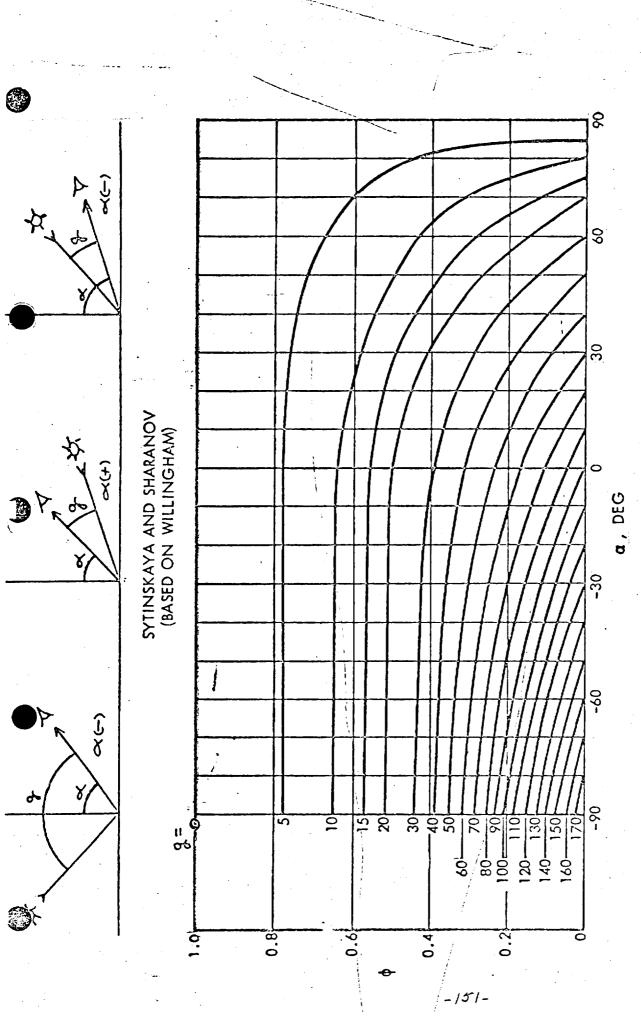


Lunar Photometric Function Based on Fedoritz's Data FIGURE 5.3-2

g=phase angle  $\alpha=phase$  and surface normal (or projection of

surface normal on plane containing viewing and incidence vectors)  $\phi$  = relative reflectance from surface, normalized for G = 0,  $\phi$  = 1.0

Sign convention for a shown above.



Lunar Photometric Function Based on Data from Sytinskaya and Sharanov (From Willingham, Reference 12) FIGURE 5.3-3

g = phase angle

= angle between viewing vector and surface normal (or projection of

surface normal on plane containing viewing and incidence vectors)  $\phi = \text{relative reflectance from surface, normalized for } G = 0, \phi = 1.0$ 

Sign convention for a shown above.

#### 5.4 STARS

The Apollo Crew is required to make guidance and navigation sightings (both of which include star sightings) with the CM SXT and the LM AOT.

The stars to be sighted are determined before the mission begins and are selected from a list which is stored in both the Command Module Computer and the Lunar Module Computer. The list is shown on the following page.

## STAR NAME

Acamar	(0 Eridani)
Achernar	(œ Fridani)
Acrux	(a Crucis)
Aldebaran	(a Tauri)
Alkaid	(n Ursae Majoris)
Alphard	(œ Hydrae)
Alphecca	(a Cornae Borealis)
Alpheratz	(α Andromedae)
Altair	(a Aquilae)
Antares	(a Scorpii)
Arcturus	(a Bootis)
Atria	(α Trianguli Austr.)
Canopus	(a Carinae)
Capella	(a Aurigae)
Dabih	(β Capricorni)
Deneb	(a Cygni)
Denebola	(ß Leonis)
Diphda	(β Ceti)
Dnoces	(ı Ursae Majoris)
Enif	(ε Pegasi)
Fomalhaut	(α Picis Astr.)
Gienah	(γ Corvi)
Menkar	(a Ceti)
Menkent	(θ Centauri)
Mirfak	(a Persei)
Navi	(γ Cassiopeiae)
Nunki	(σ Sagittarii)
Peacock	(a Pavonis)
Polaris	(α Ursae Minoris)
Procyon	(α Canis Minoris)
Rasalhague	(α Ophiuchi)
Regor	(γ Velorum)
Regulus	(a Leonis)
Rigel	(β Orionis)
Sirius	(α Canis Majoris)
Spica	(a Virginis)
Vega	(a Lyrae)
•	

## Appendix 1. - Reflectivity Data.

This appendix is comprised of "A Report on The Visual Bidirectional Reflectance Properties of Selected Apollo Materials" and a TRW Interoffice Correspondence, "Visual Properties of Apollo Materials."

#### INTEROFFICE CORRESPONDENCE

J. T. Bevans 68-3346.11u-46
cc E. Dean 0ATE 24 July 1968

C. Walker

-C. Walger K. Zeidman

SUBJECT: Visual Properties of Apollo Materials

FROM W. D. Miller
BLOG MAIL STA. Ect

R4 2012

62470

Reference: TRW IOC 68-3346.11u-30

#### I. INTRODUCTION

E. E. Luedke

The bidirectional reflectances of six Apollo spacecraft materials were reported in the Reference TRW technical report under contract NAS 9-5073. The purpose of this memorandum is to illustrate the application of these measurements to extraterrestrial viewing of the Apollo spacecraft.

TABLE 1

	MSC ple No.	Material	Area of Application	TRW Sample No.'s
	1 '	IITRI S-13	Outside of SLA	1372-67, 1398-67
•	2	MIL-C-5541 On Stricted Aluminum	Inside of SLA	1373-67, 1400-67
	3	ALZAK (Specular)	LM	1434-67, 1399-67
	4	SiO/Al/Al. Foil	LM	1435-67, 1401-78
	. 5	\$10/A1/500g KAPTON	CM	1436-67, 1432-67
	6	Al Polyurethane Paint	SM	224-66, 1429-67

#### II. DISCUSSION

The visual luminance of a reflector in a particular direction equals the illuminance multiplied by bidirectional reflectance. The angle of incidence for the illumination and the angle of viewing for the detector must be considered. The extraterrestrial illumination is 14.3 lumens/cm<sup>2</sup>. Table 2 (Table 3 of Reference) presents selected bidirectional reflectance data near the specular reflectance angle. Table 3 presents these data con-

verted to luminance values for three materials at one angle of incidence and three viewing angles.

The brightness of a diffuse, 100% reflector in the extraterrestrial illumination will be 14.3 lamberts. The data in Table 3 have been obtained by multiplying the data of Table 2 by the factor: 14.3 lamberts/ 100% diffuse reflector. The other data of Reference 1, Figures 11 through 73 may be used the same way except that the values are apparent bidirectional reflectance and the factor is  $7.5 \times 10^3$  lamberts/apparent bidirectional reflectance.

As an example consider sample 224-66, the aluminum polyurethane paint:

$$\theta_1 = 10^{\circ}$$
  $\phi_1 = 0^{\circ}$ ,  $\theta_2 = 30^{\circ}$ ,  $\phi_2 = 180^{\circ}$ 

The value of apparent bidirectional reflectance for these conditions is  $3.5 \times 10^{-2}$ , therefore the brightness of the surface illuminated by the extraterrestrial sun,  $10^{\circ}$  from the normal, viewed at  $30^{\circ}$  from the normal, on the opposite side within the plane of incidence would be

$$B = 3.5 \times 10^{-2} \times 7.5 \times 10^{3} \text{ lamberts} = 262 \text{ lamberts}$$

Orginally the SLA panels were to remain fixed to the S IV B, open at approximately 45°. In this configuration, there are many complex interactions of shadows and reflections. It has recently been decided that starting with Flight 503 Mission D, the SLA will be completely removed from the S IV B. There will be only the next flight, mission C, in which the SLA panels will remain affixed to the S IV B. In this mission the LM will not be used. In its place a target for sighting purpose will be used. Since the LM will not be used with the SLA panels, no consideration of this configuration is necessary.

#### III. SUMMARY

The method for computing the visual luminancy of Apollo Spacecraft coatings from bidirectional reflectance data has been described. The bidirectional reflectance data is available from previous work reported in the reference technical report.

		01		,	ANGLI 0°	E FROM 5:	SPECULAR 10°	REFLECTAN	CE
1.	1372-67 Outside	15° 30°			90				
	SLA	30 45°			84 84	1	1	1	
	Dair	60°			179	1	1	•	
		70°			456			•	
_									•
2.	1373-67		¢					* · · · · · · · · · · · · · · · · · · ·	
	Inside SLA		0°		61				
	DLA	45°	45°		47	Seo	Table 4		
	• • • •	43	90°		38	Dee	10016 4		
3.	1434-67	15°		•	119			to the second se	
	Specular	30°			122				
	ALZAK	45°			146				
	LEM	60° 70°		*	222	•			
		70			379			•	
4.	1435-67	15°			467				
	SiO/Al/Al Foil	<b>3</b> 0°			423			•	
	LEM	45°			406	0.4		<0.05	
		60°			444				
		70°			556				
5.	1436-67	15°			2645				
	Si0/A1 500g	30°			2287				
	KAPTON	45°			1930	0.5		<0.05	
	LEM	60°			1762			1.1	
	•	70°			1903			, , , , , , , , , , , , , , , , , , ,	
<b>6</b> .	224-66	15°			8.0	•		1.	
٠.	Al Polyure-	30°		•	10.2			18 m - 1 m	
	thane Paint	45°			15.0	13.	9.4	<.18	
	SM	60°			25.0		- • •		
		70°			36.3		;		-

TABLE 2. Relative Bidirectional Reflectances

(Relative to perfectly diffuse 100% visual reflector)

Table 3

# Brightness at Indicated Angle in Lamberts

# Incident Angle 45°

SPECULAR		5° FROM S	SPECULAR	45° FROM	SPECULAR
Sample 1 (Outside SLA)	1,201 L	13	L	13 I	
Sample 2 (Inside of SLA)		Parallel To Plane of	Perpendicular Incidence	Parallel To Plane of	Perpendicular Incidence
¢1 = 0°	872 L	43 L	786 L	<3 L	29 L
¢1 = 90°	543 L	500 L	13 L	214 L	<1 L
Sample 5 (SM Alum. Paint)	27,600 L	, 7	L	<1 L	

Signed:	Control of the contro	
	W. D. Miller	_

WDM/n11

A REPORT ON THE VISUAL BIDIRECTIONAL REFLECTANCE
PROPERTIES OF SELECTED APOLLO MATERIALS

NASA Contract Number NAS 9-5073
TRM Systems Sales Number 5143

April 1968

Signed: \_

W. D. Miller

Member of the Technical Staff,

Approved:

E. E. Lyecke

Head, Thermophysics Section

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3	TRM Bidirectional Reflectometer - High Sensitivity Configuration			• • •	9
4	Schematic Representation of the TRM Bidirectional Reflectomater, High Resolution Mode	• • • • • •		• • •	10
		TRW SAMPLE NO.	MSC SAMPLE NO.	e	
5	Spectral Directional Reflectance	1398-67	(1)	15°	11
6	Spectral Directional Reflectance	1400-67	(2)	15°	11
7	Spectral Directional Reflectance	1399-67	(3)	15°	12
8 .	Spectral Directional Reflectance	1401-67	(4)	15°	12
9	Spectral Directional Reflectance	1430-67	(5)	15°	13
10	Spectral Directional Reflectance	1429-67	(6)	15°	13
				θ,	
11	Reflectance Distribution	1372-67	(1)	15°	14
12	Reflectance Distribution	1372-67	(1)	<b>3</b> 0°	15
13	Reflectance Distribution	1372-67	(1)	/45°	16
14	Reflectance Distribution	1372-67	(1)	60°	17
15	Reflectance Distribution	1372-67	(1)	70°	18
16	Reflectance Distribution	1372-67	(1)	0 .	19
17	Reflectance Distribution	1373-67	(2)	15°	20
18	Reflectance Distribution	1373-67	(2)	15°	21
19	Reflectance Distribution	1373-67	(2)	30°	22
20	Reflectance Distribution	1373-67	(2)	30°	23

LIST OF FIGURES (Continued)

•							
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22	Reflectance Distribution	1		1373-67	(2)	45°	25
23	Reflectance Distribution	າ		1373-67	(2)	60°	26
24	Reflectance Distribution	ı .	·	1373-67	(2)	60°	27
25	Reflectance Distribution	ı		<b>13</b> 73-67	(2)	70°	28
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33	Reflectance Distribution			1434-67	(3)	30°	36
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48	Reflectance Distribution	1434-67	(3)	0	51
49	Reflectance Distribution	1435-67	(4)	15°	52
50	Reflectance Distribution	1435-67	(4)	15°	53
51	Reflectance Distribution	1435-67	(4)	<b>3</b> 0°	54
52	Reflectance Distribution	1435-67	(4)	<b>3</b> 0°	55
53	Reflectance Distribution	1435-67	(4)	45°	. 56
54	Reflectance Distribution	1435-67	(4)	45°	57
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56	Reflectance Distribution	1435-67	(4)	60°	59
57	Reflectance Distribution	1435-67	(4)	70°	60
58	Reflectance Distribution	1435-67	(4)	70°	61
<b>5</b> 9	Reflectance Distribution	1435-67	. (4)	0	62
60	Reflectance Distribution	1436-67	(5)	15°	63
61	Reflectance Distribution	1436-67	(5)	15° -	64
62	Reflectance Distribution	1436-67	<b>(</b> 5)	<b>3</b> 0°	65
63	Reflectance Distribution	1436-67	(5)	30°	66
64	Reflectance Distribution	1436-67	(5)	45°	67
65	Roflectance Distribution	1436-67	(5)	45°	68
66	Reflectance Distribution	1436-67	(5)	60°	69
67	Reflectance Distribution	1436-6	(5)	60°	70
68	Reflectance Distribution	1436-6 <sup>7</sup> 7	(5)	70°	71
69	Reflectance Distribution	1436-67	(5)	70°	72
<b>7</b> 0	Reflectance Distribution	1436-67	<b>(</b> 5)	0	73
71	Reflectance Distribution	224-66	(6)	10°	74
72	Reflectance Distribution	224-66	(6)	50°	75
73	Reflectance Distribution	224-66	(6)	70°	76 .
		5			

#### INTRODUCTION

The materials listed in Table 1 have been measured to determine the apparent brightness of the surface as a function of illumination and viewing angle. These samples were supplied by Mr. C. Wheelwright of NASA/MSC.

MSC SAMPLE NO.	MATERIAL	AREA OF APPLICATION	TRU SAMPLE NO.'S
1	S-13	Outside of SLA	1372-67, 1398-67
2	MIL-C-5541*	Inside of SLA	1373-67, 1400-67
3	ALZAK (Specular)	LEM	1434-67, 1399-67
4	\$i0/A1/A1. Foi1	LEM	1435-67, 1401-67
5	\$10/A1/500g KAPTON	CM:	1436-67, 1432-67
6	Al Polyurethane Paint	SM	224-66, 1429-67

TABLE 1. Apollo Materials New Under Test

Table 2 lists these six materials and several measured proporties. The thermal emittances are indicated for reference. The visual reflectance value applies to hemispherical illumination. The last number - specularity - is a measure of the fraction of the total reflected energy which would be reflected within several degrees of the specular reflectance.

#### MEASUREMENTS

The spectral reflectance of each sample was measured on the Beckman DK2A Spectrophoteneter with modified integrating sphere of the Edwards' design'. The selected ordinate method was used to obtain the visual reflectances listed in Table 2. These values correspond to diffuse illumination. In the case of a perfectly diffuse sample, the visual brightness is equal to this diffuse reflectance multiplied by the illumination. Unfortunately, none of these samples is perfectly diffuse, and it is necessary to measure the reflectance bidirectionally in order to characterize the visual appearance of the surfaces under unidirectional illumination (and observation).

The near-normal thermal emittance of each sample was measured with the Gier Dunkle Quick Emittance Device. These data are presented in Table 2.

The above measurements are of directional reflectance. That is the usual type of measurement in thermal control work where absorbed or enitted energy is of more importance than reflected energy. In the cases

A corrosion resistant chemical conversion conting

where the sample is not perfectly specular or perfectly diffuse, it is necessary to characterize the reflectance bidirectionally. Figure 1 shows the geometry of bidirectional reflectance measurement.

Initially, bidirectional measurements were made with the TRW Systems Bidirectional Reflectemeter (See Figures 2 and 3). In the usual mode of operation (for maximum sensitivity), the angular resolution is of the order of several degrees. This resolution gives a correct measure of bidirectional reflectance as long as the bidirectional reflectance is not rapidly varying. The bidirectional reflectance of a specularly reflecting sample does vary rapidly near the specular reflectance. All of these samples exhibit some degree of specularity as indicated in Table 2.

MSÇ SAMPLE NO.	MATERIAL	APPLICATION	ε <sub>N</sub>	VISUAL REFLECTANCE FOR DIFFUSE ILLUMINATION	SPECULARITY
1	S-13	Outside of SLA	0.88	0.90	0.01
2	MIL-C-5541 *	Inside of SLA	0.06	0.62	0.22
3	ALZAK (Specular)	LEM	0.65	0.78	0.44
4	SiO/Al/Al Foil	LEM	0.63	0.50	0.53
5	\$10/A1/\$00g KAPTON	CM	0.69	0.80	0.93
6	Al Polyurethane Paint	SM	0.31	0.71	0.12
		TABLE 2	. 1	 	

As indicated by the spectral reflectance measurements described above, the spectral reflectances of these samples are of such a nature over the visual region that the reflectance at 0.55 microns is equal to the spectral reflectance weighed by the visibility function. This can be seen by considering the selected ordinate method of calculating visibility. The three equally weighed ordinates for Source C are 515, 555, and 595 nm. For this reason, it was not necessary to make spectral bidirectional reflectance measurements. Bidirectional measurements were made on all samples at 0.55 microns. In order to check on this, several samples were also measured at 0.45 and 0.65 microns. The averages of these results were essentially identical to those at 0.55 microns.

The apparent brightness of a specularly reflecting sample is a critical function of the optical system's illuminating and viewing the surface. For this reason, the optical system in the TRW Systems Didirectional Reflectometer was modified so as to give approximately the same resolution

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as the human eye viewing a surface illuminated by the sun. This arrangement is shown in Figure 4. All of the measurements given in Table 3 near the specular reflectance were made with this arrangement. The ALZAK material listed as Sample No. 3 and measured in this study was a specular ALZAK.

The Globar Source shown in Figure 2 is replaced by a paraboloid mirror with the Globar at its focus. This arrangement allows collimated incident flux which approximates solar illumination.

The directional spectral reflectance data are presented in Figures 5 through 10.

Except for Sample 2 - MIL-C-5541 on striated aluminum - none of the samples showed a relative bidirectional reflectance greater than unity for angle-from-specular greater than 10°. In fact, the more specular samples, 4 and 7 - SiO/Al on Aluminum Foil and 500-gage KAPTON - may be nearly invisible at angles different from specular reflectance angle. The second sample - MIL-C-5541 on striated aluminum - requires special discussion. The reflection distribution function was a very strong function of incident azimuthal orientation. When the plane of incidence is parallel to the striations, most of energy is reflected perpendicular to the plane of incidence. When the plane of incidence is perpendicular to the striations, most of the energy is reflected parallel to the plane of incidence. At intermediate azimuthal orientations, the reflection distribution was intermediately oriented. This sample is the only sample which exhibited relative bidirectional reflectances greater than unity for angles from the specular of greater than 10°. For example, the relative bidirectional reflectance of this sample was 20 at 25° from specular reflectance with striations perpendicular to the plane of incidence. For these incidence and viewing angles, this surface, therefore, appears 20 times brighter than a perfect white diffuse surface under the same conditions.

The reflection distribution function for this surface is essentially the same as that from the inside of a specular hemi-cylinder (the axis of the cylinder corresponds to the line of the striations) plus a small diffuse component. This is actually the case since each striation is a concave hemi-cylinder. The distribution may be mathematically determined from the facts that the normal to the cylindrical surface is always perpendicular to the axis and the angle between the incident/ray, and the normal equals the angle between the normal and the (specularly) reflected ray, and the three are coplanar.

Table 3 provides the relative bidirectional reflectance for the reasured materials at the peak of reflectance (specular angle) and various "off specular" angles. The bidirectional reflectance is relative to a perfectly diffuse reflector with directional reflectance of 100% (Magnesium oxide approximates this.).

At the start of the measurement program, some broad bidirectional reflectance surveys were taken on these samples. The usual procedure in initial surveys of these types is to use the focused detector for maximum sensitivity. This results in a low angular resolution. These results are then directly applicable to an optical system of the same angular subtense.

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If the bidirectional reflection distribution function is not a rapidly varying function of angle, this difference is of little consequence. For ease of computation, these data may be compared to the off specular reflectance of the white paint and a relative (to diffuse 90% reflector) bidirectional reflectance calculated.

The bidirectional data taken with the focused detector is presented in Figures 11 through 73. The values presented in the graphs are direct measures of the fraction of the incident energy which is reflected into the detector by the sample. Data are presented for MSC Samples 1 through 6. Data for MSC Sample 6 has previously been presented<sup>3,4</sup>, and graphs are included in this report.

