Luminance, Contrast and Polarization of White Light
Reflected from Ground Combat Vehicles

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By

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This document presents the results of a comprehensive study for the luminance and polarization characteristics of three selected combat vehicles. The objective was to measure and analyze bi-directional reflectance data for the M60 tank, the Marine Corps amphibious Light Armored Vehicle (LAV25), the M1 tank and various background scenes. The goal was to understand the passive, visual signatures of these vehicles in terms of phenomenological parameters such as angles of incidence and reflection, polarization angles, material properties, diurnal changes, vehicle geometry and shape, and scene content. The primary illumination sources were the sun, sky and background reflections, and a laboratory xenon arc lamp. The analysis relied primarily upon the Fresnel equations for the polarization work and geometric optics for the luminance data. Important results include the identification of elevated vehicle regions as the primary sources of specular reflected solar illumination, sky illumination as the principal source of intensely polarized reflected light, temporal variations in contrast across the target as a function of diurnal time period and vehicle orientation, and the aging characteristics of the chemical agent resistant coating (CARC) paints used on the vehicle surfaces. This work is volume one of an extended effort to analyze ground combat vehicle signatures.
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SUMMARY

The primary purpose of this work is to study the visual signature of several representative ground combat vehicles. The principal focus is the acquisition and analysis of luminance and polarization data for reflected light from the target and background surfaces. A major goal is to characterize vehicle visual signatures in terms of regions with high luminance contrast. These high contrast areas in turn increase vehicle detectability and in many cases become prominent cue features for threat observers. Three vehicles were selected for extensive data acquisition and analysis: the M60 tank, the Marine Corps amphibious Light Armored Vehicle (LAV25), and the M1 Abrahms tank. In addition, luminance reflectance measurements were made on several sample plates with chemical agent resistant coating (CARC) paints.

The scope of this work included several thousand luminance measurements for the three vehicles relative to sky, concrete, dirt-gravel, grass and tree backgrounds. Extensive measurements were made over the diurnal time period between 08:00 and 15:00 hours. Several different sky conditions including cloud cover, haze, overcast and clear were conducted during the summer months at the U.S. Army Tank-Automotive Command (TACOM) in Warren, Michigan. Luminance data was acquired for four different ranges at 30, 100, 200 and 330 feet. Several different vehicle orientations were used for diurnal data acquisition. Additional data included laboratory reflectance measurements using a xenon arc lamp on an optical table. Other investigations included a diurnal photographic record of relative contrast variations as a function of solar position and vehicle orientation.

The data acquisition process included point by point luminance measurements made with a Minolta luminance meter LS-100 with a one-degree acceptance angle. A polarization axis finder, consisting of circular concentric linear polarizers, determined quantitatively the polarization angle and qualitatively the degree of polarization. A diurnal record of the sky polarization was recorded using the polarization axis finder.

Additional investigations included a comparison of reflected luminance data for new and old CARC painted surfaces. Specifically, the older painted surfaces were approximately 25 percent brighter than a freshly-painted panel prepared in an otherwise identical fashion.

An analysis of the photographic data shows that many edges with high luminance contrast result from specular reflections. Furthermore, the specular reflected light is in many cases highly polarized. The specular glare is reduced by adjusting the transmission axis of the viewing polarizer perpendicular to the polarization vector of the reflected light. Similarly, the apparent edge contrast increases by adjusting the polarizer parallel to the polarization vector. Edges with different paint colors have similar specular reflection coefficients. The specular reflected light shows characteristics of "whitening" with very little absorption by the pigment material. Controlling edge contrast is important for limiting recognition and identification capabilities of threat observers.
A linear polarizer was attached to the shaft of small DC motor rotating at 32 rpm. The entire unit was positioned in front of a video camcorder to determine the angular position for minimum and maximum transmission through the polarization filter. When the degree of polarization is large, an "apparent flashing" was observed for the reflected light originating from certain regions on the vehicle. Subsequent analysis indicated that this phenomena was more pronounced on shaded regions not directly illuminated by the sun. The indirect sky illumination emanating 90° from the orientation of the sun is highly polarized and accounts for the large variations in camcorder intensity. Direct solar illumination has a small degree of polarization; consequently, most observations of sunlit surfaces show very little "flashing" except for specular reflections. The degree of polarization for this case is greatest at the Brewster angle and less pronounced at the angle of specular reflection. If the incident light, however, is highly polarized, then the "flashing" effect is more pronounced even at nonspecular angles. An important feature is that shadowed regions on the vehicle have a lower average luminance while the "flashing" effect is more pronounced, resulting in a high contrast temporal cue feature.
INTRODUCTION

Contrast is one of many factors which influences the ability to detect targets. All successful models which predict the probability of detecting targets will contain a contrast term.

The following equation was used to calculate contrast throughout this report:

\[
C = \frac{L_T - L_B}{L_B}
\]

where \( C \) = Contrast
\( L_T \) = Luminance of target
\( L_B \) = Luminance of background

Luminance is defined as:

1. The quality or state of being luminous
2. A measure of the brightness of a luminous surface, measured in candela (cd) per unit area
3. The photometric analog of radiance
4. A measure of the amount of visible light emitted from an extended source into a given solid angle and incident on a receiving surface (measurements are weighted via the CIE curve)
5. The luminous flux (lumens) per unit solid angle emitted per unit projected area of the source

The luminance unit cd/m² is used exclusively throughout this study. The following are conversions to other units:

Units for Luminance

1 cd/m² = 1 nit = 0.292 footlambert
1 lambert = 1 cd/π cm² = 1 X 10⁴ cd/π m² = 3183 nit
1 footlambert = 1 cd/π ft² = 3.426 nit

The candela (cd) is an international unit for luminous intensity. It is one sixtieth of the luminous intensity of a square centimeter of fused thorium, a white oxide of the element thorium, maintained at 2046 K, the temperature of freezing platinum under a pressure of 101.325 newtons per square meter.
Figure 1 shows the luminance meter used for all studies. The settings used for the Minolta Luminance Meter LS-100 were as follows:

Calibration: PRESET  
Measuring Mode: ABS  
Response: FAST (two seconds)

The LS-100 has a one percent acceptance angle and measurements are virtually unaffected by light sources outside the measurement area. The photocell measures light received by the lens and is filtered to closely match the CIE Relative Photopic Luminosity Response.

A tripod was used to stabilize the meter.

A Minolta Data Printer DP-10 was used to reduce the time required between successive readings and to produce a hard copy of the data. The DP-10 was placed inside the holding strap of the LS-100 to eliminate the need for a table or an extra pair of hands.

The first nine studies include:

1. Diurnal measurements of the luminance from an M60, an M1 and a LAV25
2. Diurnal measurements of the luminance from sky, trees, grass, concrete and dirt-gravel
3. Calculations of the contrast between these vehicles and the backgrounds measured
4. Analysis of the contrasts obtained
5. Analysis of diurnal photographs of an M1

Three days were devoted to the acquisition of luminance data for reflected light from each of the three vehicles. Table 1 gives a summary of the content and conditions of each study. The cardinal directions within the parentheses of Table 1 refer to the orientation of the vehicle. For example, (north) indicates that the metered side of the vehicle was facing north during metering. The luminance meter pointed in the opposite direction.

These nine studies, as a whole, were not planned in advance but were done "on the run." After luminance data was collected and analyzed for one study, the next study was designed. Each study began as a phenomenological study; a search for high contrast areas which can become prominent cue features for threat observers.
In all of the studies where the metered side of the vehicle was facing east, 50 luminance readings were taken randomly of a wooded area directly behind the vehicle. Readings were acquired from left to right using an up and down scanning pattern.

Table 1. Summary of Study Content and Conditions

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<th>Date/Sky Conditions</th>
<th>Meter Range(s)</th>
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<td>M60 (north)</td>
<td>09 JULY, 1990</td>
<td>36'</td>
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<tr>
<td>Sky, Grass, Trees, Concrete and Dirt</td>
<td>Clear 10:00-11:30, Cloudy 11:30-15:30</td>
<td></td>
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<tr>
<td>M60 (north)</td>
<td>12 JULY, 1990</td>
<td>36'</td>
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<tr>
<td>Sky, Grass, Trees, Concrete and Dirt</td>
<td>Overcast 9:30-15:00</td>
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<tr>
<td>M60 (north)</td>
<td>17 JULY, 1990</td>
<td>36'</td>
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<tr>
<td>Sky, Grass, Trees, Concrete and Dirt</td>
<td>Hazy, Cloudy, Overcast 9:00-15:15</td>
<td></td>
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<tr>
<td>M1 (north)</td>
<td>07 JULY, 1990</td>
<td>36'</td>
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<tr>
<td>Sky, Grass, Trees, Concrete and Dirt</td>
<td>Overcast 12:00-15:00</td>
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<tr>
<td>M1 (east)</td>
<td>01 AUGUST, 1990</td>
<td>36, 100, 200 and 330'</td>
</tr>
<tr>
<td>Sky, Grass and Trees</td>
<td>Clear Skies 10:00-15:30</td>
<td></td>
</tr>
<tr>
<td>M1 (east)</td>
<td>06 AUGUST, 1990</td>
<td>36, 100, 200 and 330'</td>
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<tr>
<td>Sky, Grass and Trees</td>
<td>Overcast 10:00-15:30</td>
<td></td>
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<td>LAV25 (east)</td>
<td>23 JULY, 1990</td>
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<td>Trees</td>
<td>Clear 10:00-11:00, Cloudy 11:00-15:00</td>
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<tr>
<td>LAV25 (east)</td>
<td>26 JULY, 1990</td>
<td>36, 100, 200 and 330'</td>
</tr>
<tr>
<td>Sky, Grass, Concrete and Trees</td>
<td>Hazy 9:30-12:30, 12:30-14:30</td>
<td>Concrete 36 &amp; 100'</td>
</tr>
</tbody>
</table>

All studies were conducted at the U.S. Army Tank-Automotive Research, Development and Engineering Center in Warren, Michigan in the vicinity of building 200C and were conducted during Eastern Daylight Standard Time.

All photographs were taken with a Canon A1 set for automatic exposure. The camera was fitted with a Canon Zoom Lens FD 28-85 mm and loaded with Kodak TMAX 400 film.

When two nonparallel surfaces of a vehicle meet, a rounded edge is formed. Under the right conditions, this edge may appear as a white line and can be used as a cue feature for threat observers. The "Glare and Edge Effect" study represents an initial investigation of the factors producing this phenomena and the nature of the light leaving the rounded edge.
In the study "Horizontal and Vertical Polarization of the M1A1", diurnal luminance readings and photographs were acquired for the M1A1 turret and skirt areas from 08:30 to 16:00 at thirty minute intervals under clear skies. The photographs show pictorially how luminance, contrast, shadows and shading vary diurnally over the elevated areas of the vehicle. The luminance data includes readings both without a polarizer and through a polarizer with its transmission axis oriented horizontally and vertically. This study also includes photographs of the Eastern hemispherical sky at a 30° altitude taken through a polarization axis finder. This study initiates the idea that the polarization of the sky is the major source of polarized light reflected from the M1A1.

The "Luminance, Polarization and Chromaticity Study on 15 July, 1991" was conducted to determine the degree and nature of linearly polarized reflected light from a CARC-painted M1A1. The study was also designed to determine how the three coordinates of the CIE Chromaticity Diagram vary diurnally for three different facets on the M1A1 and two backgrounds; a grass area and three tree areas. Data was collected simultaneously by two researchers. One used the Minolta LS-100 luminance meter fitted with a linear polarizer and the other used the Minolta CS-100 chromaticity meter. The range of the M1A1 and grass area was 36 feet. The range of the tree area was approximately 1000 feet. Data was collected at 30-minute intervals from 08:00 to 14:30. Skies were clear until 12:00; cloudy and overcast after 12:00. This study also describes the results of video tapes obtained by positioning a rotating (32 rpm) linear polarizer in front of a camcorder. This study was designed to determine when and where the greatest degree of reflected polarized light can be detected from a ground vehicle. When polarized light passes through the rotating linear polarizer a "flicker" effect is produced. The degree of "flicker" is a measure of the degree of polarization.

To obtain a more comprehensive understanding of the luminance and polarization of reflected light from a CARC-painted surface, under controlled conditions, a nine-by-ten inch steel plate was prepared and painted using the same procedures and materials as would be used for a combat-prepared M1A1. A luminance comparison test was conducted using two weathered M1A1 areas and the newly painted surface. Diurnal measurements of the luminance from the two M1A1 areas and the CARC-painted steel plate positioned adjacent to these areas can be found in the study "Luminance of New and Old CARC-Painted Surfaces." Data was collected from 08:00 to 15:00 at 30-minute intervals under clear skies at a range of 36 feet.