#### REFERENCES

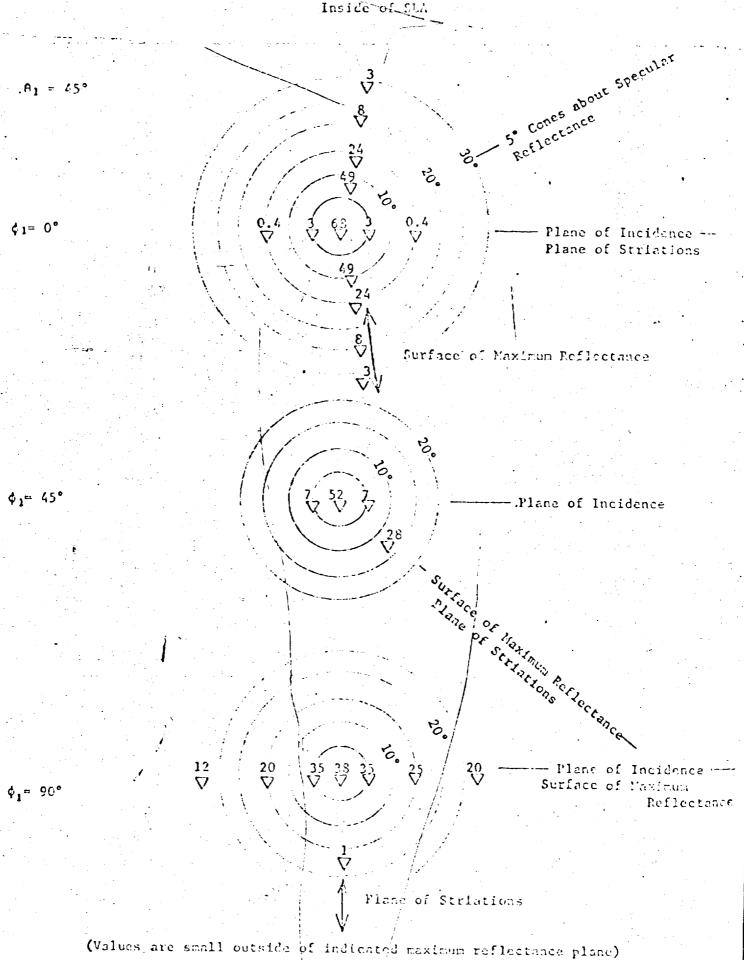
- 1. D. K. Edwards, et al., :Integrating Sphere for Imperfectly Diffuse Samples," J.O.S.A. 51:1279-88 (1961).
- 2. J. T. Bevans, E. E. Luedke, and K. E. Nelson, "A Device for the Rapid Measurement of Total Emitbance," Journal of Spacecraft and Fockets 3: 758-760 (May 1966).
- 3. Measurements Report: Evaluation of Unidirectional Thermal Radiation Properties of Materials Contract NAS 9-5073, 27 September 1966, Sales Number 5143.000.
- 4. TRW 10C 68-3346.11w-19, "Measurements Report for NASA/MSC Unidirectional Thermal Radiation Property Measurements," Sales No. 5143.000, Contract NAS 9-5073.

.,									
		e <sub>1</sub>				ANGLE 0°	FROM 5°	SPECULAR 10°	PEFLECTANCE 45°
	1372-67	15°			÷	90		•	•
1.	Outside	30°				84			
	SLA	45°	- '	•		84	1	1	1
•	Jim	60°				179	-	-	
		70°	•			456			•
2.	1373-67			ф			•		
	Inside		•	0°					
	SLA	45°		45°		61	٠	T-11-1	
•		45		90°		47	500	Table 4	
			•	90		38	÷		•
3.	1434-67	15°				119			1
	Specular	30°	•			122		•	•
	ALZAK	45°				146			
	LEM	<b>6</b> 0°				222	•		
		70°				379			
4.	1435-67	15°				467		•	
	SiO/Al/#1 Foil	30°				423			* * * * * * * * * * * * * * * * * * * *
	LEM	45°				406	0.4		<0.05
		eo°				444			
•		70°				556			
5.	1436-67	15°				2645		•	
	SiO/Al 500g	30° .				2287			•
	KAPTON	45°			- ]	<b>19</b> 30	0.5		<0.05
	LEM	60°				1762			
.*		70°	, _		1	1903			
6.	224-66	15°		***		8.0	*		• • •
	Al Polyure-	· 30°			•	10.2			
	thane Paint	45°		*		15.0	13.	9.4	<.18
	SM -	<b>6</b> 0°				25.0			•
		70°				36.3			

TABLE 3. Relative Bidirectional Reflectances (Relative to perfectly diffuse 100% visual reflector)

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#### NSC Sample No. 2: MIL-C-5541 - Aluminum Inside of SLA



\* TABLE 4. Relative Bidirectional Reflectance

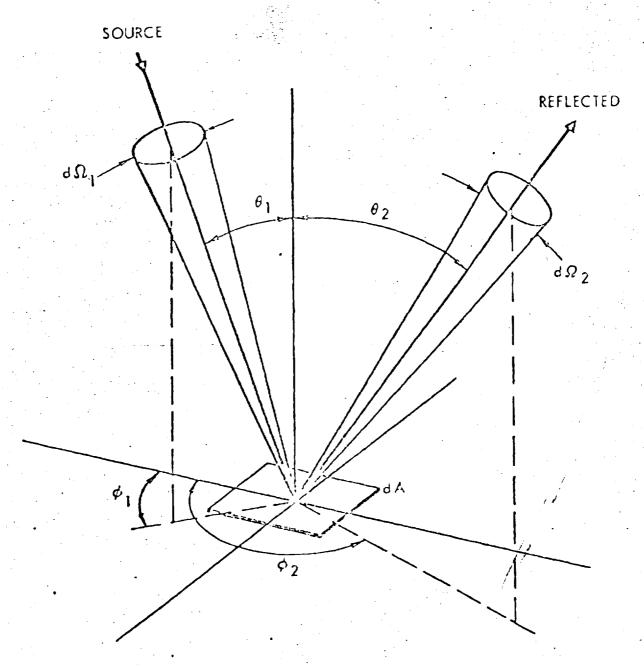


FIGURE 1: GEOMETRY OF RADIATION INCIDENT AND LEAVING A DIFFERENTIAL AREA

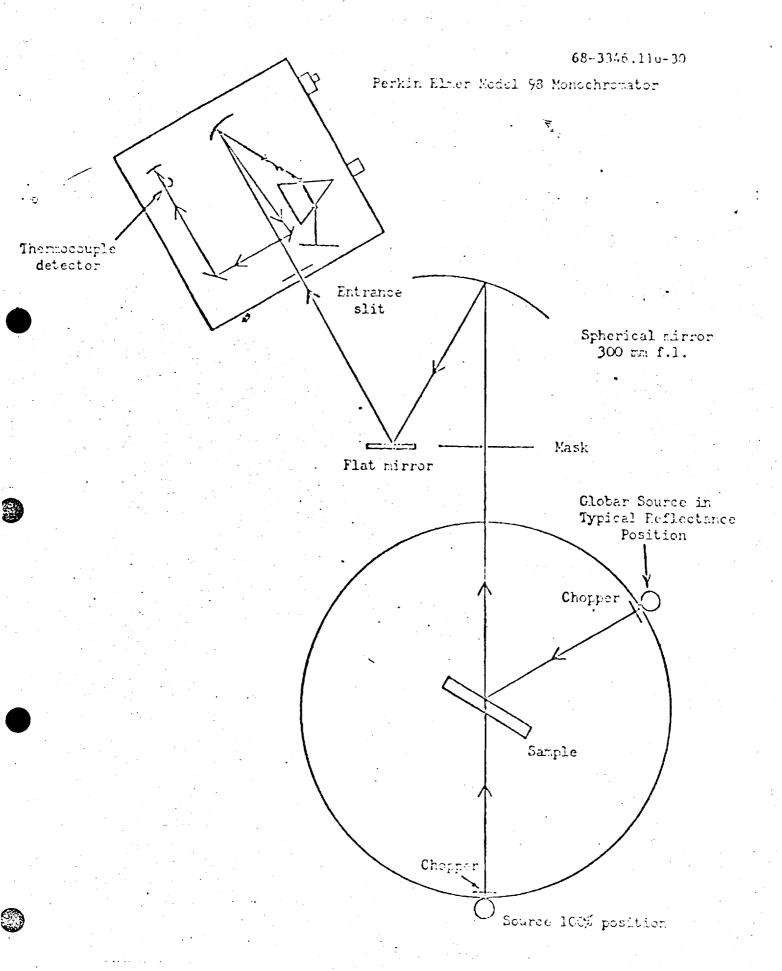


Figure 2: Schematic Pepresentation of the TRM Bidirectional Reflectorator - High Sensitivity Configuration -170-

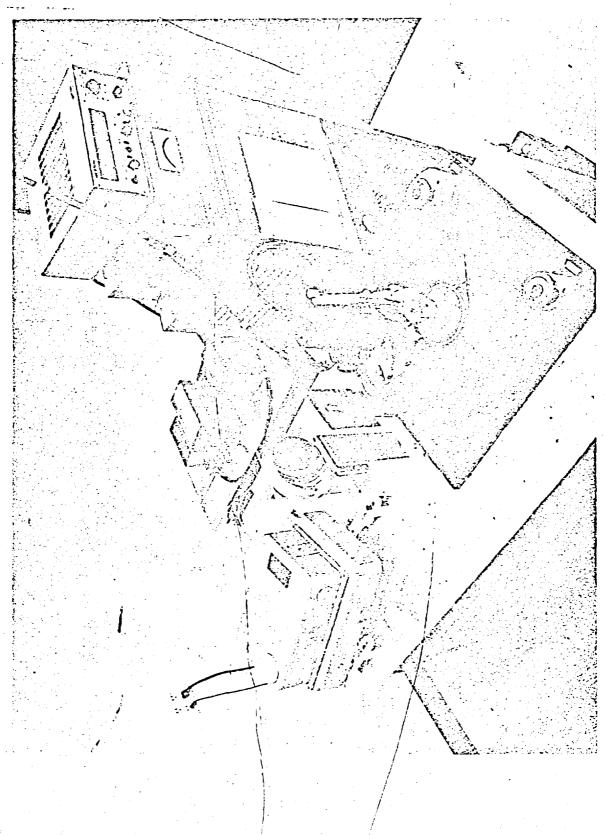


Figure 3. TRW Bidirectional Reflectometer - High Sensitivity Configuration

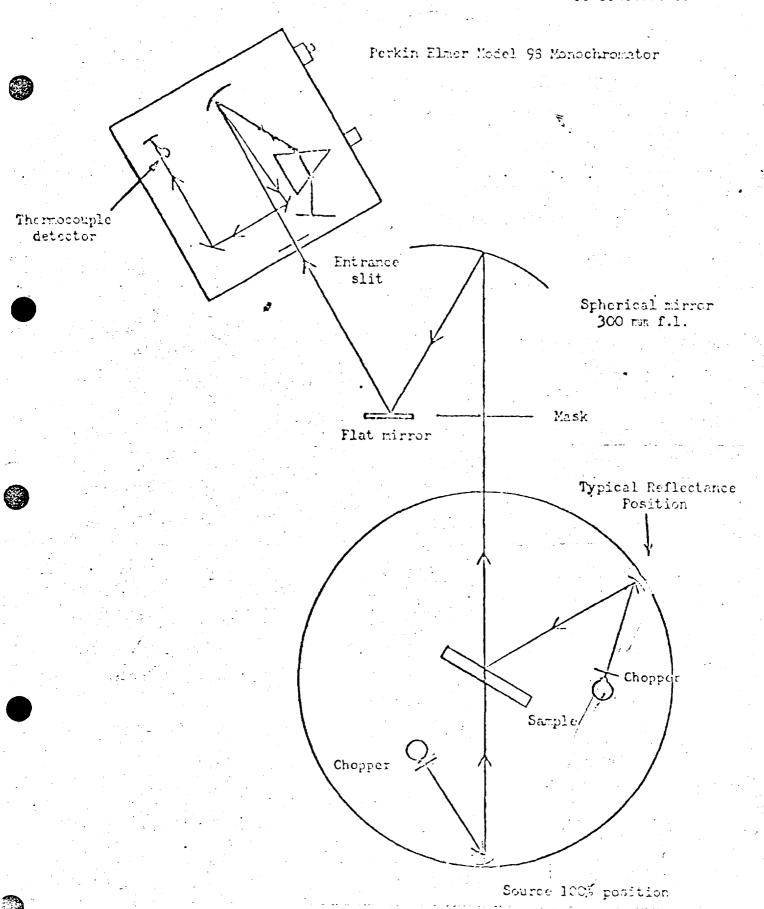
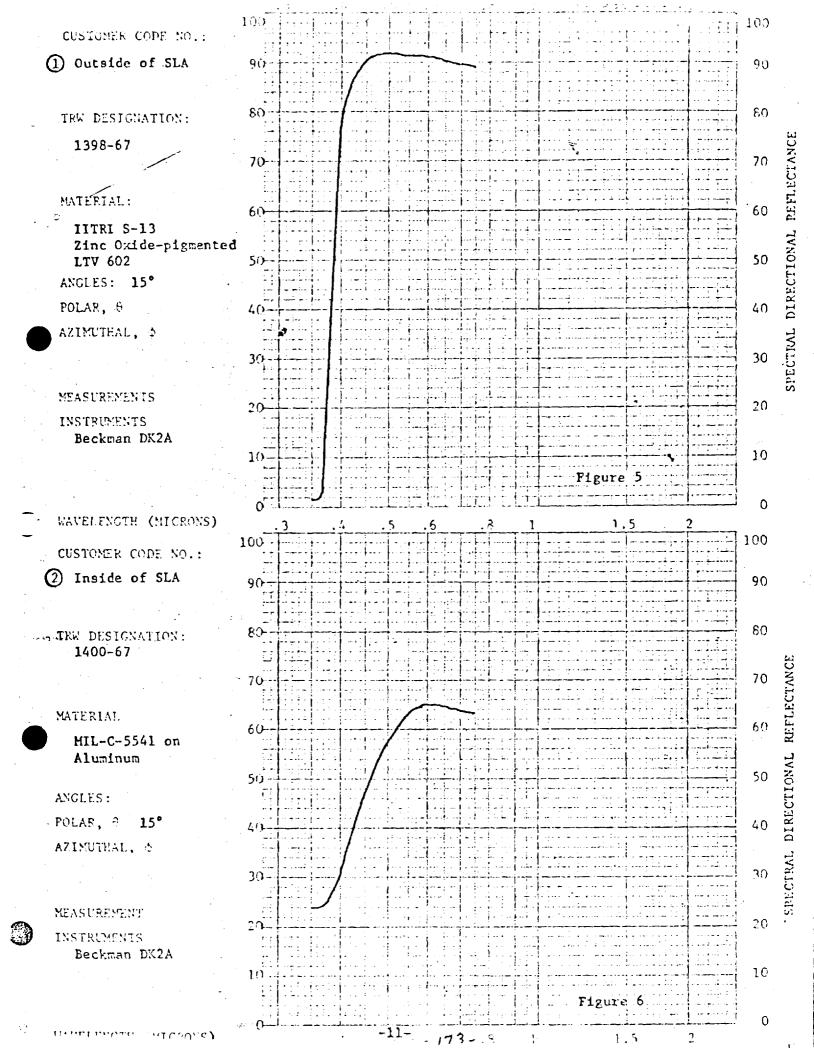
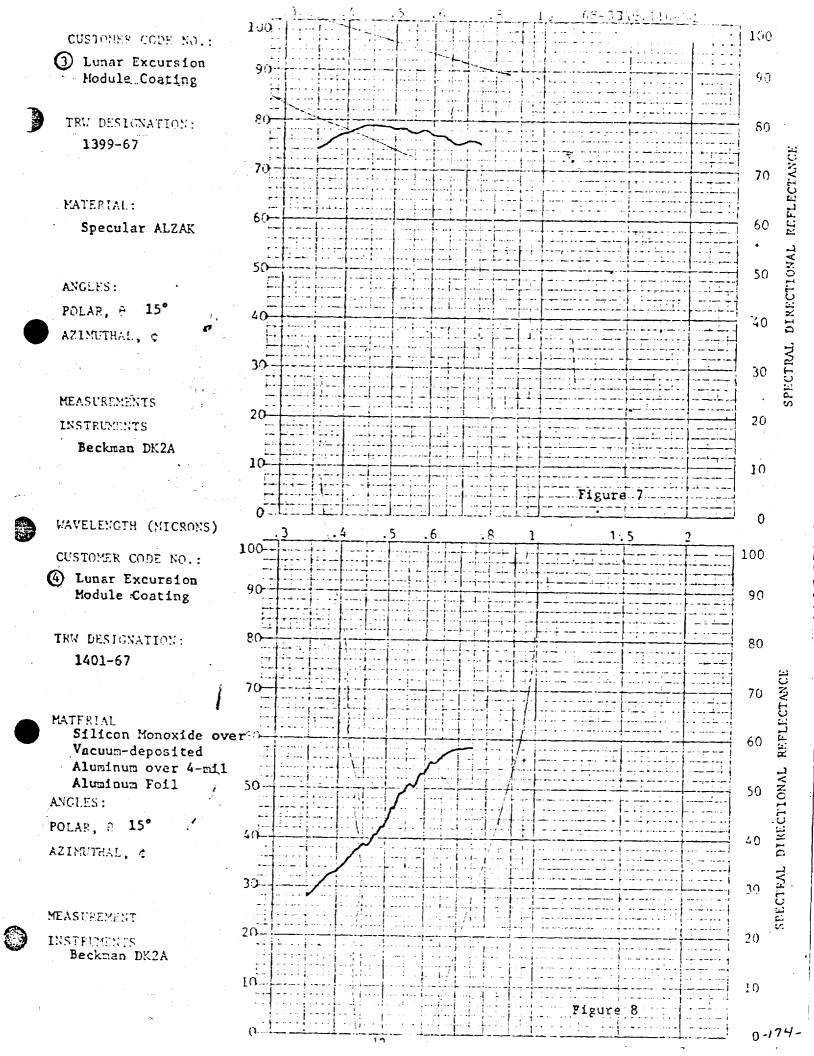
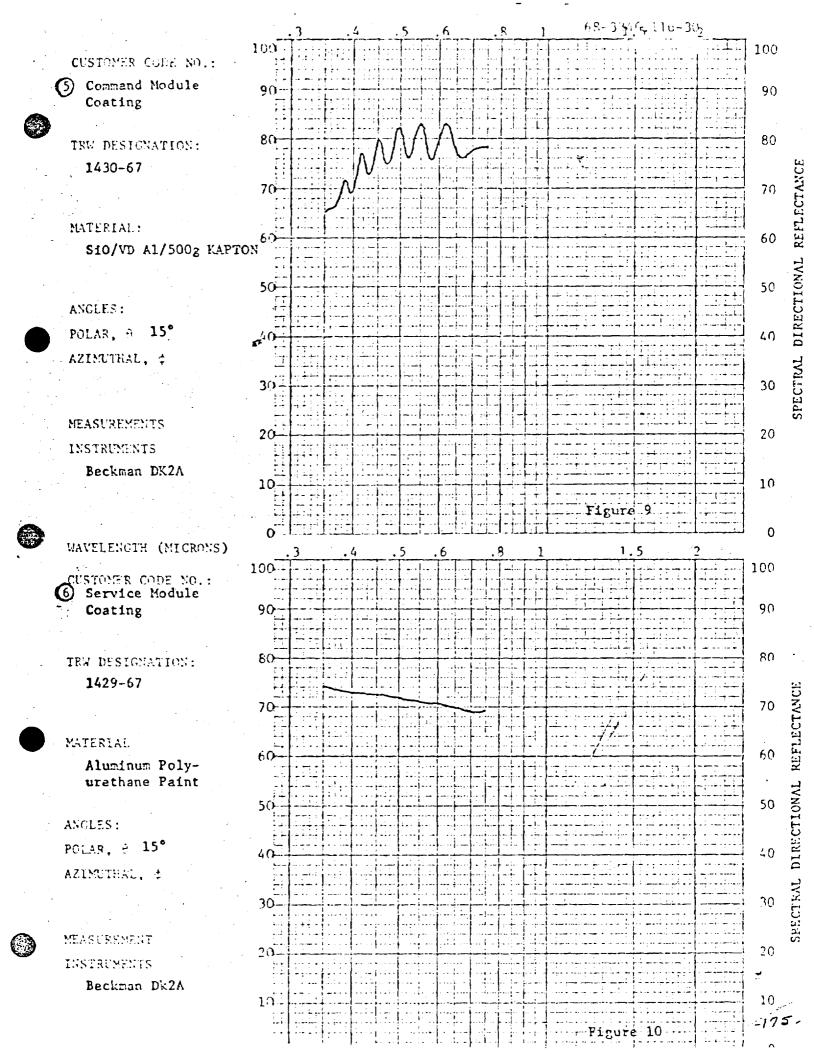


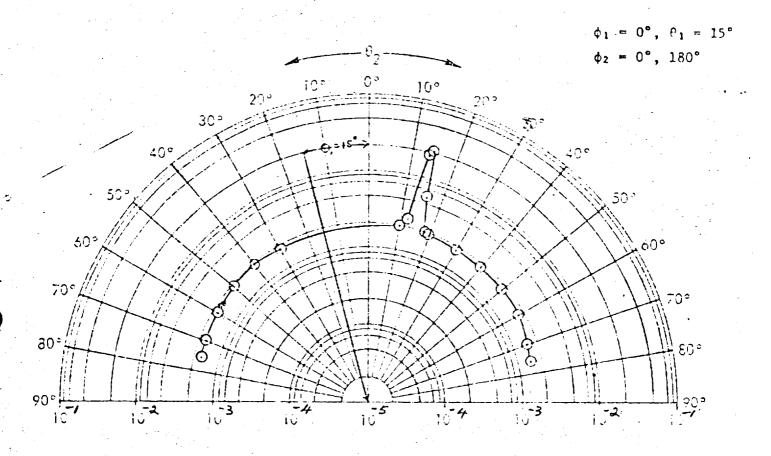
Figure 4. Schematic Representation of the TRW Bidlrectional reflectometer, High Resolution Mode - 172-