Three goniophotometric studies of the CARC-painted steel plate were designed to acquire information on the light distributing properties of the sample illuminated by sunlight. The first, "Azimuthal Study", shows how luminance is affected by changes in the azimuthal viewing angle when the altitude of the viewing angle (30°) is constant. Data was acquired at 12:00 under clear skies. The study "Goniophotometric Readings in the Plane of Incidence" shows how luminance is affected by changes in the surface altitude of the viewing angle for readings in the plane of incidence. The study "Goniophotometric Readings Perpendicular to the Plane of Incidence" shows how luminance is affected by changes in the surface altitude of the viewing angle for readings perpendicular to the plane of incidence.
The last two studies of this report were designed to acquire information on the light distributing properties of the CARC-painted steel plate without the influence of sky conditions. These studies were conducted inside, in a darkroom setting, using a Xenon light source as the only source of illumination.

The study "Luminance from a CARC-Painted Sample Using Xenon Light" consists of two different kinds of measurement. In the first part of the study, luminance readings were acquired outside the plane of incidence using a linear polarizer in front of the Xenon light source with its transmission axis horizontal. The collimated Xenon light rays made a 40° angle with the horizontal and the meter slope was adjusted to produce luminance readings at angles of 0°, 10°, 20°, and 30° from the horizontal. The CARC-painted sample was positioned in a vertical plane at all times and was rotated about a vertical axis producing a range of azimuthal angles between 0° and 90° in 10-degree increments. The azimuthal angle of the meter was held constant at 40°. In the second part of the study, luminance measurements were acquired in the plane of incidence using horizontal, unpolarized light from the Xenon light source. The luminance meter was also positioned to acquire readings from the horizontal. The CARC-painted sample was positioned in a vertical plane at all times and was rotated about a vertical axis producing a range of azimuthal angles between 0° and 90° in 10-degree increments. The luminance meter was positioned to produce azimuthal angles of 40° and 60°.

The purpose of the study "Polarization Axis of Reflected White Light from a CARC-Painted Sample" was to determine how the degree of polarization and the polarization angle are affected by changes in azimuthal viewing angle when the altitude of the viewing angle is constant. The source of light for this study was a collimated Xenon light source with a linear polarizer placed in front of the collimating lens. Both the luminance meter and the Xenon light source were positioned with a 40° slope. Azimuthal angles ranged from 20° to 180° in 20-degree increments. The polarization axis of the incident light ranged from 0° to 90° in 10-degree increments. All of the data for this study is in the form of photographs of reflected light passing through a polarization axis finder. The polarization axis finder determines the polarization axis of linear polarized light and visually indicates the intensity of polarization. As a first attempt at quantifying observations, this study compares experimental results with a modified version of Fresnel's laws of reflection.
M60 STUDIES

Figure 2 shows the setup used to obtain luminance readings for the three studies involving the M60 tank. The LS-100 was positioned 36 feet from a stationary M60. The M60 was not moved during the three days of data collection. The M60 side was facing north and the LS-100 was pointed toward the south.

Figure 2
Setup Used to Obtain Luminance Readings for M60 Studies
Figure 3
Position and Area of Luminance Readings for M60 Studies

The circled numbers of Figure 3 show the position and measurement area used for all M60 studies. The LS-100 measurement area is approximately the same as is circled on the photograph.

Area #9, tree background, does not show in the photograph. Area #9 is located to the far right (west) of the M60. This tree line is oriented along a north-south line. The LS-100 meter pointed toward the west when area #9 was measured.

The M60 side was facing north and metering was toward the south.

Two studies were conducted on 17 July, 1990. To distinguish between them, they will be referred to as Study A and Study B. Study A consisted of 10 luminance readings taken every 15 minutes. Study B consisted of 44 luminance readings taken at 10:35, 11:35 and 13:05.

Study 09 July, 1990  Overcast 10:30 - 11:00, Partly Cloudy 11:30 - 15:30

This is the only study for which the DP-10 Data Printer was not used. Luminance readings for the same area were observed during a 15-second time interval and only the minimum and maximum values were recorded. Graphs, contrast calculations and analysis for this study are based on the averages of these minimum and maximum readings.
M60 Study of 09 July, 1990

Table 2. Summary of Luminance Readings for 09 July, 1990
(Clear Skies 10:30 - 11:30, Cloudy 11:30 - 15:30)

<table>
<thead>
<tr>
<th>Measurement Area</th>
<th>Range of Measurements (cd/m²)</th>
<th>Average Luminance (cd/m²)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 (Sky)</td>
<td>5,500 - 14,600</td>
<td>10,809</td>
<td>2,903</td>
</tr>
<tr>
<td>#2 (M60 Turret)</td>
<td>574 - 1,400</td>
<td>917</td>
<td>176</td>
</tr>
<tr>
<td>#3 (M60 Turret)</td>
<td>640 - 1,150</td>
<td>857</td>
<td>135</td>
</tr>
<tr>
<td>#4 (M60 Turret)</td>
<td>380 - 660</td>
<td>508</td>
<td>84</td>
</tr>
<tr>
<td>#5 (M60 Wheel)</td>
<td>210 - 466</td>
<td>336</td>
<td>68</td>
</tr>
<tr>
<td>#6 (Concrete)</td>
<td>1,100 - 6,100</td>
<td>3,405</td>
<td>1,533</td>
</tr>
<tr>
<td>#7 (Dirt-Gravel)</td>
<td>1,320 - 5,900</td>
<td>3,816</td>
<td>1,923</td>
</tr>
<tr>
<td>#8 (Grass)</td>
<td>1,020 - 2,780</td>
<td>2,011</td>
<td>632</td>
</tr>
<tr>
<td>#9 (Trees)</td>
<td>250 - 1,000</td>
<td>558</td>
<td>166</td>
</tr>
</tbody>
</table>

M60 TANK LUMINANCE
RANGE = 36 FEET

Figure 4

BACKGROUND LUMINANCE

Figure 5
M60 Study of 09 July, 1990 (Clear Skies 10:30 - 11:30, Cloudy 11:30 - 15:30)

M60 TANK
SKY BACKGROUND

![Graph](image)

Figure 6

M60 TANK
CONCRETE BACKGROUND

![Graph](image)

Figure 7

M60 TANK
DIRT-GRAVEL BACKGROUND

![Graph](image)

Figure 8

M60 TANK
GRASS BACKGROUND

![Graph](image)

Figure 9
Table 3. Summary of Contrast Calculations for 09 July, 1990  
(Clear Skies 10:30 - 11:30, Cloudy 11:30 - 15:30)

<table>
<thead>
<tr>
<th>Targ./Backg.</th>
<th>#2/Sky</th>
<th>#3/Sky</th>
<th>#4/Sky</th>
<th>#5/Sky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.946</td>
<td>-0.954</td>
<td>-0.971</td>
<td>-0.978</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.818</td>
<td>-0.813</td>
<td>-0.897</td>
<td>-0.930</td>
</tr>
<tr>
<td>Average</td>
<td>-0.905</td>
<td>-0.911</td>
<td>-0.948</td>
<td>-0.966</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.043</td>
<td>0.040</td>
<td>0.021</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>#2/Concrete</td>
<td>#3/Concrete</td>
<td>#4/Concrete</td>
<td>#5/Concrete</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.890</td>
<td>-0.875</td>
<td>-0.910</td>
<td>-0.930</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.293</td>
<td>-0.280</td>
<td>-0.574</td>
<td>-0.825</td>
</tr>
<tr>
<td>Average</td>
<td>-0.652</td>
<td>-0.675</td>
<td>-0.813</td>
<td>-0.885</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.187</td>
<td>0.184</td>
<td>0.101</td>
<td>0.039</td>
</tr>
<tr>
<td></td>
<td>#2/Dirt</td>
<td>#3/Dirt</td>
<td>#4/Dirt</td>
<td>#5/Dirt</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.889</td>
<td>-0.874</td>
<td>-0.919</td>
<td>-0.937</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.402</td>
<td>-0.317</td>
<td>-0.596</td>
<td>-0.830</td>
</tr>
<tr>
<td>Average</td>
<td>-0.697</td>
<td>-0.709</td>
<td>-0.832</td>
<td>-0.898</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.163</td>
<td>0.176</td>
<td>0.097</td>
<td>0.040</td>
</tr>
<tr>
<td></td>
<td>#2/Grass</td>
<td>#3/Grass</td>
<td>#4/Grass</td>
<td>#5/Grass</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.791</td>
<td>-0.762</td>
<td>-0.851</td>
<td>-0.885</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.075</td>
<td>-0.211</td>
<td>-0.527</td>
<td>-0.663</td>
</tr>
<tr>
<td>Average</td>
<td>-0.488</td>
<td>-0.512</td>
<td>-0.712</td>
<td>-0.817</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.197</td>
<td>0.203</td>
<td>0.120</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td>#2/Trees</td>
<td>#3/Trees</td>
<td>#4/Trees</td>
<td>#5/Trees</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.084</td>
<td>-0.175</td>
<td>-0.535</td>
<td>-0.641</td>
</tr>
<tr>
<td>Maximum</td>
<td>2.046</td>
<td>1.724</td>
<td>0.611</td>
<td>0.143</td>
</tr>
<tr>
<td>Average</td>
<td>0.783</td>
<td>0.713</td>
<td>0.015</td>
<td>-0.354</td>
</tr>
<tr>
<td>Std. Dev</td>
<td>0.587</td>
<td>0.639</td>
<td>0.384</td>
<td>0.205</td>
</tr>
</tbody>
</table>
Table 4. Summary of Luminance Readings for 12 July, 1990
(Overcast 9:30-15:00)

<table>
<thead>
<tr>
<th>Measurement Area</th>
<th>Range of Measurements (cd/m²)</th>
<th>Average Luminance (cd/m²)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 (Sky)</td>
<td>3,570 - 15,400</td>
<td>10,177</td>
<td>4,396</td>
</tr>
<tr>
<td>#2 (M60 Turret)</td>
<td>440 - 1,110</td>
<td>769</td>
<td>167</td>
</tr>
<tr>
<td>#3 (M60 Turret)</td>
<td>470 - 1,170</td>
<td>853</td>
<td>187</td>
</tr>
<tr>
<td>#4 (M60 Turret)</td>
<td>255 - 730</td>
<td>475</td>
<td>129</td>
</tr>
<tr>
<td>#5 (M60 Wheel)</td>
<td>125 - 503</td>
<td>297</td>
<td>98</td>
</tr>
<tr>
<td>#6 (Concrete)</td>
<td>630 - 5,100</td>
<td>2,647</td>
<td>1,346</td>
</tr>
<tr>
<td>#7 (Dirt-Gravel)</td>
<td>440 - 5,500</td>
<td>2,479</td>
<td>1,603</td>
</tr>
<tr>
<td>#8 (Grass)</td>
<td>550 - 3,060</td>
<td>1,946</td>
<td>839</td>
</tr>
<tr>
<td>#9 (Trees)</td>
<td>170 - 1,150</td>
<td>672</td>
<td>312</td>
</tr>
</tbody>
</table>

M60 TANK LUMINANCE
RANGE - 36 FEET

BACKGROUND LUMINANCE

Figure 10

Figure 11
M60 Study of 12 July, 1990 (Overcast 9:30-15:00)

Figure 12

Figure 13

Figure 14

Figure 15
Table 5. Summary of Contrast Calculations for 12 July, 1990 (Overcast 9:30-15:00)

<table>
<thead>
<tr>
<th>Targ./Backg.</th>
<th>#2/Sky</th>
<th>#3/Sky</th>
<th>#4/Sky</th>
<th>#5/Sky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.955</td>
<td>-0.947</td>
<td>-0.969</td>
<td>-0.983</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.845</td>
<td>-0.828</td>
<td>-0.905</td>
<td>-0.938</td>
</tr>
<tr>
<td>Average</td>
<td>-0.909</td>
<td>-0.900</td>
<td>-0.947</td>
<td>-0.967</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.040</td>
<td>0.043</td>
<td>0.019</td>
<td>0.012</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ./Backg.</th>
<th>#2/Concrete</th>
<th>#3/Concrete</th>
<th>#4/Concrete</th>
<th>#5/Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.844</td>
<td>-0.823</td>
<td>-0.881</td>
<td>-0.921</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.303</td>
<td>-0.254</td>
<td>-0.587</td>
<td>-0.802</td>
</tr>
<tr>
<td>Average</td>
<td>-0.633</td>
<td>-0.597</td>
<td>-0.784</td>
<td>-0.871</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.162</td>
<td>0.170</td>
<td>0.081</td>
<td>0.038</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ./Backg.</th>
<th>#2/Dirt</th>
<th>#3/Dirt</th>
<th>#4/Dirt</th>
<th>#5/Dirt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.856</td>
<td>-0.837</td>
<td>-0.888</td>
<td>-0.927</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.067</td>
<td>0.156</td>
<td>-0.409</td>
<td>-0.700</td>
</tr>
<tr>
<td>Average</td>
<td>-0.521</td>
<td>-0.476</td>
<td>-0.725</td>
<td>-0.838</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.292</td>
<td>0.309</td>
<td>0.145</td>
<td>0.073</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ./Backg.</th>
<th>#2/Grass</th>
<th>#3/Grass</th>
<th>#4/Grass</th>
<th>#5/Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.787</td>
<td>-0.764</td>
<td>-0.859</td>
<td>-0.902</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.127</td>
<td>-0.055</td>
<td>-0.536</td>
<td>-0.755</td>
</tr>
<tr>
<td>Average</td>
<td>-0.532</td>
<td>-0.485</td>
<td>-0.724</td>
<td>-0.834</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.182</td>
<td>0.190</td>
<td>0.081</td>
<td>0.038</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ./Backg.</th>
<th>#2/Trees</th>
<th>#3/Trees</th>
<th>#4/Trees</th>
<th>#5/Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.316</td>
<td>-0.242</td>
<td>-0.547</td>
<td>-0.747</td>
</tr>
<tr>
<td>Maximum</td>
<td>2.400</td>
<td>2.500</td>
<td>0.550</td>
<td>-0.125</td>
</tr>
<tr>
<td>Average</td>
<td>0.440</td>
<td>0.581</td>
<td>-0.159</td>
<td>-0.493</td>
</tr>
<tr>
<td>Std. Dev</td>
<td>0.711</td>
<td>0.740</td>
<td>0.312</td>
<td>0.159</td>
</tr>
</tbody>
</table>
M60 Study A on 17 July, 1990.