-10-









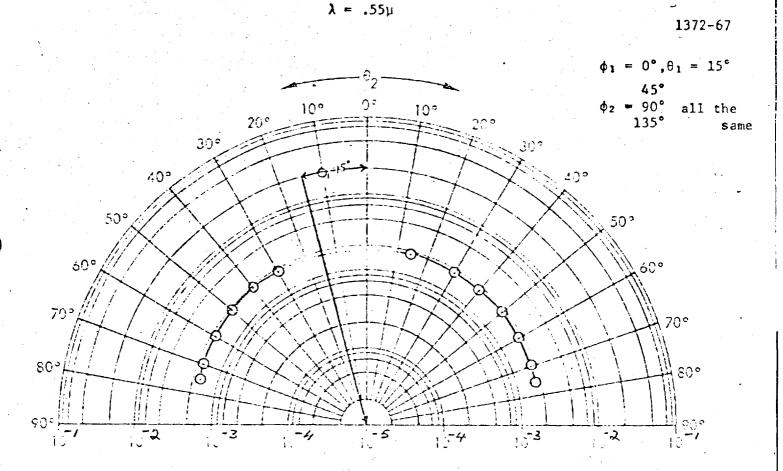
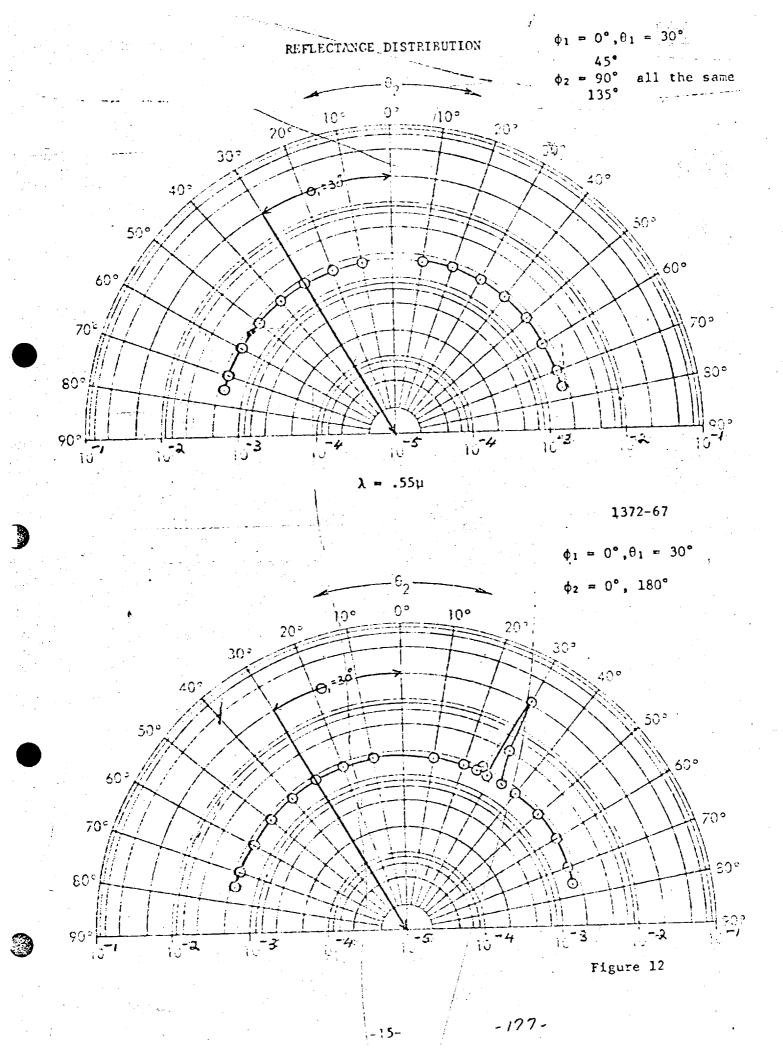


Figure 11



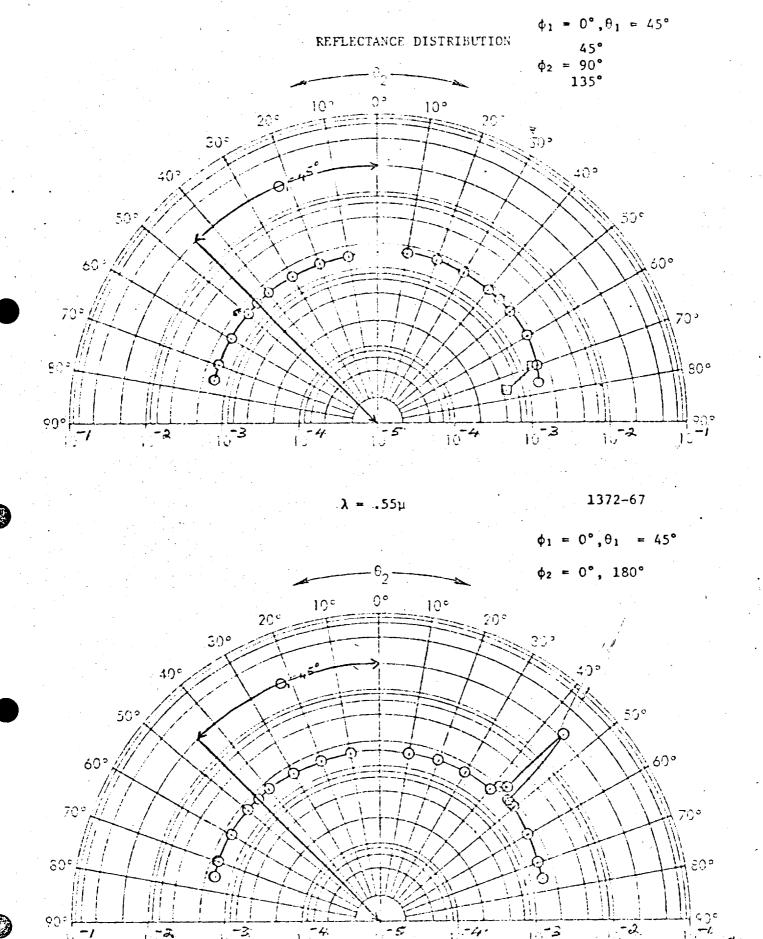
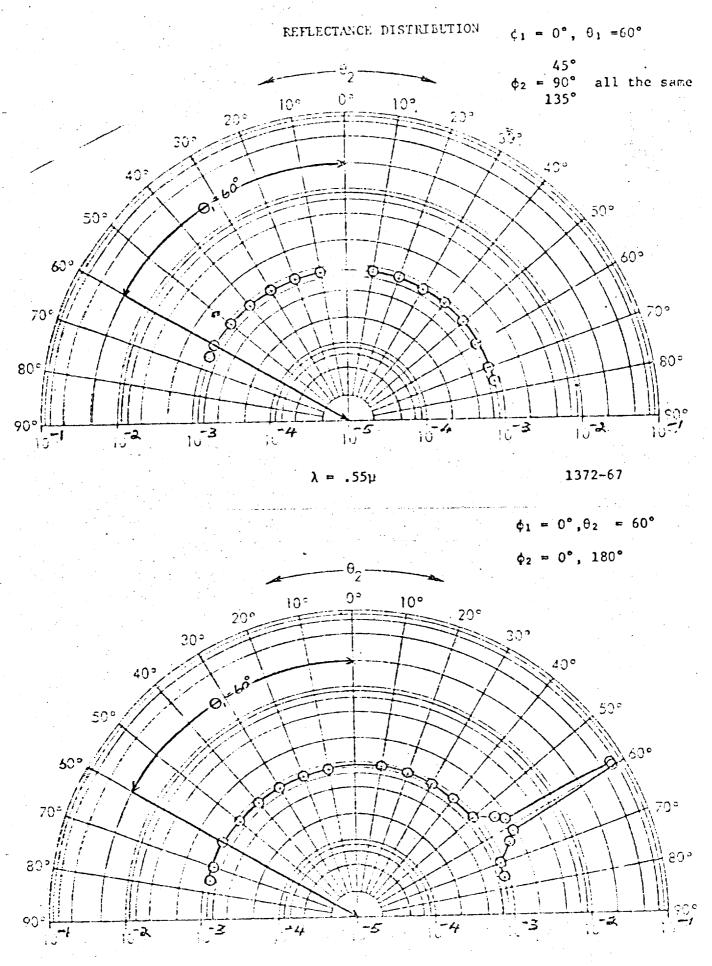
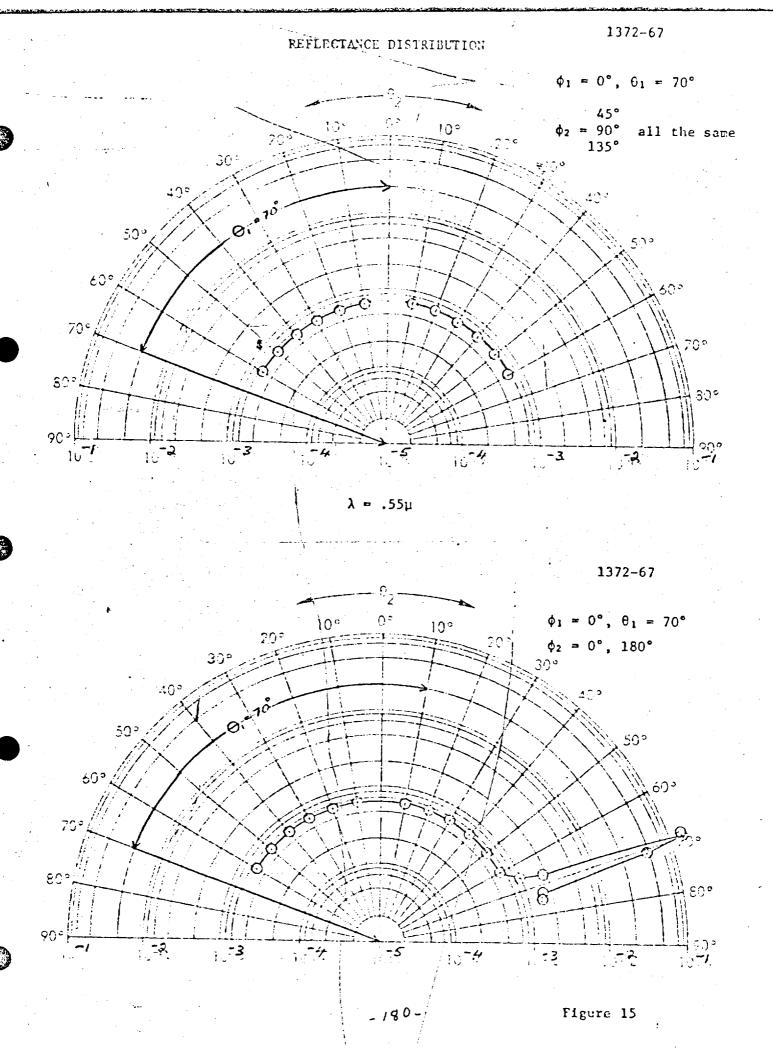


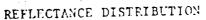
Figure 13

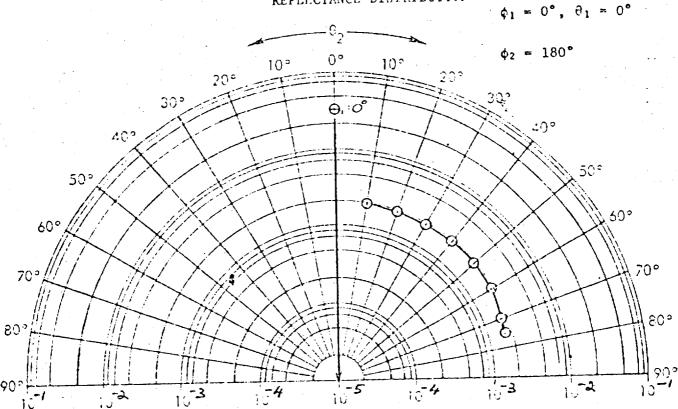


-179-.

Figure 14









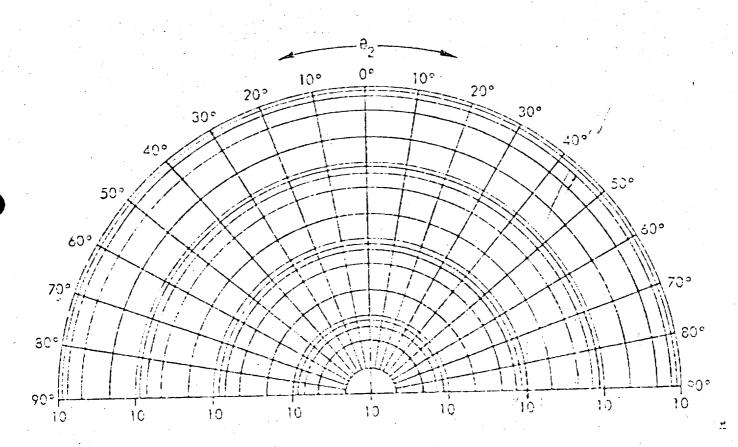
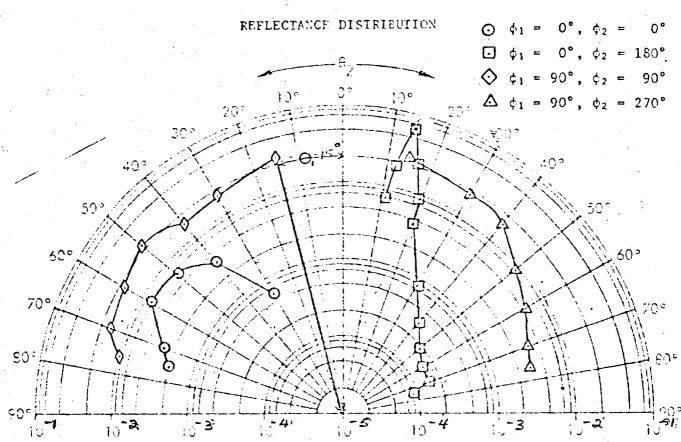
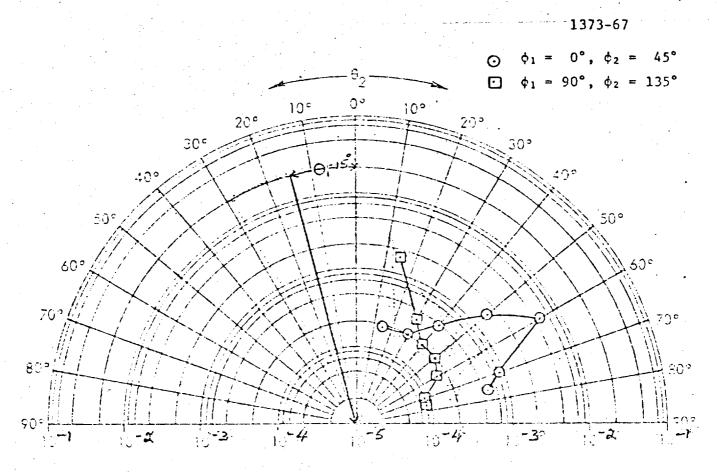
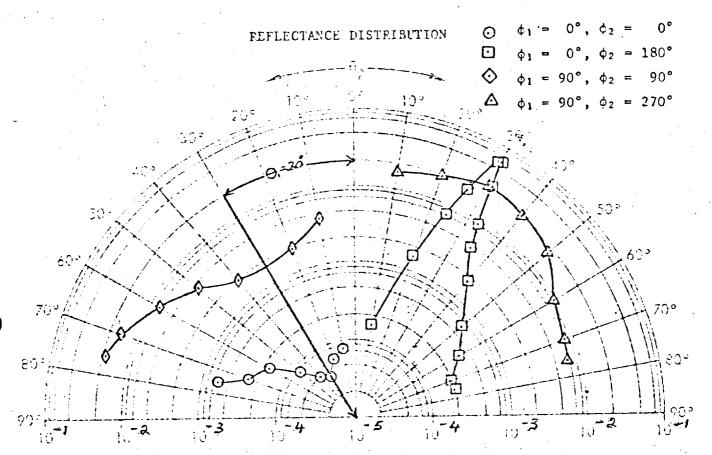


Figure 16









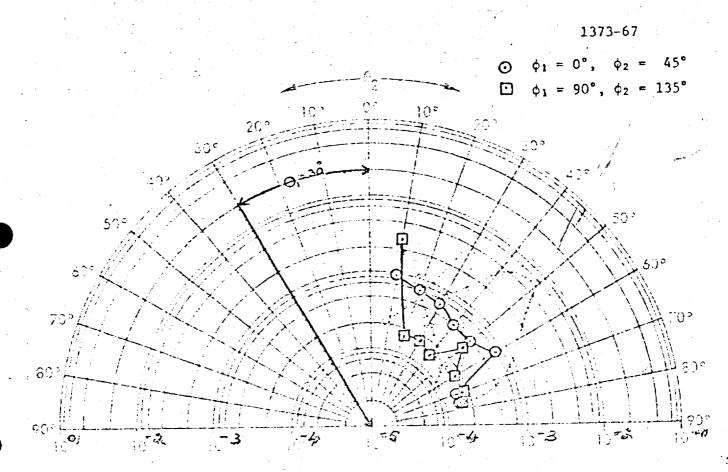
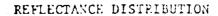
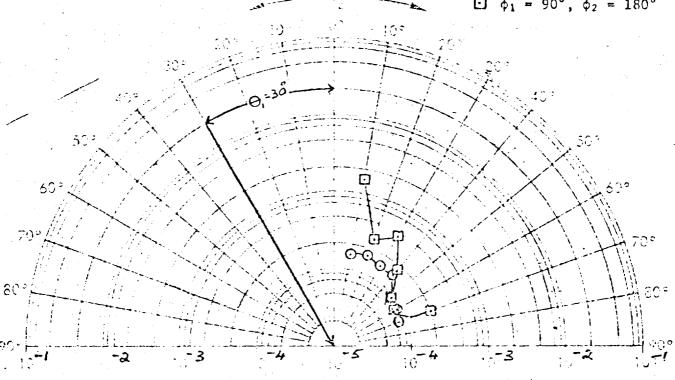