Table 6. Summary of Luminance Readings for Study A on 17 July, 1990
(Hazy, Cloudy, Overcast 9:00-15:15)

<table>
<thead>
<tr>
<th>Measurement Area</th>
<th>Range of Measurements (cd/m²)</th>
<th>Average Luminance (cd/m²)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 (Sky)</td>
<td>5,850 - 16,500</td>
<td>10,575</td>
<td>3,134</td>
</tr>
<tr>
<td>#2 (M60 Turret)</td>
<td>690 - 1,520</td>
<td>1,081</td>
<td>276</td>
</tr>
<tr>
<td>#3 (M60 Turret)</td>
<td>690 - 1,575</td>
<td>1,032</td>
<td>265</td>
</tr>
<tr>
<td>#4 (M60 Turret)</td>
<td>305 - 950</td>
<td>478</td>
<td>165</td>
</tr>
<tr>
<td>#5 (M60 Wheel)</td>
<td>192 - 510</td>
<td>310</td>
<td>94</td>
</tr>
<tr>
<td>#6 (Concrete)</td>
<td>2,700 - 5,100</td>
<td>3,673</td>
<td>639</td>
</tr>
<tr>
<td>#7 (Dirt-Gravel)</td>
<td>1,325 - 4,280</td>
<td>2,669</td>
<td>832</td>
</tr>
<tr>
<td>#8 (Grass)</td>
<td>2,200 - 3,700</td>
<td>2,964</td>
<td>348</td>
</tr>
<tr>
<td>#9 (Trees)</td>
<td>685 - 1,120</td>
<td>836</td>
<td>102</td>
</tr>
<tr>
<td>#10 (M60 Base)</td>
<td>101 - 321</td>
<td>180</td>
<td>50</td>
</tr>
</tbody>
</table>

M60 TANK LUMINANCE
RANGE • 36 FEET

BACKGROUND LUMINANCE

Figure 16

Figure 17
M60 Study A on 17 July, 1990 (Hazy, Cloudy, Overcast 9:00-15:15)

Figure 18

M60 TANK
SKY BACKGROUND

Figure 19

M60 TANK
CONCRETE BACKGROUND

Figure 20

M60 TANK
DIRT-GRAVEL BACKGROUND

Figure 21

M60 TANK
GRASS BACKGROUND
Table 7. Summary of Contrast Calculations for Study A on 17 July, 1990
(Hazy, Cloudy, Overcast 9:00-15:15)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.951</td>
<td>-0.948</td>
<td>-0.970</td>
<td>-0.986</td>
<td>-0.988</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.740</td>
<td>-0.756</td>
<td>-0.930</td>
<td>-0.955</td>
<td>-0.974</td>
</tr>
<tr>
<td>Average</td>
<td>-0.882</td>
<td>-0.890</td>
<td>-0.954</td>
<td>-0.970</td>
<td>-0.983</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.063</td>
<td>0.055</td>
<td>0.011</td>
<td>0.006</td>
<td>0.003</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ/Backg</th>
<th>#2/Concr.</th>
<th>#3/Concr.</th>
<th>#4/Concr.</th>
<th>#5/Concr.</th>
<th>#10/Concr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.840</td>
<td>-0.831</td>
<td>-0.917</td>
<td>-0.955</td>
<td>-0.965</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.469</td>
<td>-0.500</td>
<td>-0.733</td>
<td>-0.853</td>
<td>-0.926</td>
</tr>
<tr>
<td>Average</td>
<td>-0.695</td>
<td>-0.710</td>
<td>-0.869</td>
<td>-0.915</td>
<td>-0.951</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.099</td>
<td>0.091</td>
<td>0.043</td>
<td>0.024</td>
<td>0.010</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ/Backg</th>
<th>#2/Dirt</th>
<th>#3/Dirt</th>
<th>#4/Dirt</th>
<th>#5/Dirt</th>
<th>#10/Dirt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.794</td>
<td>-0.791</td>
<td>-0.880</td>
<td>-0.941</td>
<td>-0.947</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.147</td>
<td>0.079</td>
<td>-0.626</td>
<td>-0.794</td>
<td>-0.900</td>
</tr>
<tr>
<td>Average</td>
<td>-0.526</td>
<td>-0.555</td>
<td>-0.813</td>
<td>-0.879</td>
<td>-0.930</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.264</td>
<td>0.237</td>
<td>0.061</td>
<td>0.032</td>
<td>0.014</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ/Backg</th>
<th>#2/Grass</th>
<th>#3/Grass</th>
<th>#4/Grass</th>
<th>#5/Grass</th>
<th>#10/Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.777</td>
<td>-0.772</td>
<td>-0.894</td>
<td>-0.937</td>
<td>-0.960</td>
</tr>
<tr>
<td>Maximum</td>
<td>-0.399</td>
<td>-0.435</td>
<td>-0.730</td>
<td>-0.841</td>
<td>-0.897</td>
</tr>
<tr>
<td>Average</td>
<td>-0.630</td>
<td>-0.648</td>
<td>-0.839</td>
<td>-0.896</td>
<td>-0.940</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.108</td>
<td>0.098</td>
<td>0.047</td>
<td>0.026</td>
<td>0.013</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Targ/Backg</th>
<th>#2/Trees</th>
<th>#3/Trees</th>
<th>#4/Trees</th>
<th>#5/Trees</th>
<th>#10/Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.244</td>
<td>-0.218</td>
<td>-0.627</td>
<td>-0.771</td>
<td>-0.884</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.040</td>
<td>0.879</td>
<td>-0.052</td>
<td>-0.478</td>
<td>-0.625</td>
</tr>
<tr>
<td>Average</td>
<td>0.310</td>
<td>0.243</td>
<td>-0.433</td>
<td>-0.632</td>
<td>-0.786</td>
</tr>
<tr>
<td>Std. Dev</td>
<td>0.366</td>
<td>0.318</td>
<td>0.159</td>
<td>0.088</td>
<td>0.047</td>
</tr>
</tbody>
</table>
The circled numbers of Figure 22 show the position of the 44 luminance measurements acquired at 10:35, 11:35 and 13:05 on 17 July, 1990. The LS-100 measurement area is approximately the same as is circled on the photograph.