Figure 19





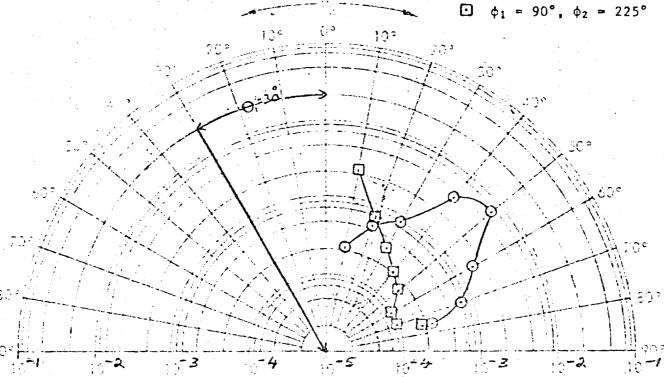


$$\lambda = .55\mu$$

## 1373-67

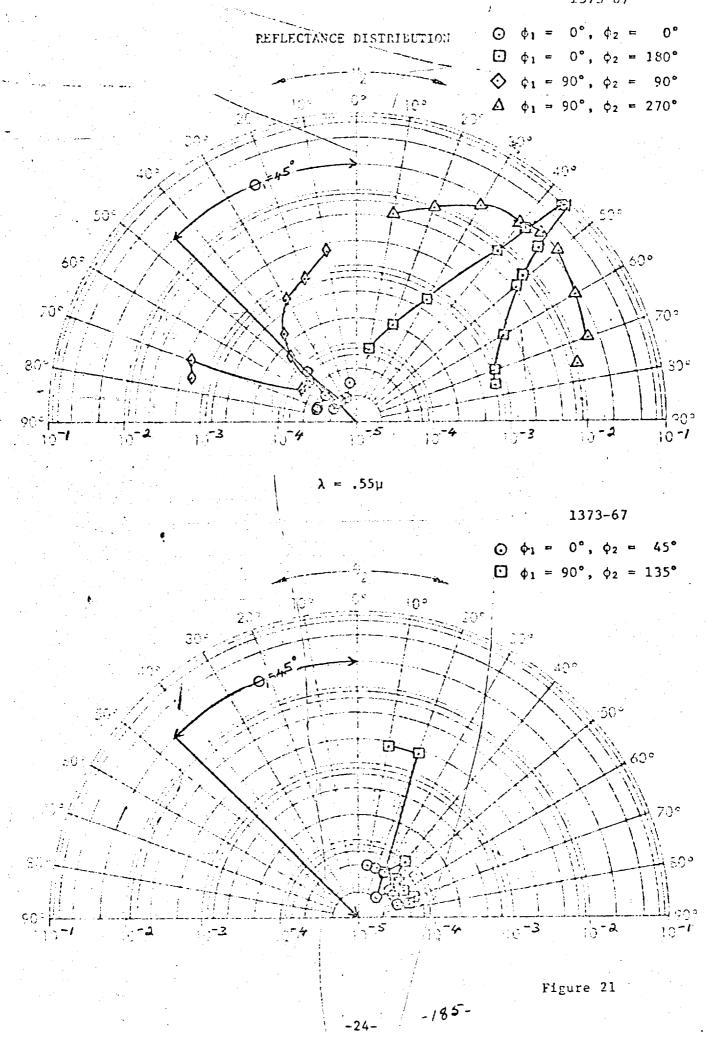
$$\bigcirc$$
  $\phi_1 = 0^{\circ}, \phi_2 = 135^{\circ}$ 

$$\bigcirc$$
  $\phi_1 = 90^\circ$ ,  $\phi_2 = 225^\circ$ 



-23-

Figure 20

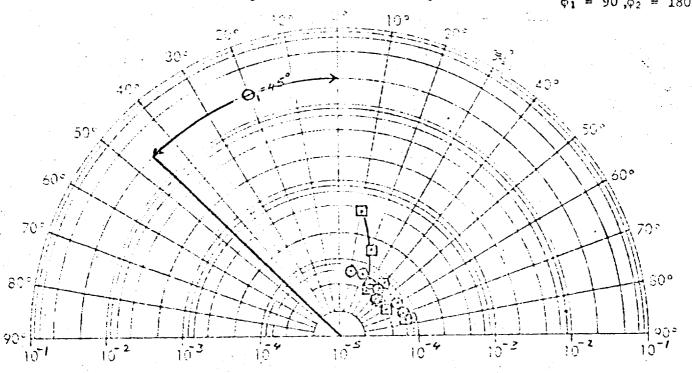




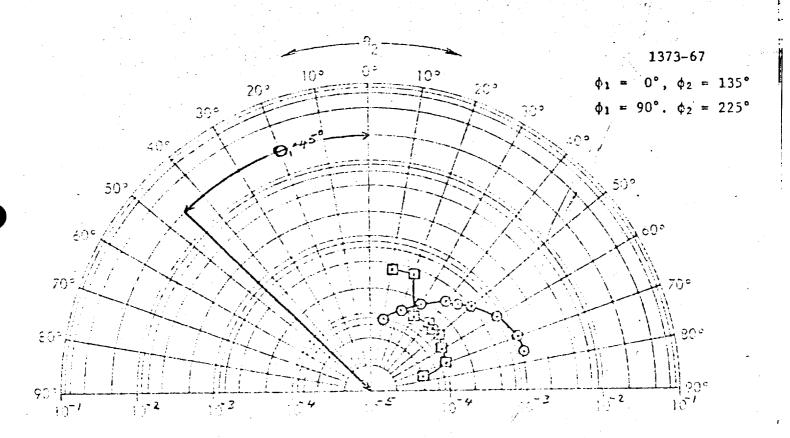


$$\phi_1 = 0^{\circ}, \phi_2 = 90^{\circ}$$

$$\phi_1 = 90^{\circ}, \phi_2 = 180^{\circ}$$



 $\lambda = .55\mu$ 



-25-

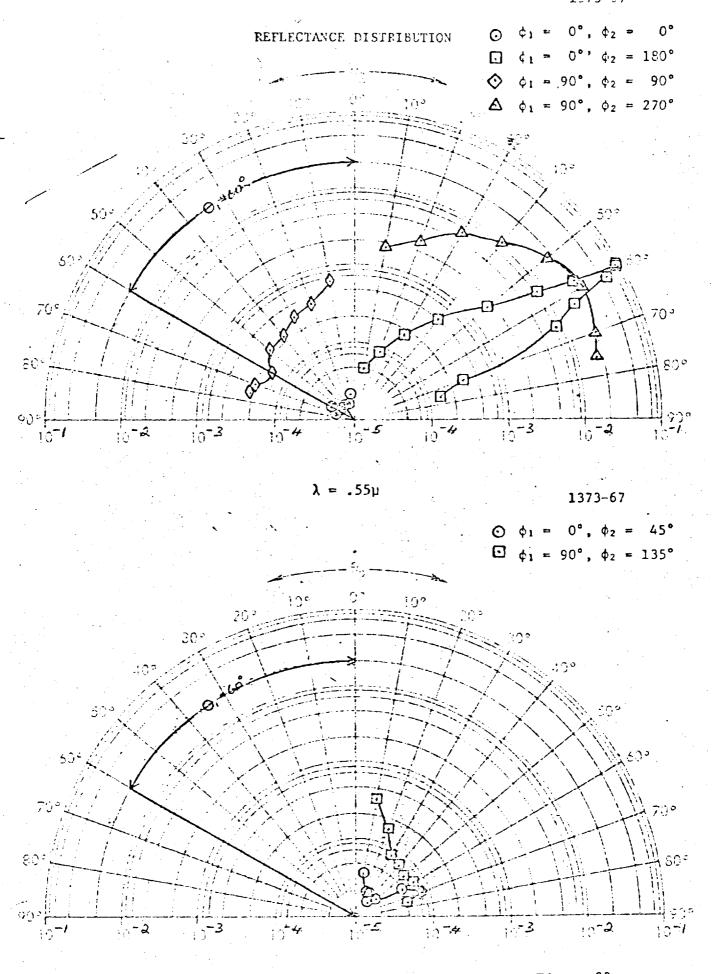
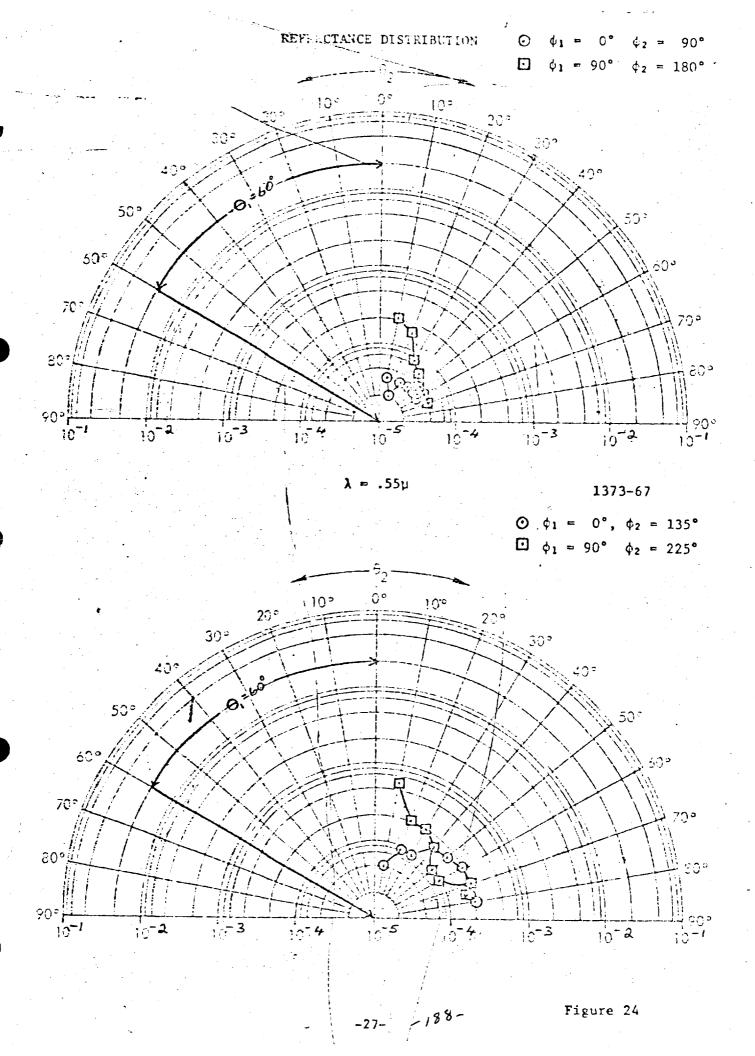
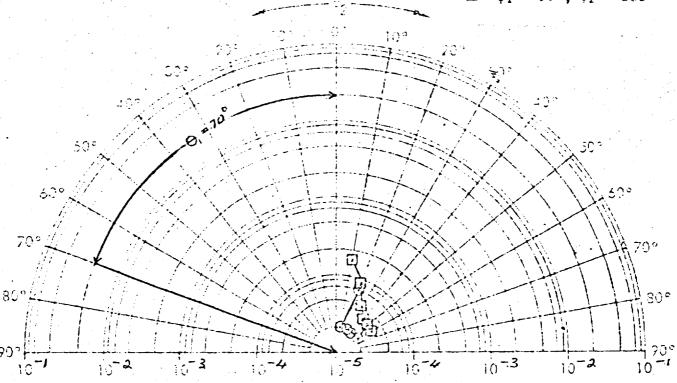


Figure 23



REFLECTANCE DISTRIBUTION



$$\Phi_1 = 90^{\circ}, \ \phi_2 = 225^{\circ}$$

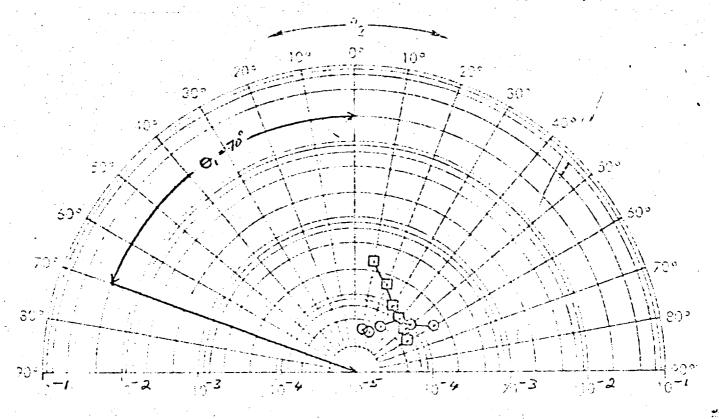
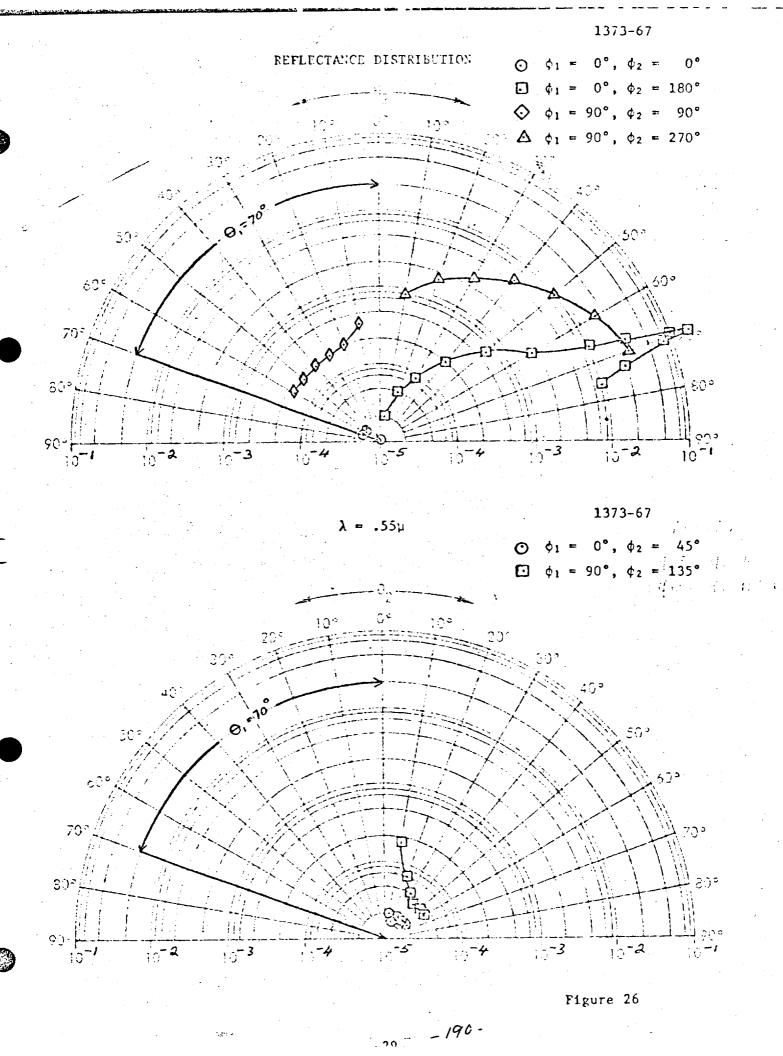


Figure 25



1373-67. REFLECTANCE DISTRIBUTION\_  $\phi_1 = 90^{\circ}, \phi_2 = 270^{\circ}$ O1 = 0° 50° 60° 70° L # 50° £0°∭ λ = .55μ 10° 30° 50° 60° 60° 70° ∯ ° 03 Á 30° %

1.0

-191-

10

10

1.)

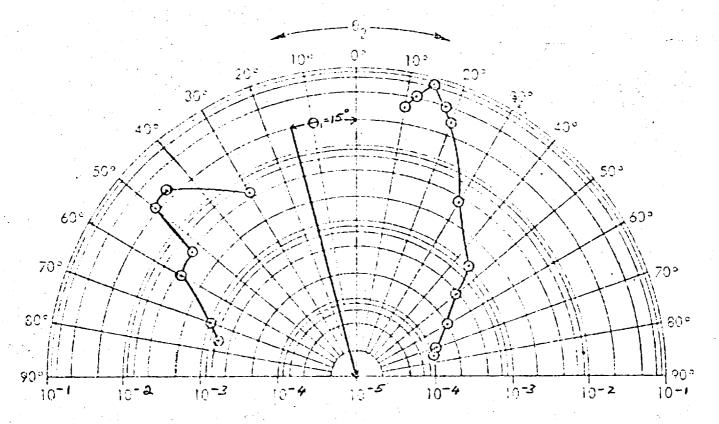
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Figure 27

10

REFLECTANCE DISTRIBUTION

 $\phi_1 = 0^{\circ}, \ \phi_2 = 0^{\circ}, \ 180^{\circ}$ 



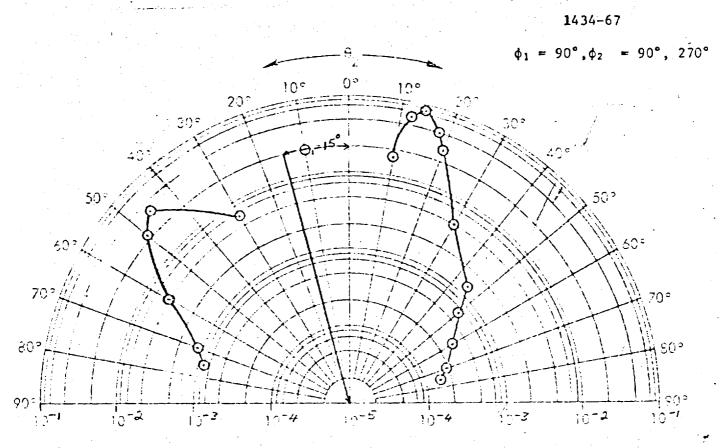
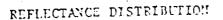
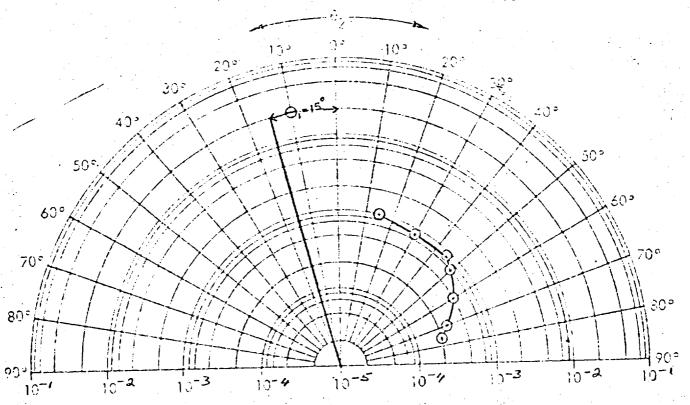


Figure 28



 $\phi_1 = 0^{\circ}, \ \phi_2 = 45^{\circ}$ 



 $\lambda = .55u$ 

1434-67

 $\phi_1 = 90^{\circ}, \ \phi_2 = 135^{\circ}$ 

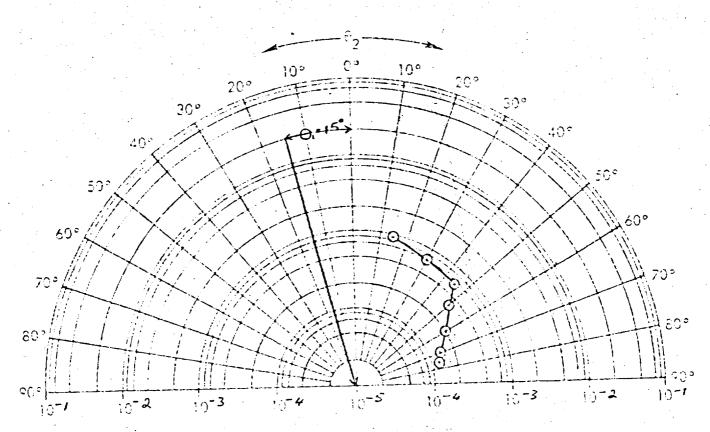
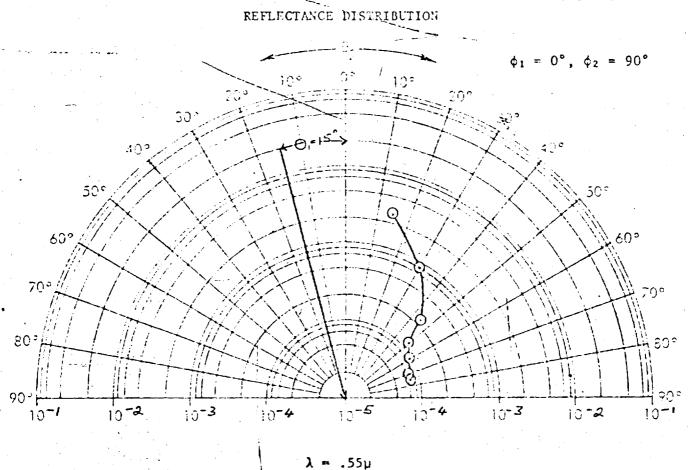
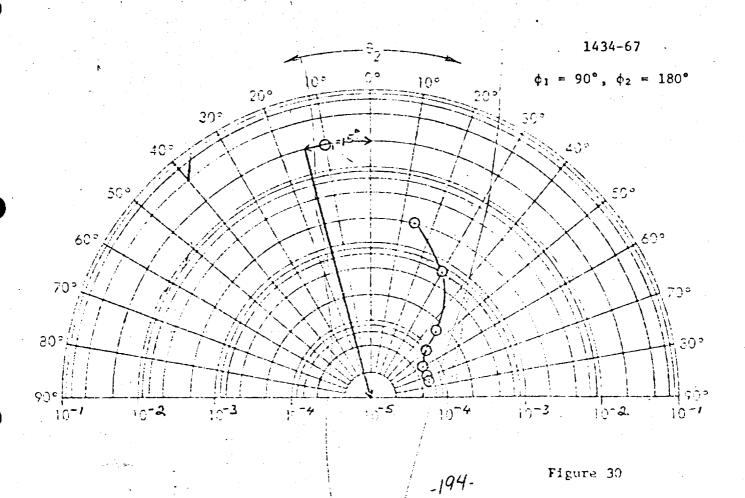


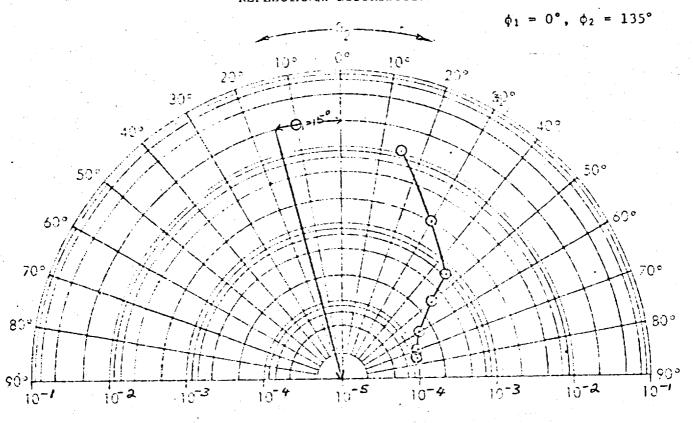
Figure 29











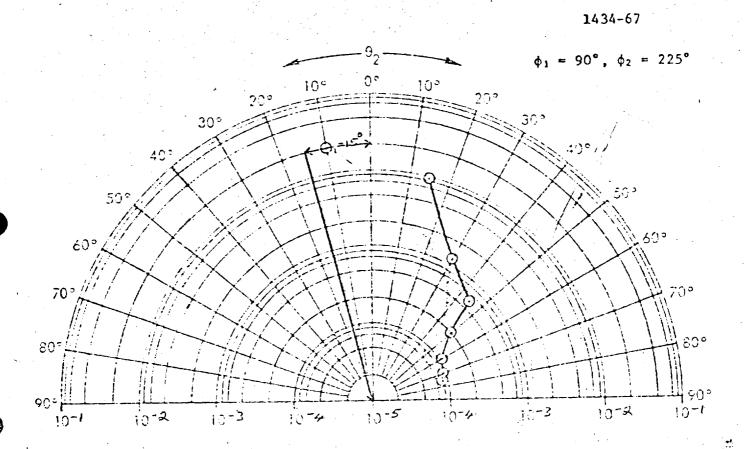
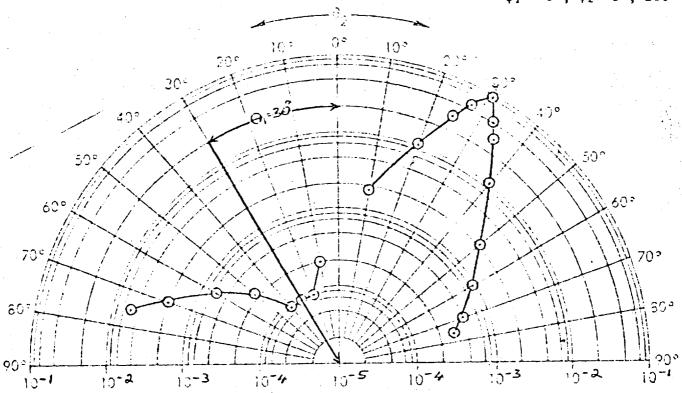