Figure 22
Position and Area of Luminance Readings for Study B on 17 July, 1990

M60 LUMINANCE
RANGE - 36 FEET
10:35 AM, 17 JULY 1990

Figure 23

M60 TANK
GRASS BACKGROUND
10:35, 17 JULY 1990

Figure 24

Area #1 is excluded.
See Figure 25.

Area #1 is excluded.
See Figure 27.
Table 8. M60 Luminance Study for Study B on 17 July, 1990

<table>
<thead>
<tr>
<th>Area #</th>
<th>Luminance (cd/m²)</th>
<th>Contrast Calculations (M60/Grass)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10:35 11:35 13:05</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5541 14000 5969</td>
<td>0.835  3.795  0.907</td>
</tr>
<tr>
<td>2</td>
<td>2232  3249  5551</td>
<td>-0.261 -0.113  0.773</td>
</tr>
<tr>
<td>3</td>
<td>857   587   1723</td>
<td>-0.706 -0.799 -0.450</td>
</tr>
<tr>
<td>4</td>
<td>1227  851   694</td>
<td>-0.594 -0.709 -0.778</td>
</tr>
<tr>
<td>5</td>
<td>1253  773   789</td>
<td>-0.585 -0.735 -0.748</td>
</tr>
<tr>
<td>6</td>
<td>325   365   500</td>
<td>-0.829 -0.875 -0.840</td>
</tr>
<tr>
<td>7</td>
<td>291   259   550</td>
<td>-0.904 -0.877 -0.826</td>
</tr>
<tr>
<td>8</td>
<td>2250  1699  1295</td>
<td>-0.242 -0.418 -0.586</td>
</tr>
<tr>
<td>9</td>
<td>507   441   569</td>
<td>-0.832 -0.849 -0.818</td>
</tr>
<tr>
<td>10</td>
<td>1016  845   734</td>
<td>-0.564 -0.711 -0.765</td>
</tr>
<tr>
<td>11</td>
<td>519   519   636</td>
<td>-0.828 -0.822 -0.797</td>
</tr>
<tr>
<td>12</td>
<td>293   320   484</td>
<td>-0.903 -0.890 -0.845</td>
</tr>
<tr>
<td>13</td>
<td>382   487   844</td>
<td>-0.874 -0.833 -0.730</td>
</tr>
<tr>
<td>14</td>
<td>396   506   1337</td>
<td>-0.869 -0.827 -0.573</td>
</tr>
<tr>
<td>15</td>
<td>214   561   806</td>
<td>-0.929 -0.808 -0.742</td>
</tr>
<tr>
<td>16</td>
<td>469   574   957</td>
<td>-0.845 -0.803 -0.694</td>
</tr>
<tr>
<td>17</td>
<td>328   423   361</td>
<td>-0.891 -0.855 -0.885</td>
</tr>
<tr>
<td>18</td>
<td>453   546   480</td>
<td>-0.850 -0.813 -0.847</td>
</tr>
<tr>
<td>19</td>
<td>340   334   408</td>
<td>-0.887 -0.886 -0.870</td>
</tr>
<tr>
<td>20</td>
<td>449   501   517</td>
<td>-0.851 -0.828 -0.835</td>
</tr>
<tr>
<td>21</td>
<td>278   336   237</td>
<td>-0.908 -0.885 -0.924</td>
</tr>
<tr>
<td>22</td>
<td>360   442   285</td>
<td>-0.881 -0.849 -0.909</td>
</tr>
<tr>
<td>23</td>
<td>295   322   397</td>
<td>-0.902 -0.890 -0.873</td>
</tr>
<tr>
<td>24</td>
<td>186   219   282</td>
<td>-0.938 -0.925 -0.910</td>
</tr>
<tr>
<td>25</td>
<td>283   312   395</td>
<td>-0.906 -0.893 -0.874</td>
</tr>
<tr>
<td>26</td>
<td>249   234   364</td>
<td>-0.918 -0.920 -0.884</td>
</tr>
<tr>
<td>27</td>
<td>182   221   289</td>
<td>-0.940 -0.924 -0.908</td>
</tr>
<tr>
<td>28</td>
<td>265   303   384</td>
<td>-0.912 -0.896 -0.877</td>
</tr>
<tr>
<td>29</td>
<td>191   205   290</td>
<td>-0.937 -0.930 -0.907</td>
</tr>
<tr>
<td>30</td>
<td>155   238   316</td>
<td>-0.949 -0.918 -0.899</td>
</tr>
<tr>
<td>31</td>
<td>261   297   407</td>
<td>-0.914 -0.898 -0.870</td>
</tr>
<tr>
<td>32</td>
<td>238   257   354</td>
<td>-0.921 -0.912 -0.887</td>
</tr>
<tr>
<td>33</td>
<td>218   252   315</td>
<td>-0.928 -0.914 -0.899</td>
</tr>
<tr>
<td>34</td>
<td>179   189   256</td>
<td>-0.941 -0.935 -0.918</td>
</tr>
<tr>
<td>35</td>
<td>174   151   219</td>
<td>-0.942 -0.948 -0.930</td>
</tr>
<tr>
<td>36</td>
<td>130   142   213</td>
<td>-0.957 -0.951 -0.932</td>
</tr>
<tr>
<td>37</td>
<td>127   145   223</td>
<td>-0.558 -0.950 -0.929</td>
</tr>
<tr>
<td>38</td>
<td>147   185   267</td>
<td>-0.951 -0.937 -0.915</td>
</tr>
<tr>
<td>39</td>
<td>295   307   377</td>
<td>-0.902 -0.895 -0.880</td>
</tr>
<tr>
<td>40</td>
<td>263   283   341</td>
<td>-0.913 -0.903 -0.891</td>
</tr>
<tr>
<td>41</td>
<td>248   265   342</td>
<td>-0.918 -0.909 -0.891</td>
</tr>
<tr>
<td>42</td>
<td>249   268   359</td>
<td>-0.913 -0.908 -0.885</td>
</tr>
<tr>
<td>43</td>
<td>245   261   354</td>
<td>-0.919 -0.911 -0.887</td>
</tr>
<tr>
<td>44</td>
<td>258   280   366</td>
<td>-0.915 -0.904 -0.883</td>
</tr>
</tbody>
</table>

MINIMUM 127 142 213  -0.958 -0.951 -0.932
MAXIMUM 5541 14000 5969  0.835  3.795  0.907
AVERAGE 566 774 746  -0.813 -0.735 -0.762
ST. DEV. 893 2078 1139  0.296  0.712  0.364

20
M60 Luminance for Study 8 on 17 July, 1990

M60 LUMINANCE
RANGE = 36 FEET
10:35 AM, 17 JULY 1990

M60 LUMINANCE
RANGE = 36 FEET
11:35 AM, 17 JULY 1990

Figure 25

M60 TANK
GRASS BACKGROUND
10:35, 17 JULY 1990

M60 TANK
GRASS BACKGROUND
11:35 AM, 17 JULY 1990

Figure 26

Figure 27

Figure 28
SUMMARY OF M60 STUDIES

The largest luminance measurement for the M60 was 14,000 cd/m². This reading was acquired for area #1 (Figure 22 and Figure 26; Study B on 17 July, 1990; 11:35). Since the majority of the luminance readings for the M60 were below 1,000 cd/m², readings above 1,000 cd/m² are most likely due to intense specular reflection.

Specular reflection exists when the majority of the light incident on a surface reflects sharply away from the surface. The majority of the light leaving the surface travels in the same general direction. Diffuse reflection exists when reflected light travels in many different directions.

Specular reflection by an M60 area is enhanced by the following conditions:

1. Smooth surface
2. Elevated position
3. Beveled, rounded shape
4. Light color
5. Location on east side of vehicle
6. Clearance from shadows

Area #1, area #2, ..., area #5 (Figure 22) satisfy these conditions and account for the very large luminance readings acquired from them.

As the sun, relative to the M60, rises from the east and moves toward the west, different areas on the M60 exhibit intense specular reflection at different times. For example, the luminance of area #3, located on the west side of the turret, increases from 10:35 to 13:05. Whereas, area #4, located on the east side of the turret, decreases in luminance for the same period of time.

Luminance readings for the M60 decrease, in general, for areas closer to the ground (Figure 23, Figure 25 and Figure 26; Table 8).

The alternating high and low luminance readings for area #16, area #17, ..., area #22 (Figure 22 and Figure 23; Table 8) are due to the alternating colors in the camouflage pattern.

The alternating high and low luminance readings for area #23, area #24, ..., area #44 (Figure 22 and Figure 23; Table 8) are primarily due to some areas being located in cavities. For example, area #34, area #35, ..., area #38 are located in cavities close to the bottom base of the M60. These cavity areas produced the lowest luminance readings (minimum = 127 cd/m²; maximum = 267 cd/m²).

Figure 16, which relates to the regular study on 17 July, 1990, also suggests intense specular reflection from turret areas during the morning hours (9:00 - 12:00). There is a significant diurnal change in luminance for area #2 (turret) and area #3 (turret; Figure 3). Area #4 (turret) and area #5 (wheel) do not show this kind of change. Although area #4 is also on the turret, it is located on the west side of the turret on a flatter, darker area. Area #5 is close to the ground, located to the west of the luminance meter and is not smooth. Luminance readings from area #4 and area #5 are less likely to be affected by specular reflection.
Figure 30 illustrates how specular reflection from area #2 and area #3 (Figure 3) decreased as the sun rose and passed behind the M60. The luminance ratio of area #2 (turret) or area #3 (turret) to area #5 (wheel) decreased by nearly 1.3/hr from 9:00 to 12:00 on 17 July, 1990. The sky condition for this period of time was hazy.

Figure 29 illustrates how specular reflection from area #2 and area #3 was reduced by the overcast sky condition on 12 July, 1990. The luminance ratio of area #4 (turret) to area #5 (wheel) not only remained nearly constant throughout the day on both days, but also was nearly the same value on both days. The average luminance ratio, area #4/area #5, on 12 July, 1990 was 1.64. On 17 July, 1990 the average ratio was 1.55.

Sky conditions also contribute to variance in luminance. During the study of 9 July, 1990, luminance readings were observed for 15-second intervals for each target and background measured. Even though the sky condition did not appear to change visually during this time interval, variance in luminance occurred to the extent shown in Table 10 below.

Table 10. Largest Difference in Luminance Readings for 9 July, 1990

<table>
<thead>
<tr>
<th>Area</th>
<th>#1 Sky</th>
<th>#2 Turret</th>
<th>#3 Turret</th>
<th>#4 Turret</th>
<th>#5 Wheel</th>
<th>#6 Conc.</th>
<th>#7 Dirt</th>
<th>#8 Grass</th>
<th>#9 Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. (cd/m²)</td>
<td>8300</td>
<td>830</td>
<td>980</td>
<td>540</td>
<td>280</td>
<td>2000</td>
<td>5100</td>
<td>1450</td>
<td>600</td>
</tr>
<tr>
<td>Max. (cd/m²)</td>
<td>9200</td>
<td>1150</td>
<td>1150</td>
<td>630</td>
<td>330</td>
<td>3000</td>
<td>5300</td>
<td>1650</td>
<td>1000</td>
</tr>
<tr>
<td>Avg. (cd/m²)</td>
<td>8900</td>
<td>990</td>
<td>1045</td>
<td>585</td>
<td>305</td>
<td>2500</td>
<td>5200</td>
<td>1550</td>
<td>800</td>
</tr>
<tr>
<td>Diff. (cd/m²)</td>
<td>600</td>
<td>320</td>
<td>170</td>
<td>90</td>
<td>50</td>
<td>1000</td>
<td>200</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>% Diff.</td>
<td>7</td>
<td>32</td>
<td>16</td>
<td>15</td>
<td>16</td>
<td>40</td>
<td>4</td>
<td>13</td>
<td>50</td>
</tr>
<tr>
<td>Time</td>
<td>13:00</td>
<td>10:30</td>
<td>11:00</td>
<td>11:00</td>
<td>11:30</td>
<td>11:00</td>
<td>15:00</td>
<td>11:00</td>
<td>12:00</td>
</tr>
</tbody>
</table>

The '％Diff.' row of Figure 10 was obtained using: \( \frac{\text{Max} - \text{Min}}{\text{Average}} \times 100 \)

The 'Time row' indicates the time when the largest luminance difference occurred on 9 July, 1990 during the 15-second observing interval.