Figure 31



 $\phi_1 = 0^{\circ}, \ \phi_2 = 0^{\circ}, \ 180^{\circ}$ 



 $\lambda = .55\mu$ 

1434-67

 $\phi_1 = 90^{\circ}$ ,  $\phi_2 = 90^{\circ}$ , 270°

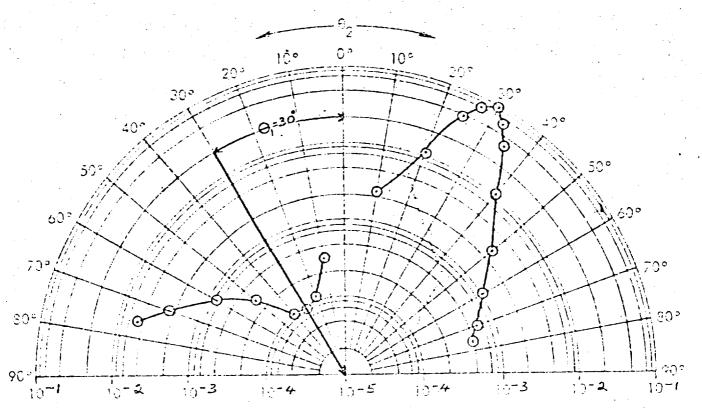
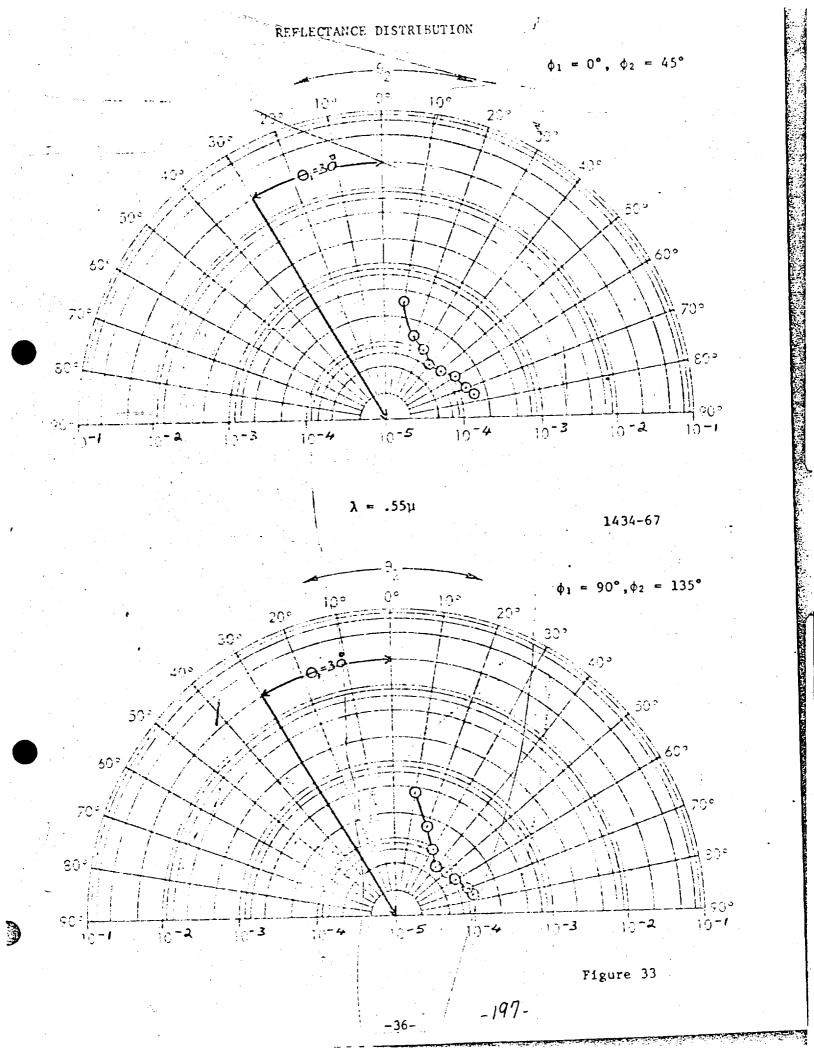
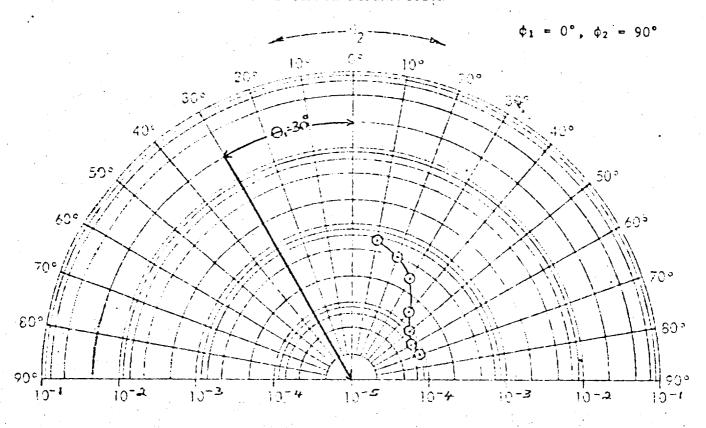
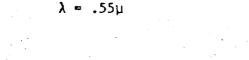


Figure 32







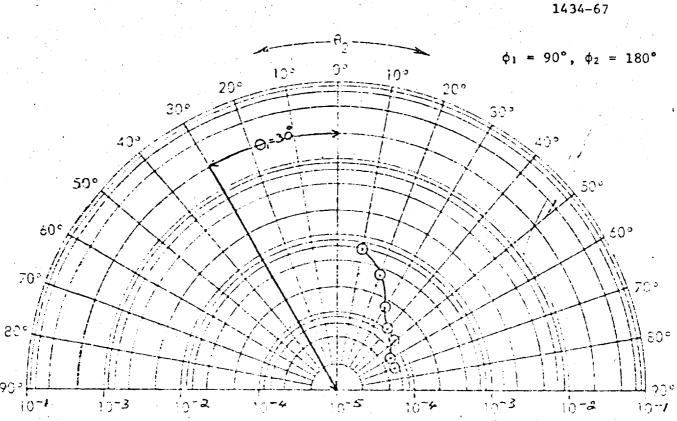
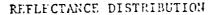
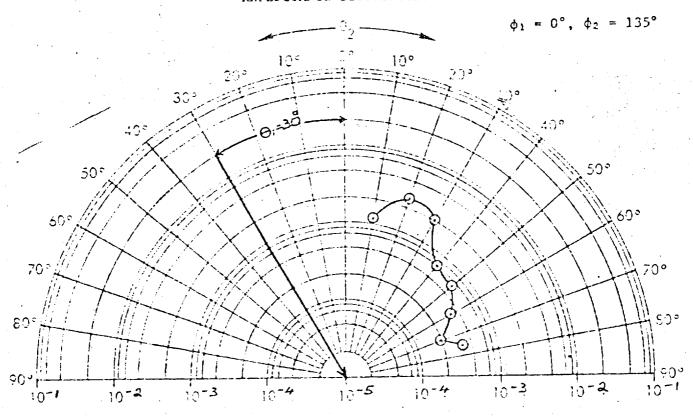


Figure 34





 $\lambda = .55\mu$  1434-67

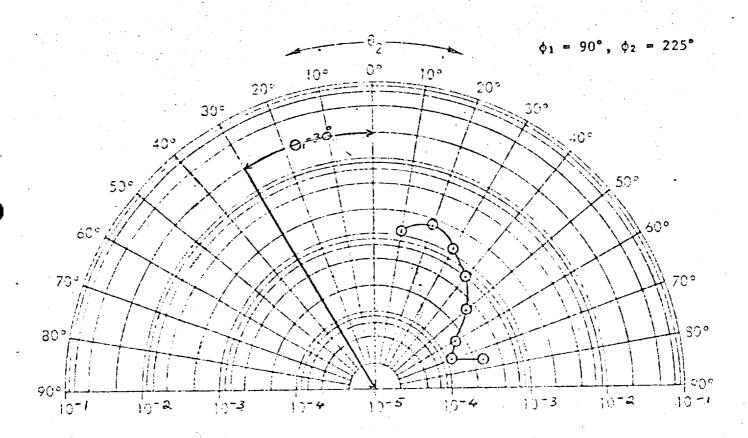


Figure 35

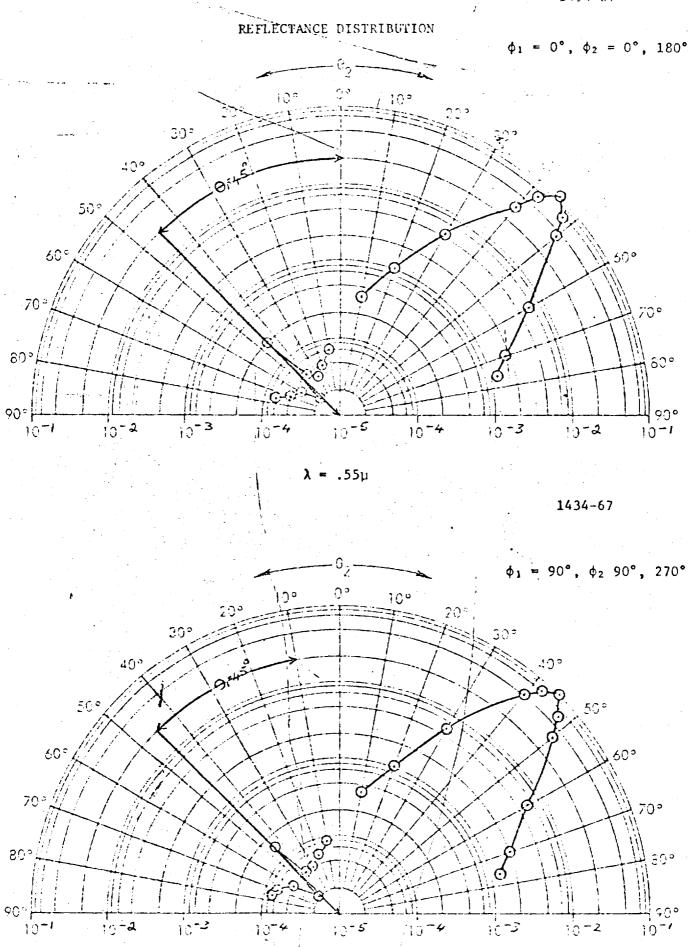
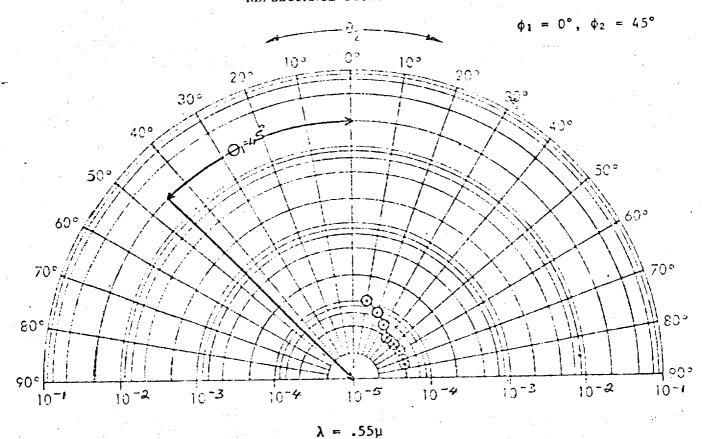


Figure 36

-200-

## REFLECTANCE DISTRIBUTION



1434-67

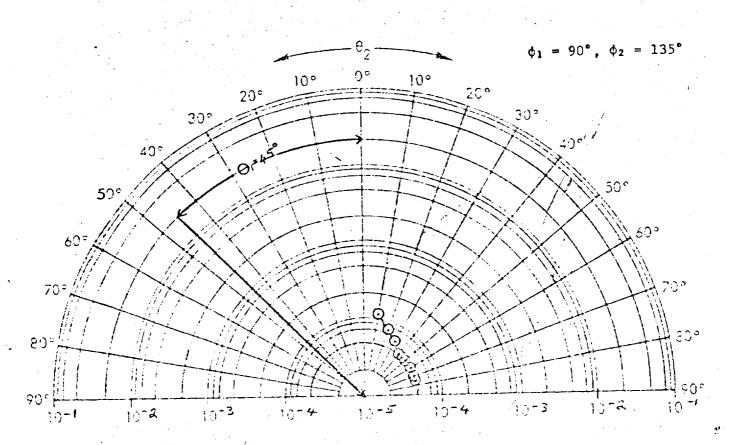
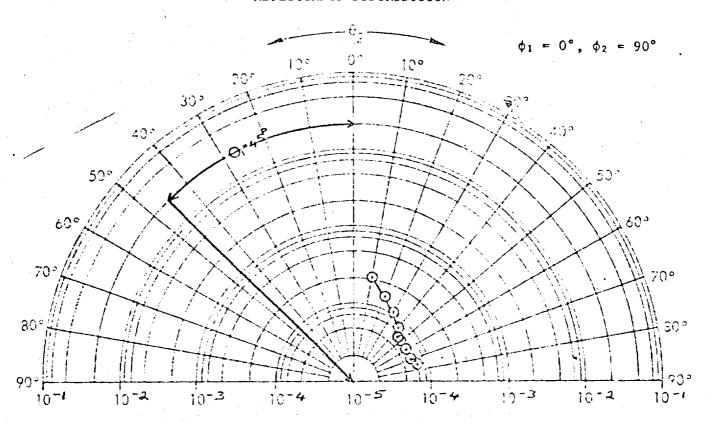
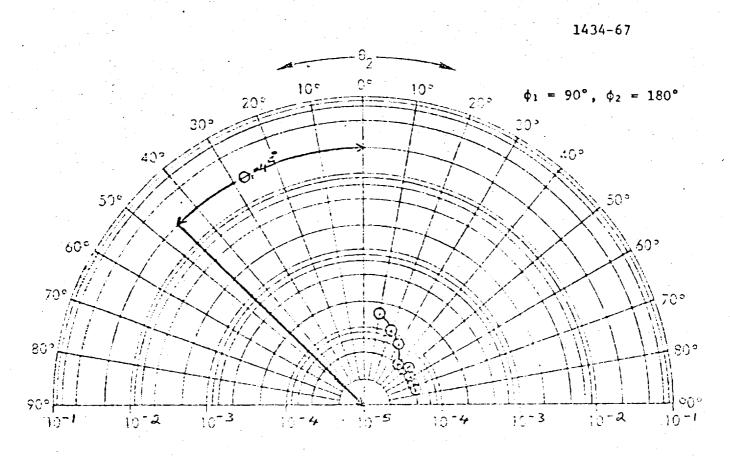
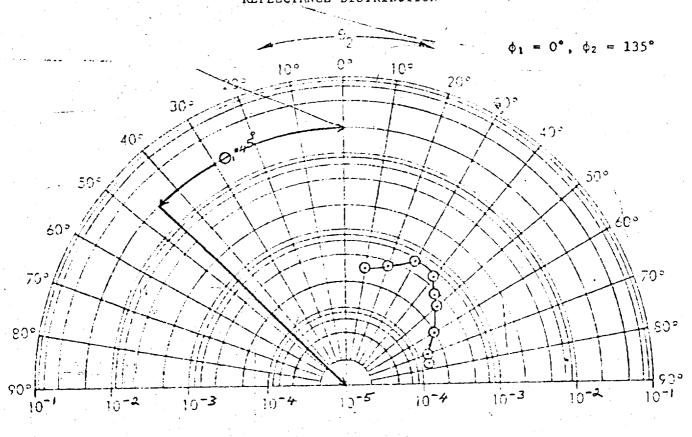


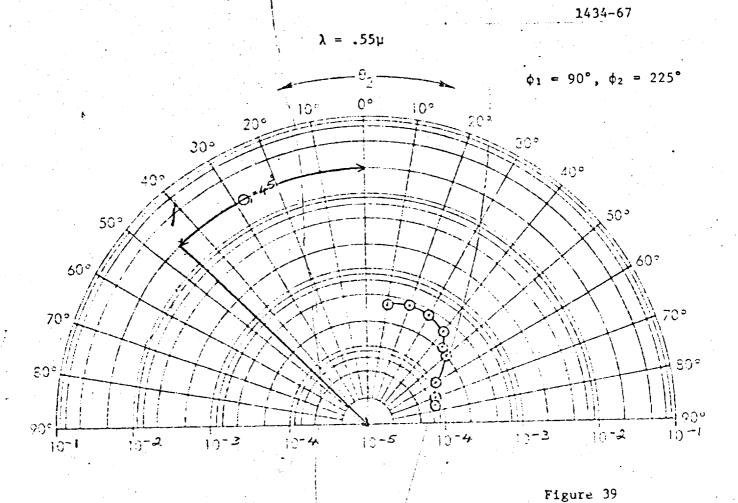
Figure 37





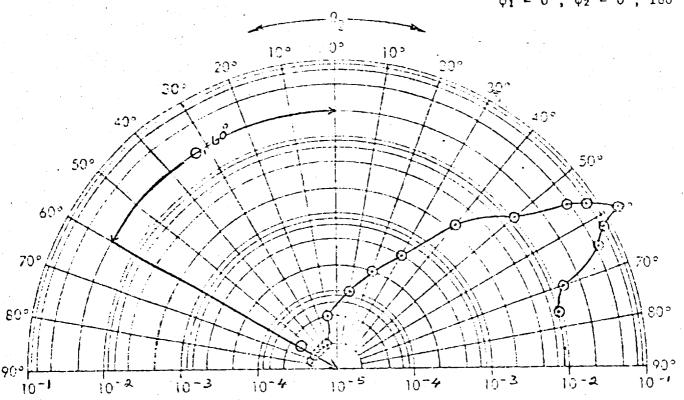
Pigure 38





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 $\phi_1 = 0^\circ$ ,  $\phi_2 = 0^\circ$ , 180°



 $\lambda = .55\mu$ 

1434-67

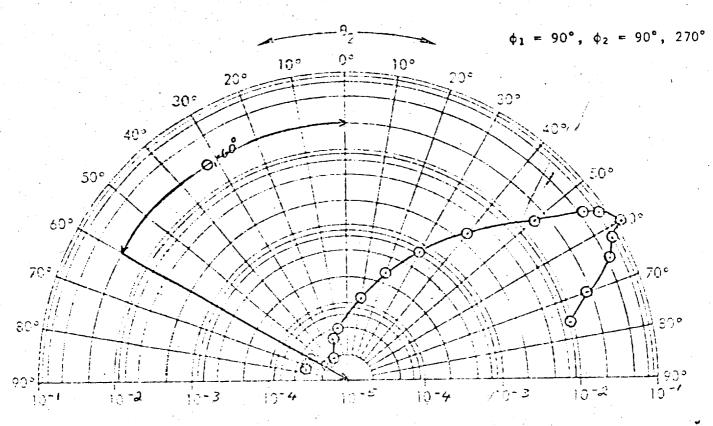
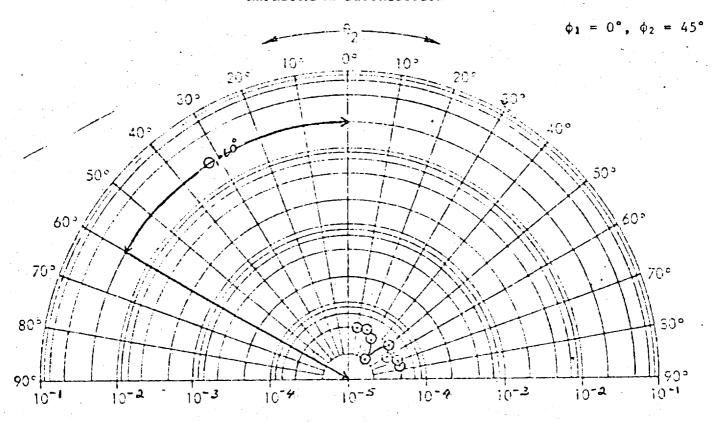


Figure 40



## $\lambda = .55\mu$

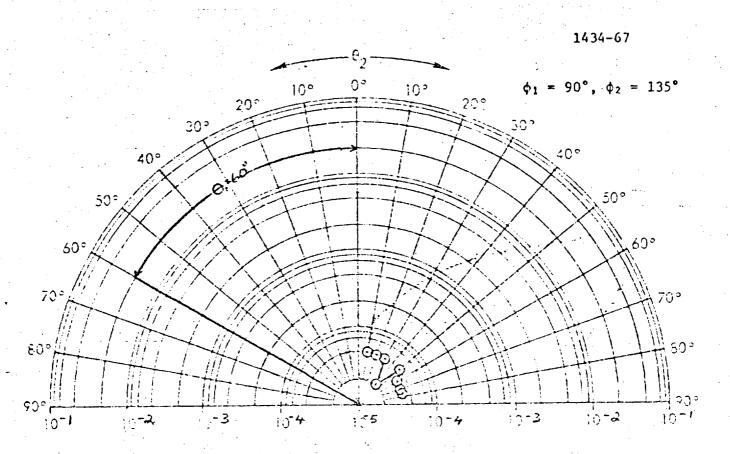
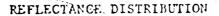
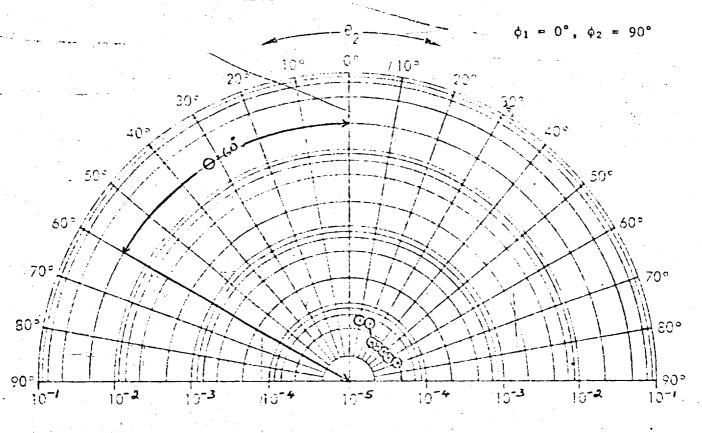
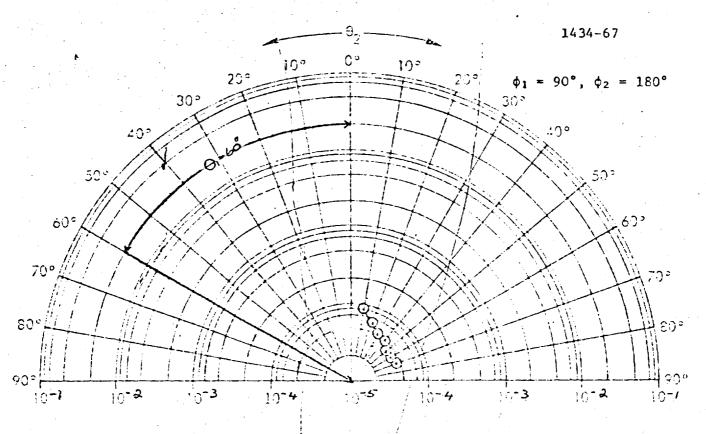


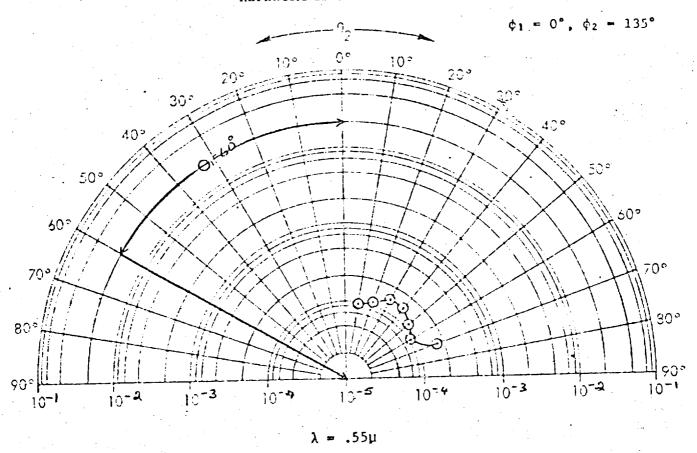
Figure 41





 $\lambda = .55u$ 





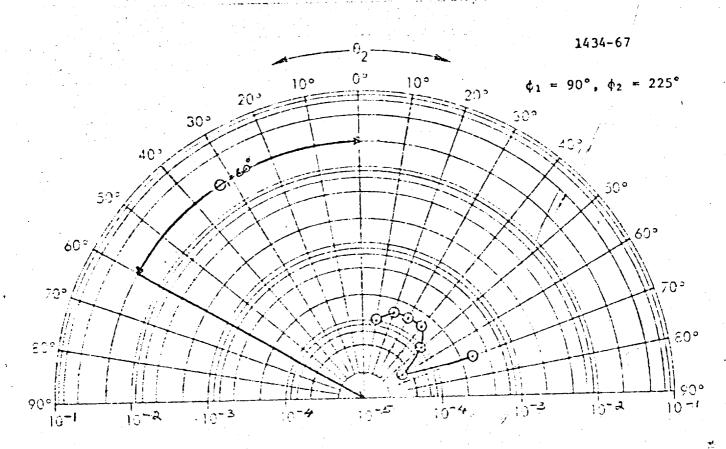
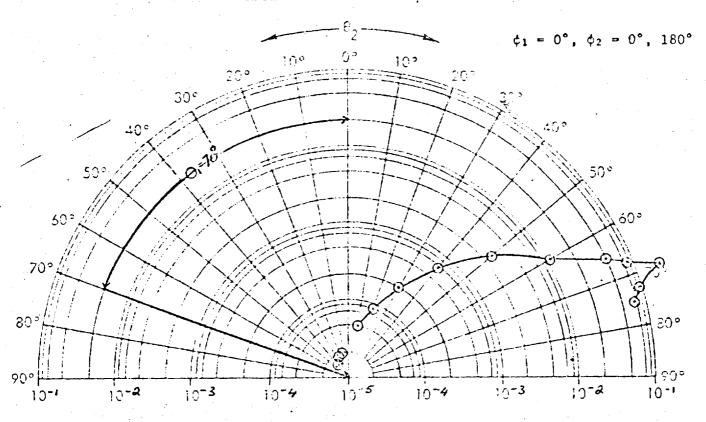
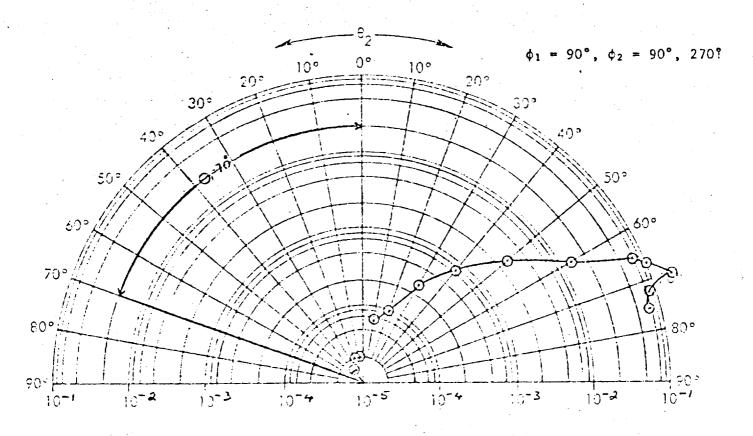


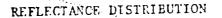
Figure 43

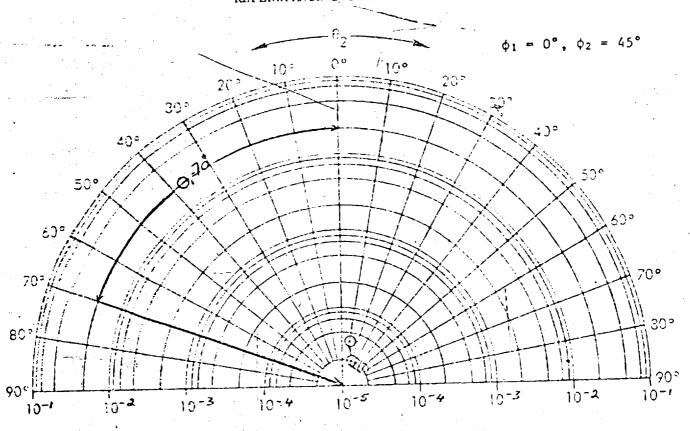


λ = .55µ

1434-67

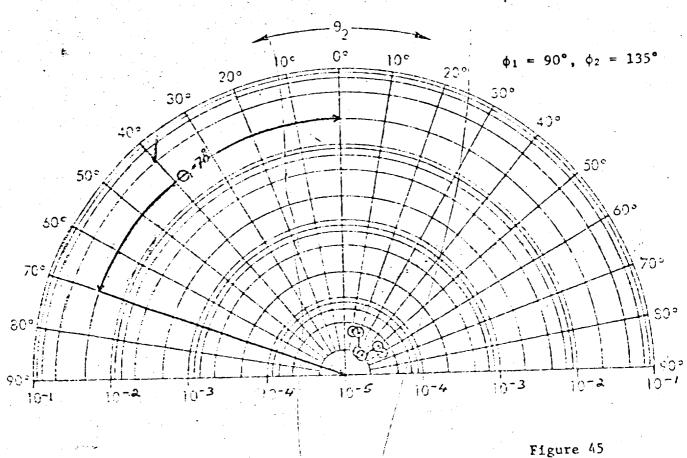




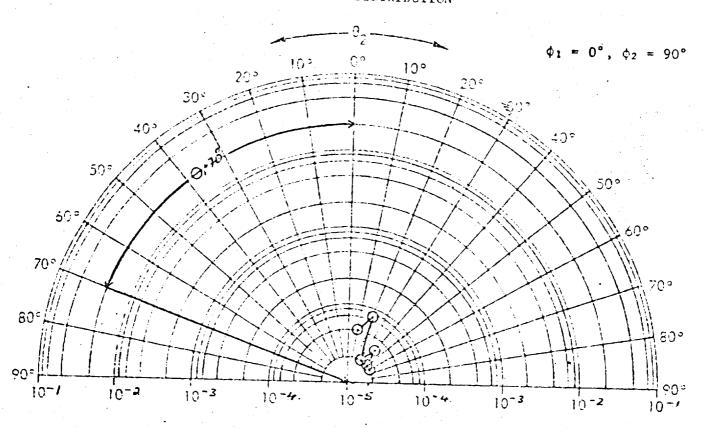


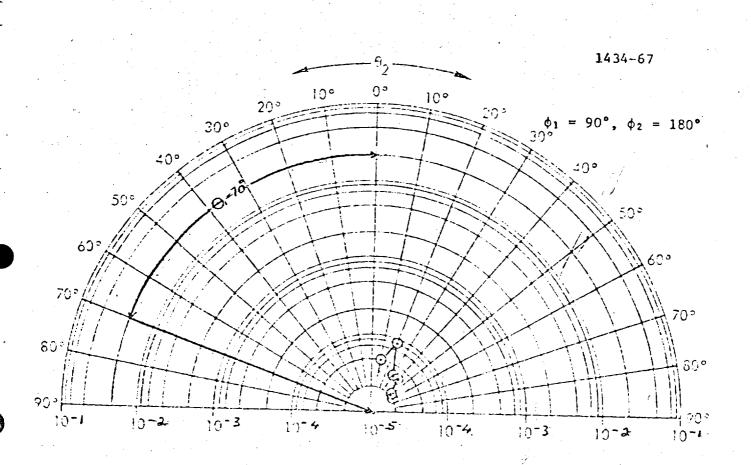
 $\lambda = .55\mu$ 

1434-67



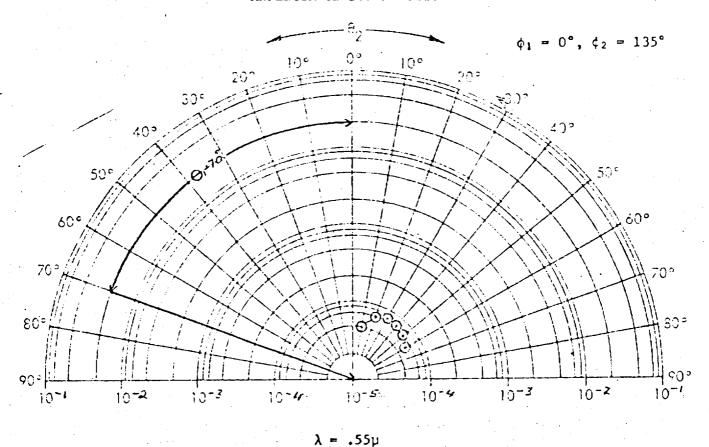
-209-





 $\lambda - .55\mu$ 

Figure 46



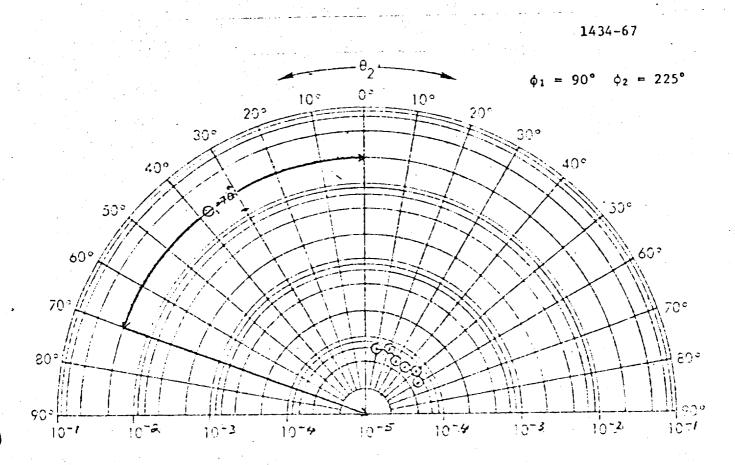
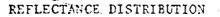
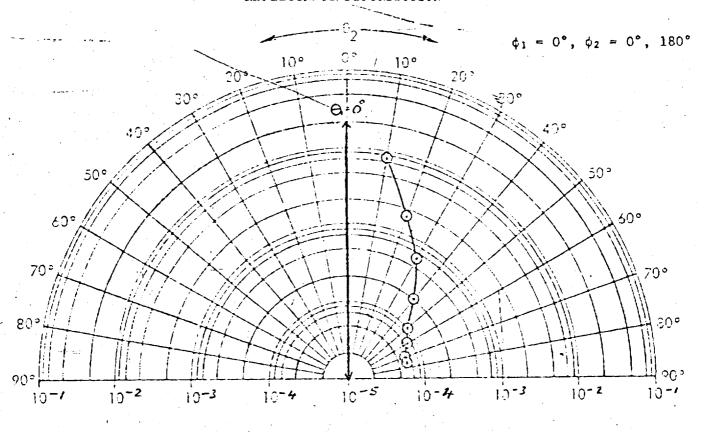
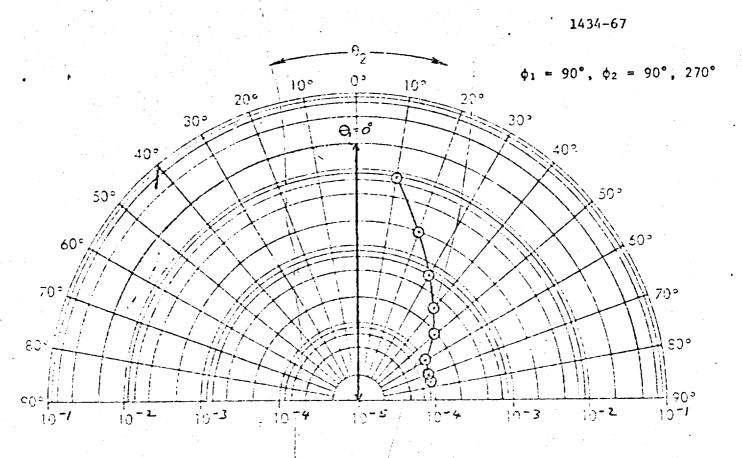


Figure 47



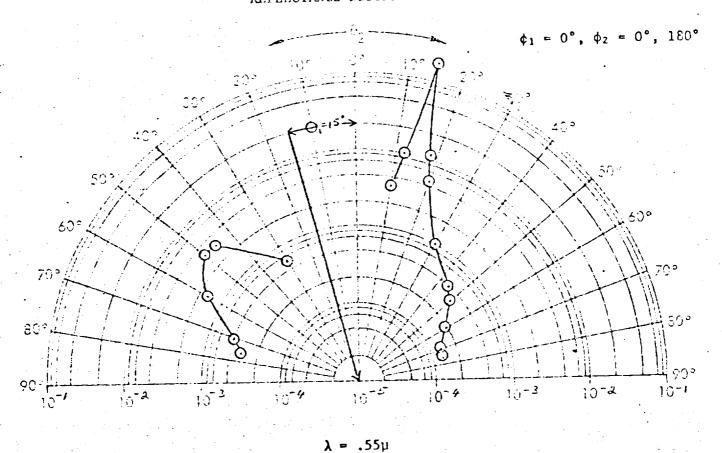






-212-

Figure 48



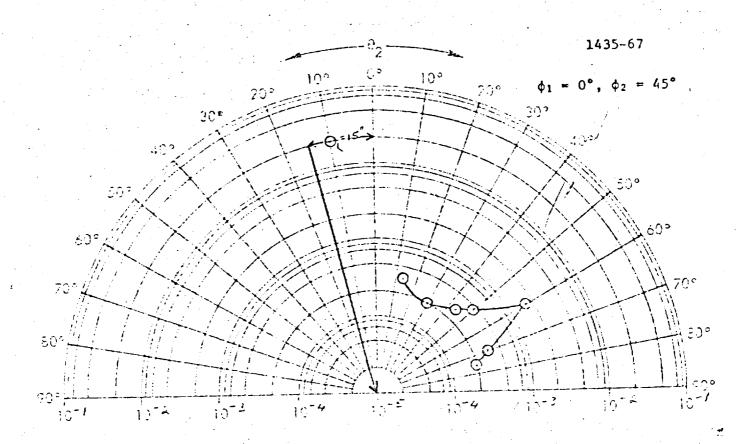
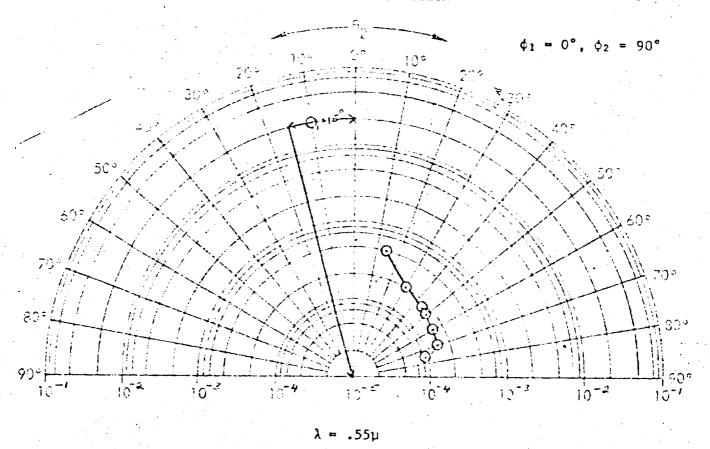


Figure 49



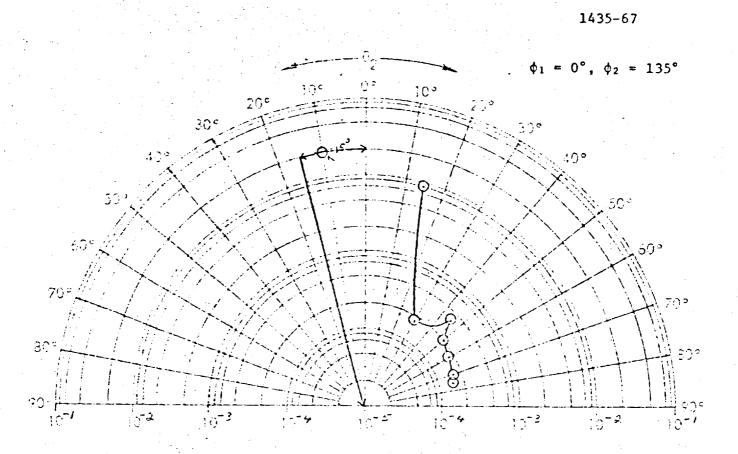
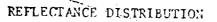
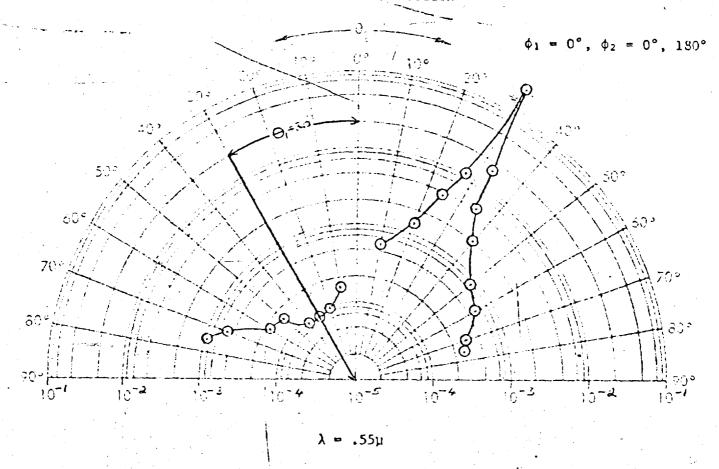
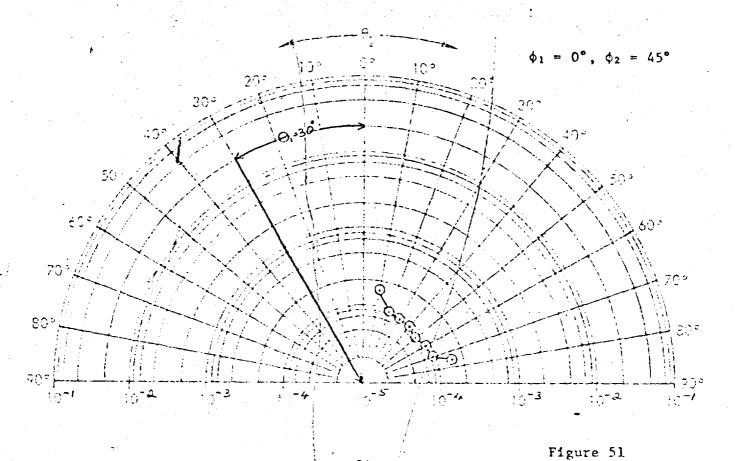
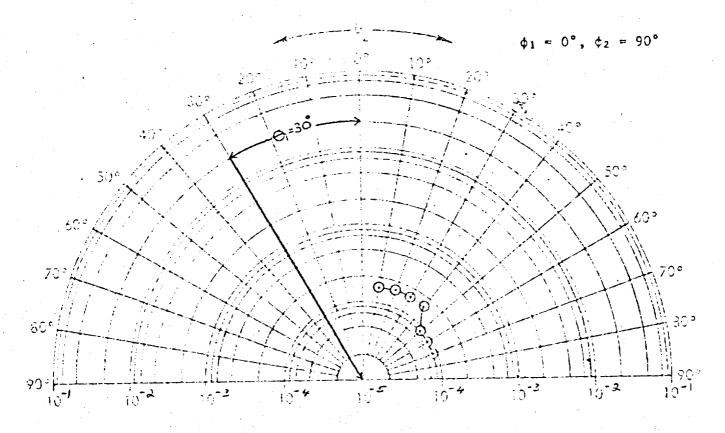


Figure 50









$$\lambda = .55\mu$$

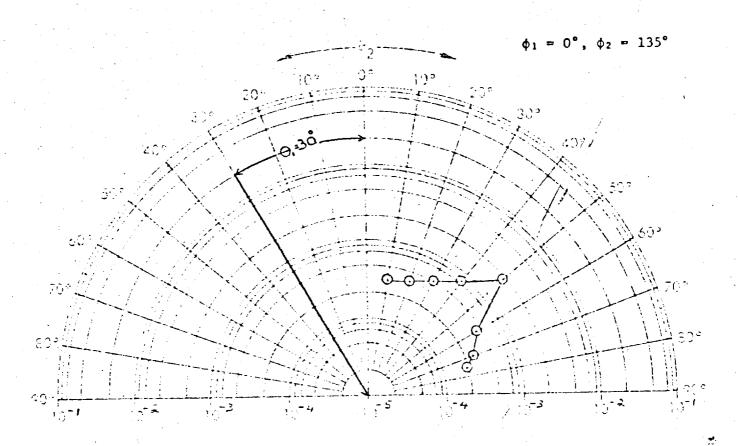
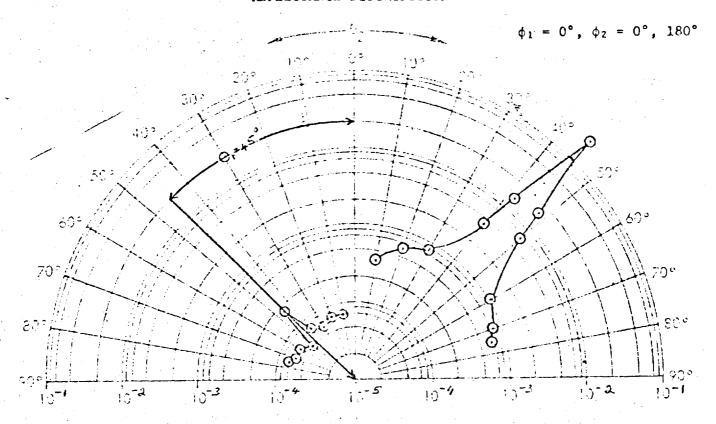
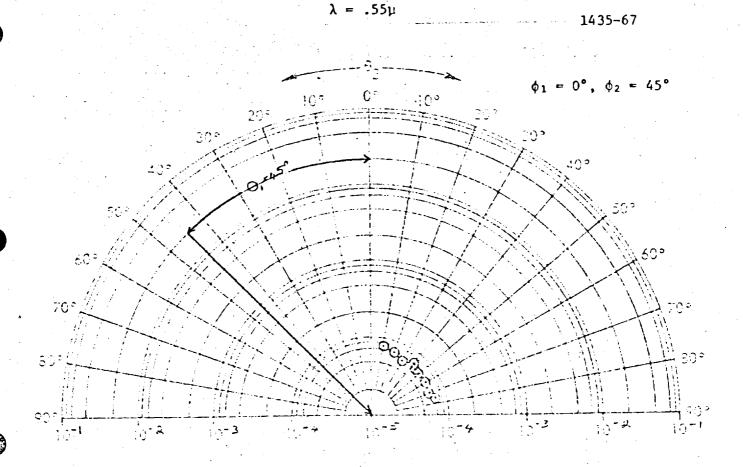
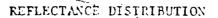
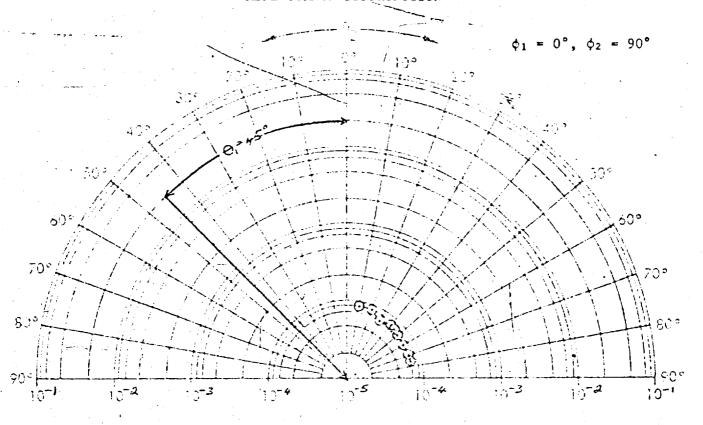


Figure 52

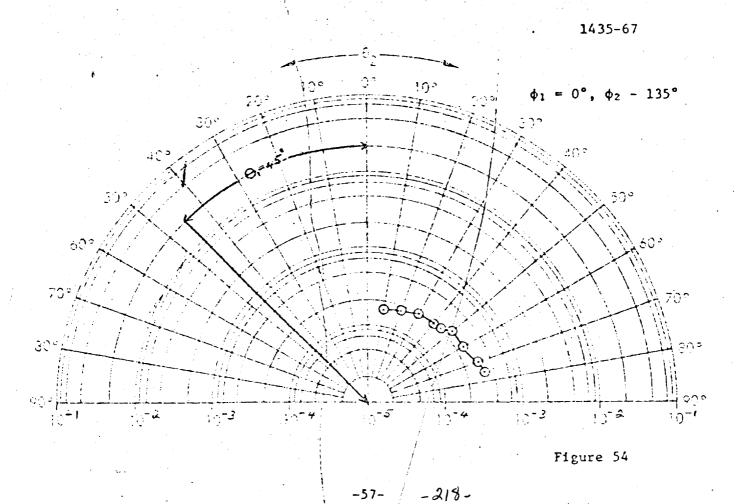


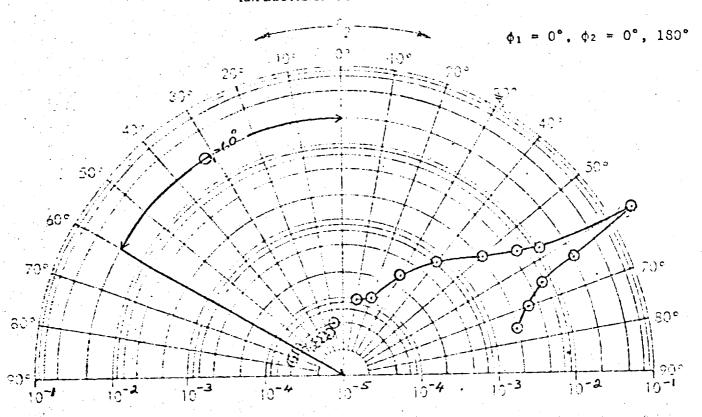






$$\lambda = .55\mu$$





$$\lambda = .55\mu$$

1435-67

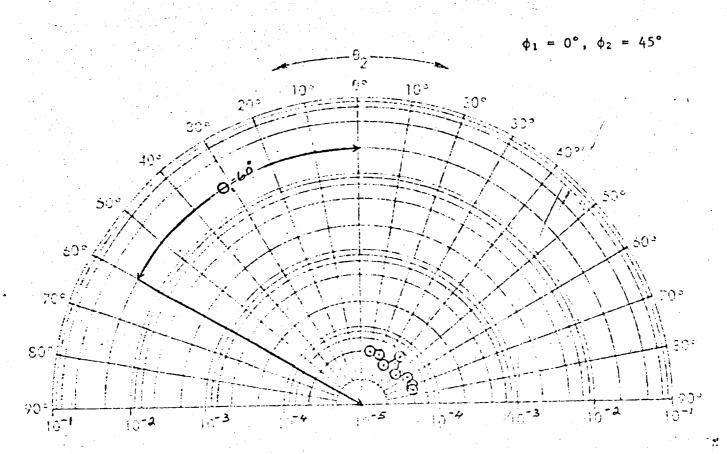
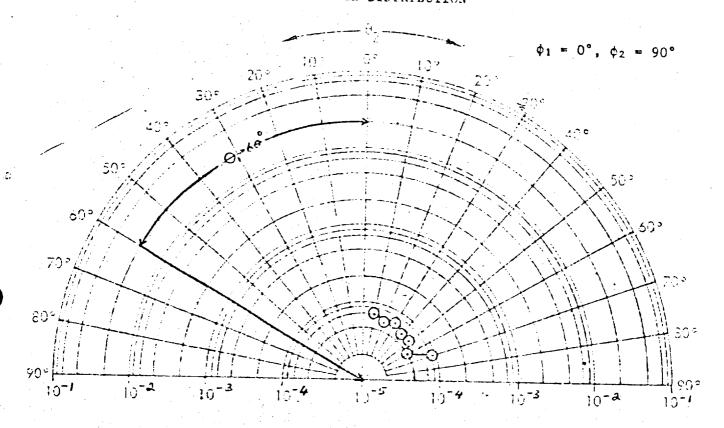


Figure 55



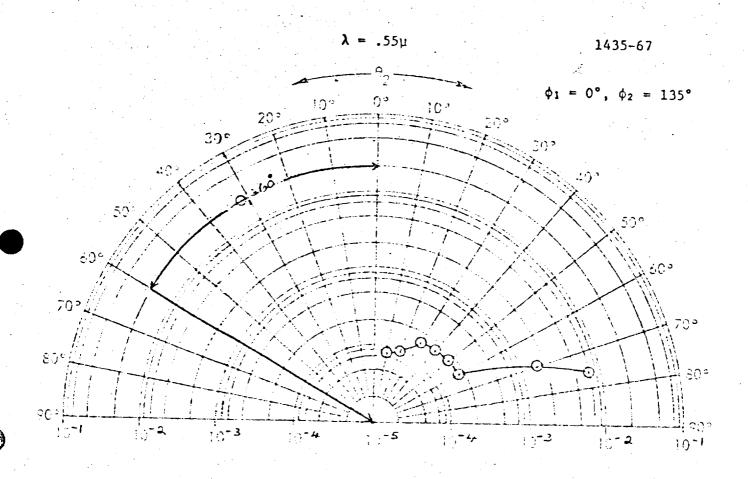
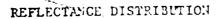
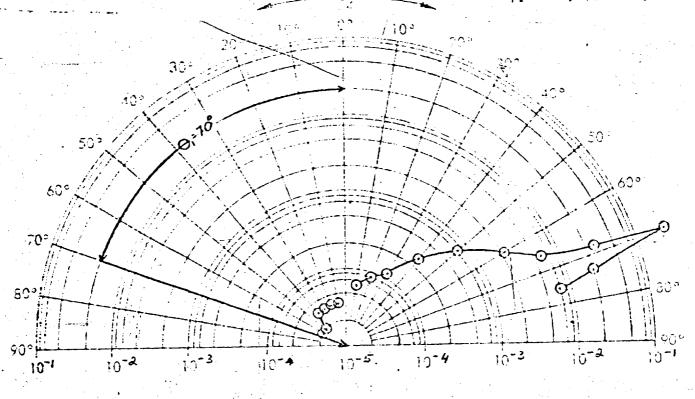


Figure 56

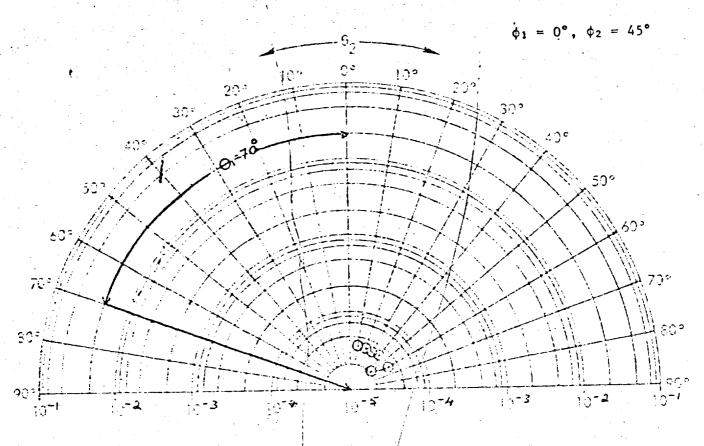


 $\phi_1 = 0^{\circ}, \ \phi_2 = 0^{\circ}, \ 180^{\circ}$ 



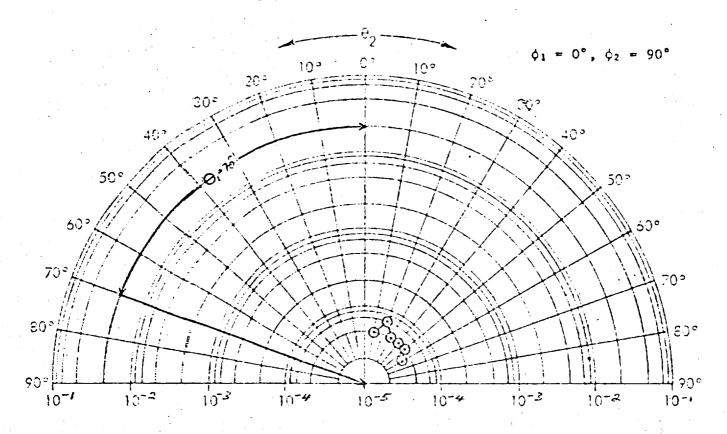
$$\lambda = .55\mu$$

1435-67



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Figure 57





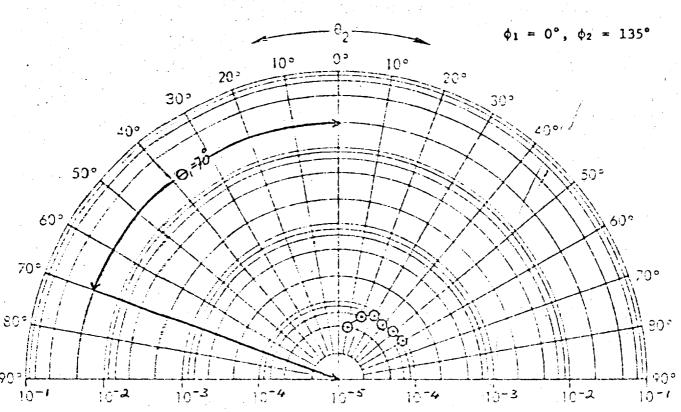
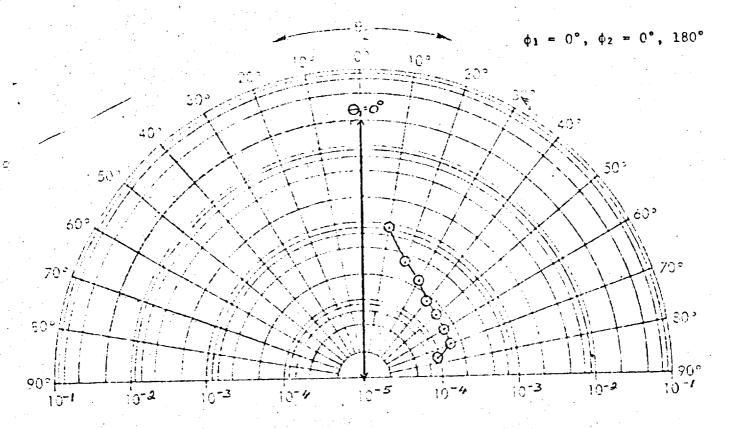


Figure 58



 $\lambda = .55\mu$ 

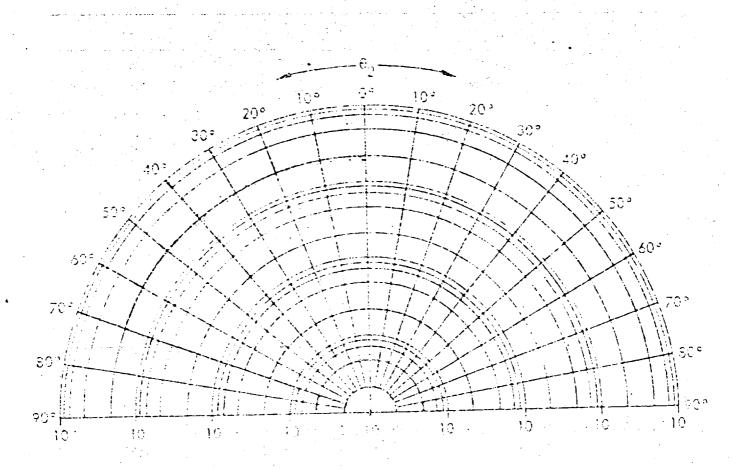
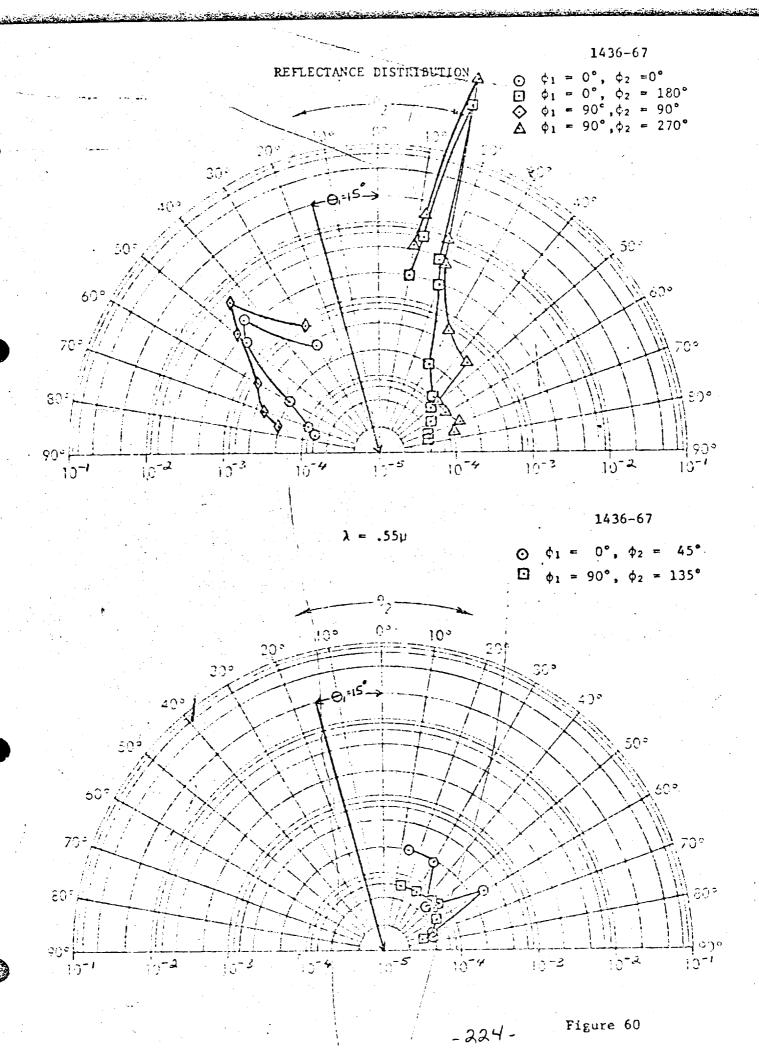
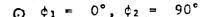


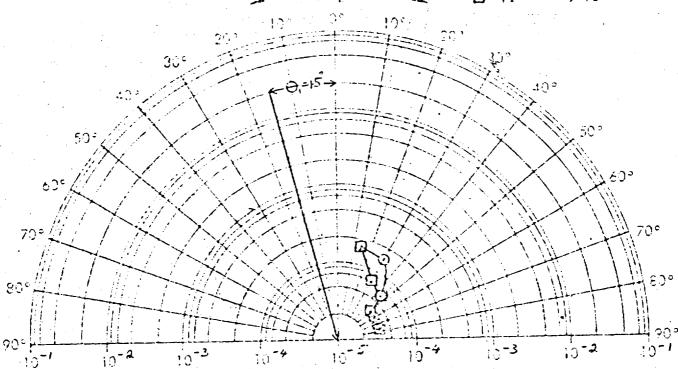
Figure 59







$$\phi_1 = 90^{\circ}, \phi_2 = 180^{\circ}$$



$$\lambda = .55\mu$$

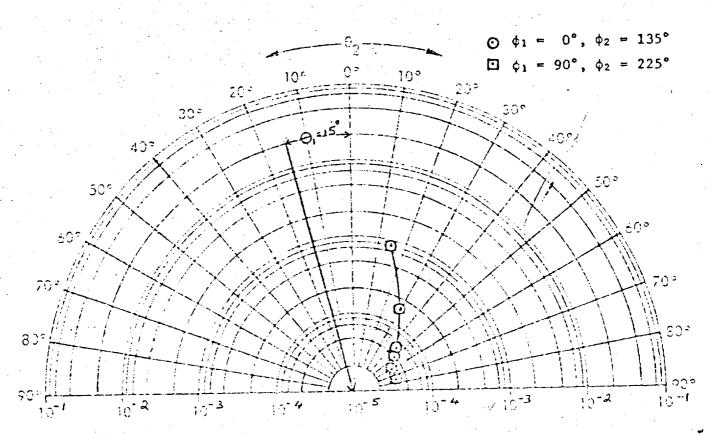
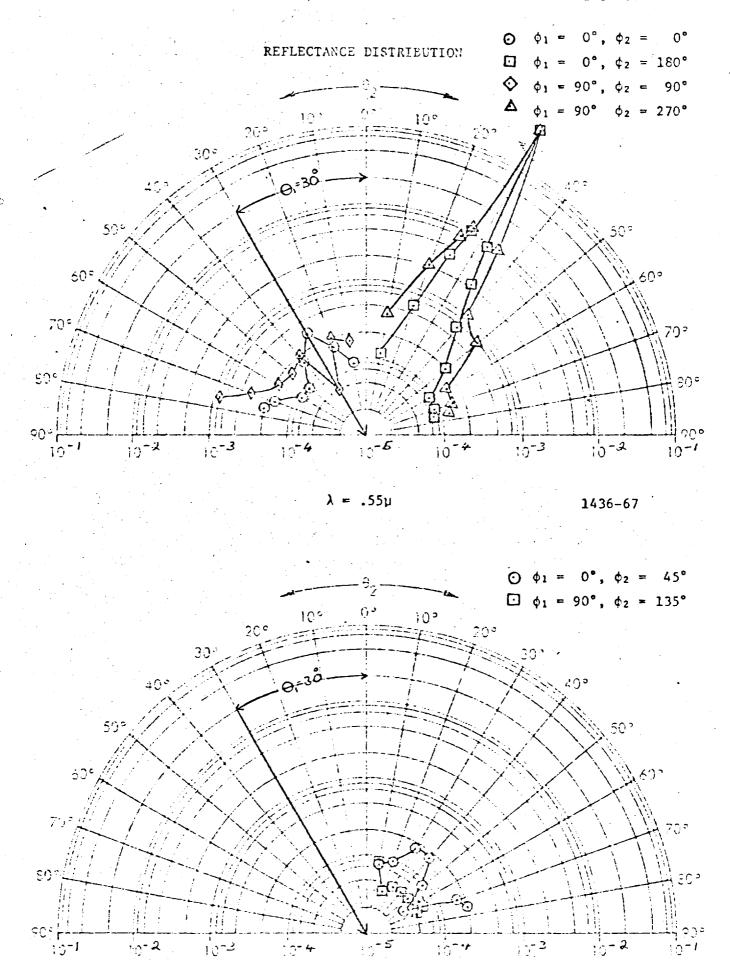
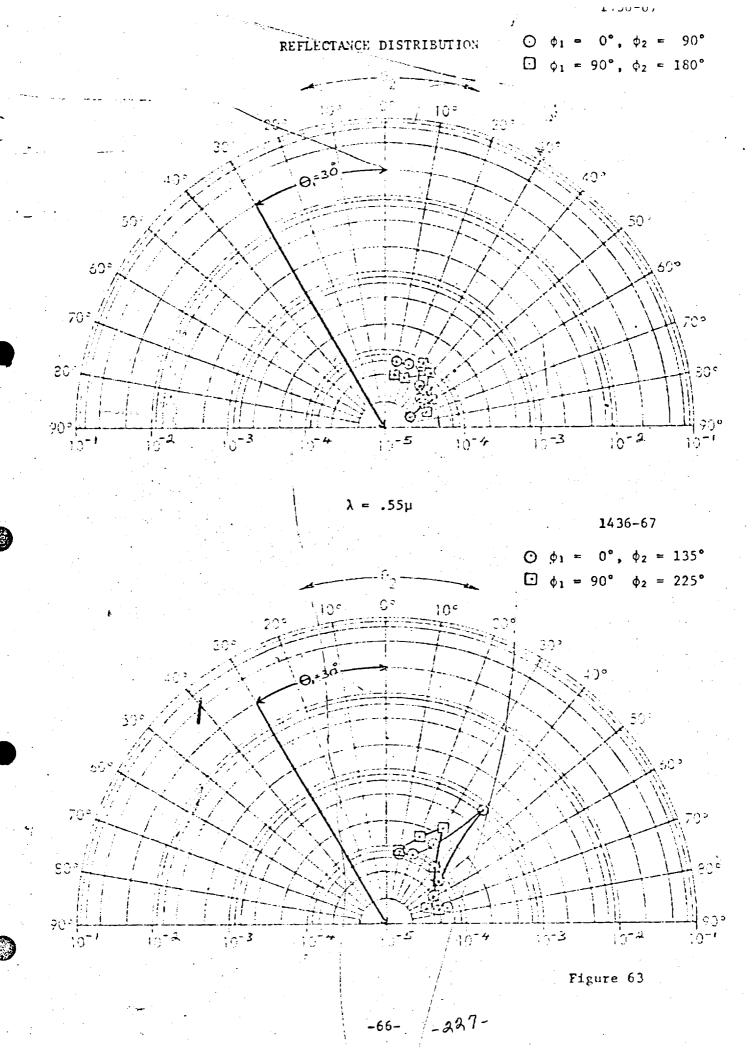


Figure 61



-226 - Figure 62



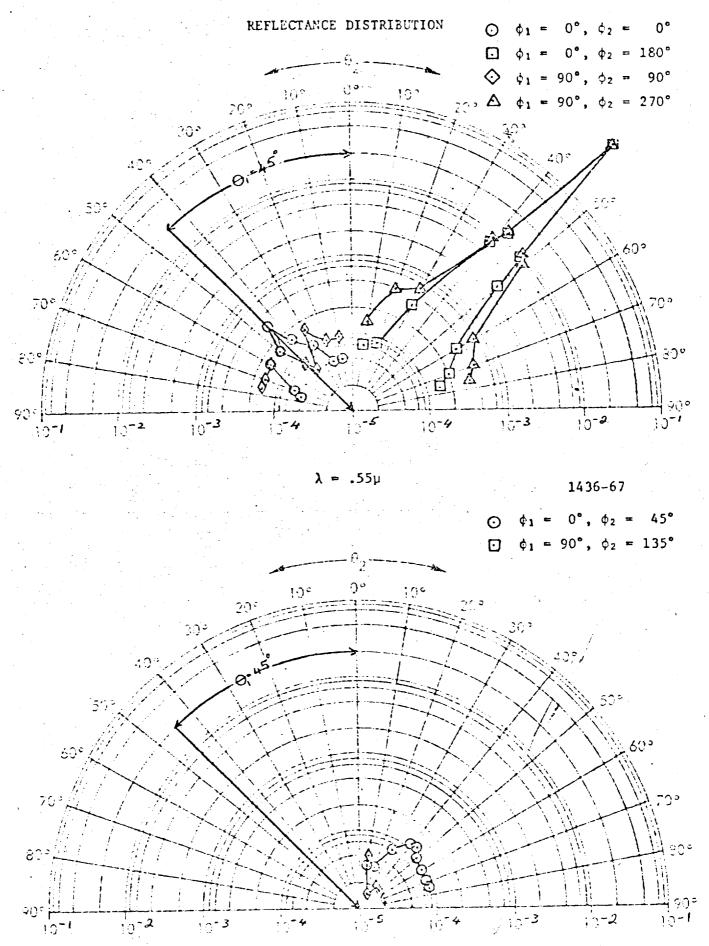
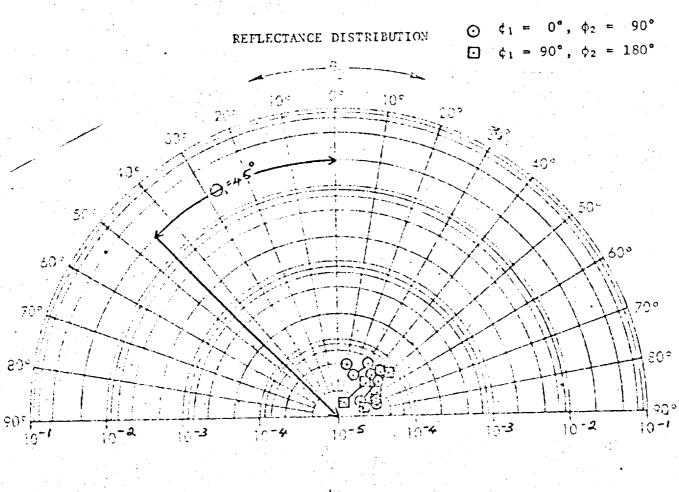
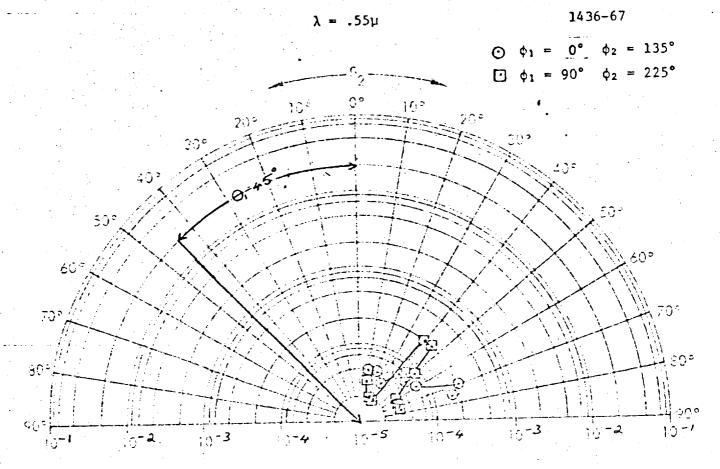
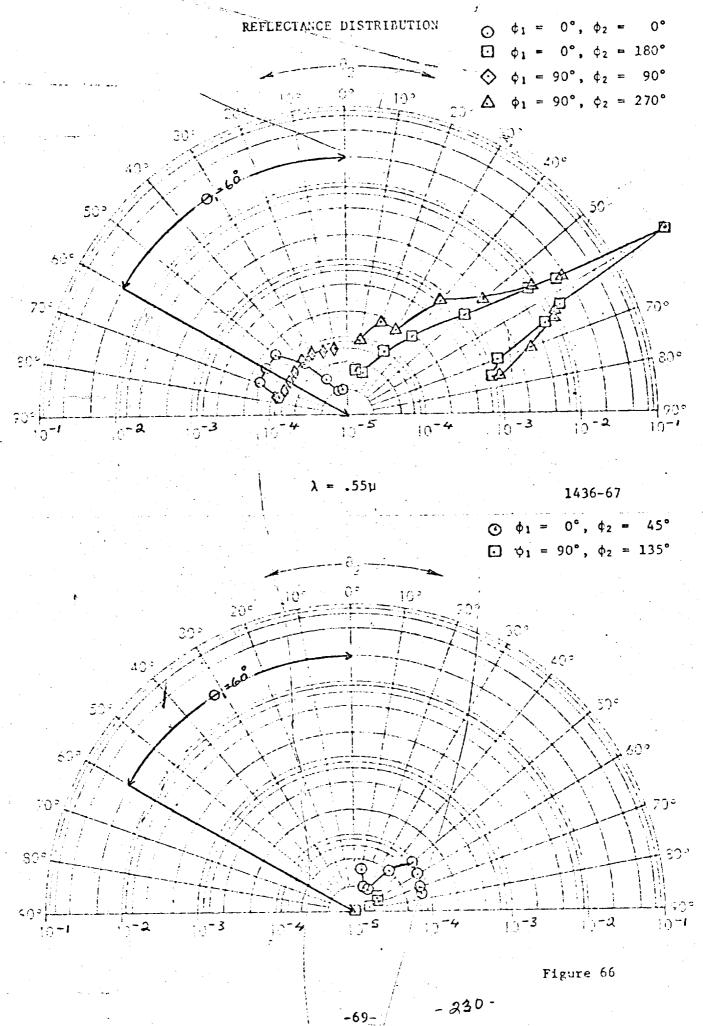


Figure 64

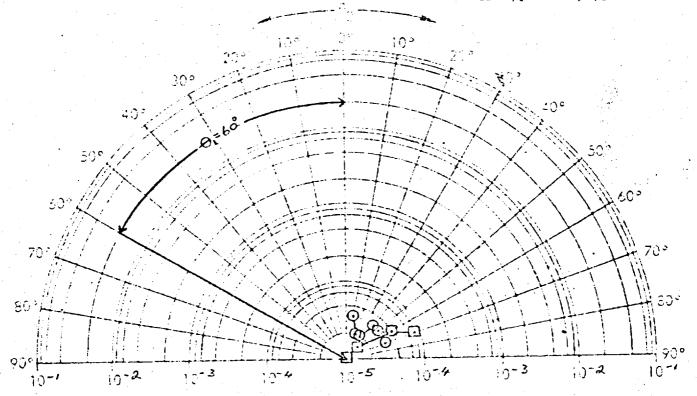




-229- Figure 65



- $\phi_1 = 90^\circ$ ,  $\phi_2 = 180$



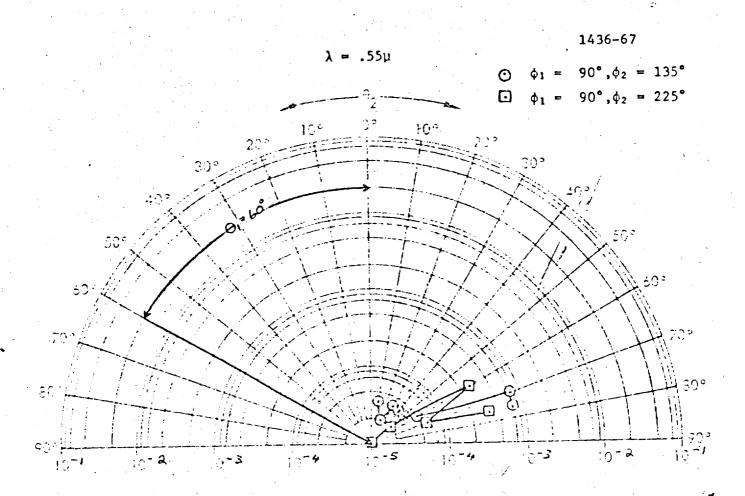
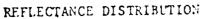
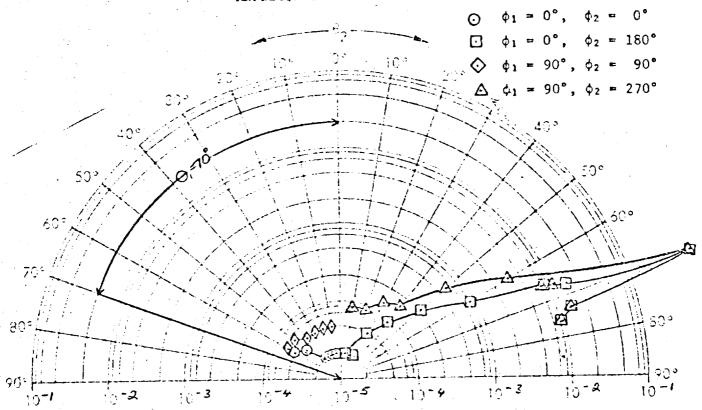


Figure 67





 $\lambda = .55\mu$ 

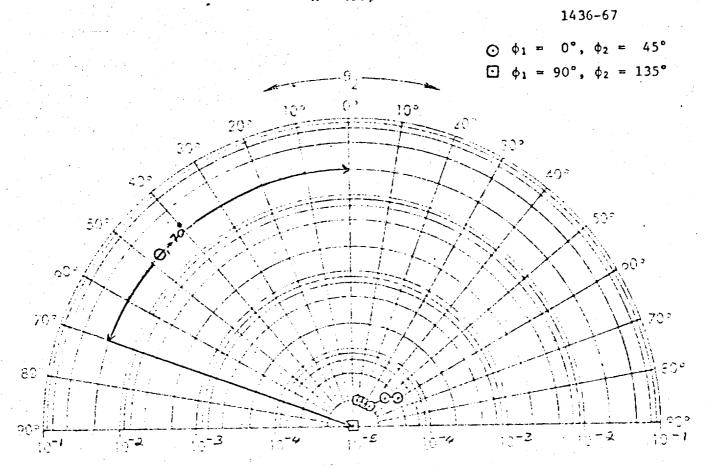
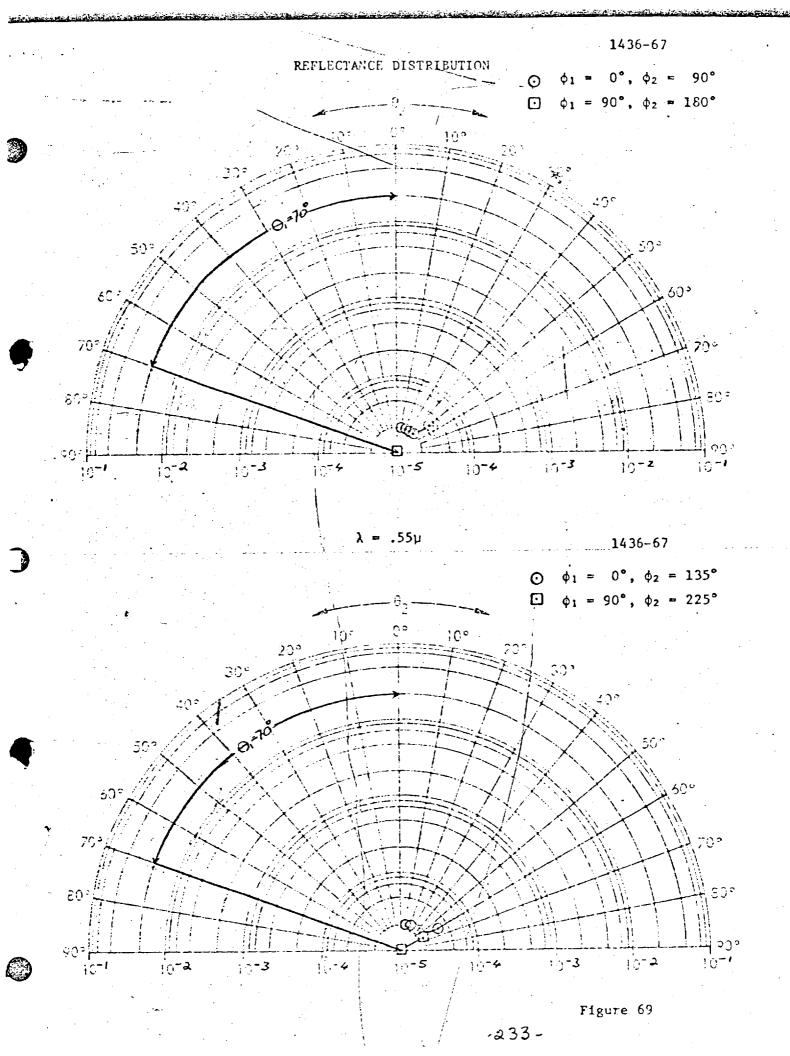
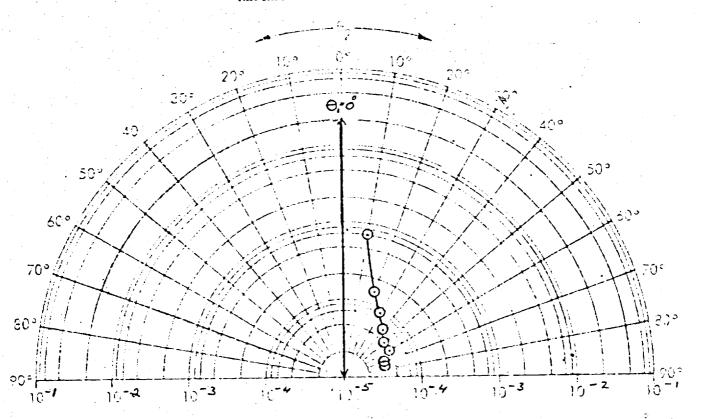


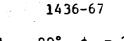
Figure 68

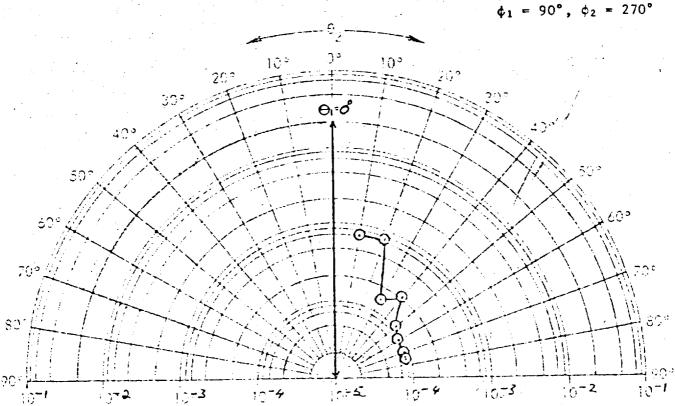


 $\phi_1 = 0^{\circ}, \quad \phi_2 = 180^{\circ}$ 



 $\lambda = .55\mu$ 





1.) 0

 $\lambda = .55\mu$ 

20°

50°

303

7007