An interesting phenomenon was observed when cumulus clouds approached the sun. Luminance readings were observed to increase. The clouds, behaving as mirrors, reflected more light onto a target area than would be produced by light coming directly from the sun alone.

Figure 10 also illustrates the effect of sky conditions on luminance readings. Openings in the cloud cover on 12 July, 1990 produced considerable variance in the luminance readings. As mentioned earlier, overcast sky conditions do, however, tend to make the luminance ratios more constant (Figure 29 and Figure 30).
Table 9. Summary of M60 Luminance Readings (excluding Study B of 17 July 1990)

<table>
<thead>
<tr>
<th>Measurement Area (Targets)</th>
<th>Luminance (cd/m²)</th>
<th>Measurement Area (Backgrounds)</th>
<th>Luminance (cd/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Avg</td>
</tr>
<tr>
<td>#2 (Turret)</td>
<td>440</td>
<td>1,520</td>
<td>922</td>
</tr>
<tr>
<td>#3 (Turret)</td>
<td>470</td>
<td>1,575</td>
<td>914</td>
</tr>
<tr>
<td>#4 (Turret)</td>
<td>305</td>
<td>950</td>
<td>487</td>
</tr>
<tr>
<td>#5 (Wheel)</td>
<td>125</td>
<td>730</td>
<td>314</td>
</tr>
<tr>
<td>#10 (Base)</td>
<td>101</td>
<td>321</td>
<td>180</td>
</tr>
</tbody>
</table>

M60 LUMINANCE RATIOS

OVERCAST

M60 LUMINANCE RATIOS

HAZY - CLOUDY - OVERCAST

Figure 29

Figure 30
Contrast values for the M60 varied considerably; for a given area and for the entire vehicle. From Table 8, using grass as a background, the largest variance in contrast for a single area was acquired from area #1 (Figure 22; Range of contrast: +0.835 to +3.795). The higher elevated eastern turret areas always produced the greatest variance in contrast. When considering the contrast of the M60 as whole, using a grass background, the range of contrast extends from -0.951 (area #36; Figure 22) to +3.795 (area #1; Figure 22).

The range of contrast, using trees as a background, extends from -0.242 to +2.50 for area #3 (Figure 3; Table 5). Of the five backgrounds measured, the trees produced the greatest variance in contrast. As mentioned earlier, the tree line was oriented along a north-south line and the M60 along an east-west line. This orthogonal relationship does not appear to have any relevance to the shape of the tree background contrast curves of Figure 31, Figure 32 or Figure 33. The shapes of the contrast graphs for M60 targets and grass background, Figures 9, Figure 15 and Figure 21, look similar to the corresponding tree background contrast graphs of Figures 31, Figure 32 and Figure 33. As will be seen in later studies, the range of luminance readings for the trees in the M60 studies (100 - 1000 cd/m²) are similar to those obtained in studies for the M1 and LAV25.

The least variance in contrast occurred between the M60 and the sky. This is expected, since the sky luminance is approximately 10 times greater than the M60. The range of contrast values, using a sky background on 17 July, 1990, was from -0.74 to -0.95 (Table 7; area #2/Sky).
M60 TANK
TREE BACKGROUND

Figure 31

M60 TANK
TREE BACKGROUND

Clear Skies 10:30 - 11:30
Cloudy 11:30 - 15:30

Figure 32

M60 TANK
TREE BACKGROUND

Hazy, Cloudy, Overcast

Figure 33

26
M1 STUDIES

Study 19 July, 1990  Hazy 9:00-12:00, Overcast 12:00-15:00

Two studies were conducted on 19 July, 1990. To distinguish between them, they will be referred to as Study A and Study B. Study A consisted of 11 luminance readings taken every 15 minutes from 9:00 to 15:00. Study B consisted of 45 luminance readings taken every 30 minutes from 10:05 to 15:05.

Figure 34 shows the setup used to obtain luminance readings for the two studies involving the M1 on 19 July, 1990. The LS-100 was positioned 36 feet from a stationary M1. The M1 was not moved during data collection. The M1 side was facing north and the LS-100 was pointed toward the south.

The circled numbers of Figure 35 and Figure 36 show the position and measurement areas used for the 19 July, 1990 M1 studies. The LS-100 measurement area is approximately the same as is circled on the photograph.

Area #11 of Study A (tree background) does not show in the photograph. Area #11 is located to the far right (west) of the M1. This tree line is oriented along a north-south line. The LS-100 meter pointed toward the west when area #11 was measured.

The M1 side was facing north and metering was toward the south.
Figure 34
M1 Luminance Reading Setup for Study A and Study B on 19 July, 1990
Figure 35
Position and Area of M1 Luminance Readings for Study A on 19 July, 1990

Figure 36
Position and Area of M1 Luminance Readings for Study B on 19 July, 1990
M1 Study A on 19 July, 1990.

Table 11. Summary of Luminance Readings for Study A on 19 July, 1990 (Hazy 9:00-12:00, Overcast 12:00-15:00)

<table>
<thead>
<tr>
<th>Measurement Area</th>
<th>Range of Measurements (cd/m²)</th>
<th>Average Luminance (cd/m²)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 (Sky)</td>
<td>5,523 - 14,270</td>
<td>9,9005</td>
<td>2,659</td>
</tr>
<tr>
<td>#2 (M1 Turret)</td>
<td>639 - 1,783</td>
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<td>#3 (M1 Turret)</td>
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<td>#4 (M60 Turret)</td>
<td>690 - 1,950</td>
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<td>#5 (M1 Turret)</td>
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<td>#6 (M1 Skirt)</td>
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<td>#7 (M1 Wheel)</td>
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<td>#9 (Dirt-Gravel)</td>
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<td>#10 (Grass)</td>
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M1 Luminance
Range - 36 Feet

Background Luminance

Figure 37

Figure 38
M1 Study A on 19 July, 90 (Hazy 9:00-12:00, Overcast 12:00-15:00)

M1 CONTRAST
SKY BACKGROUND

M1 CONTRAST
CONCRETE BACKGROUND

M1 CONTRAST
DIRT-GRAVEL BACKGROUND

M1 CONTRAST
GRASS BACKGROUND

Figure 39

Figure 40

Figure 41

Figure 42
Table 12. Summary of Contrast Calculations for Study A on 19 July, 1990  
(Hazy 9:00-12:00, Overcast 12:00-15:00)

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<td>Maximum</td>
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<td>Average</td>
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<td>-0.852</td>
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<td>0.034</td>
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<td>0.007</td>
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<td>-0.658</td>
<td>-0.599</td>
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<td>Maximum</td>
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<tr>
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<td>0.072</td>
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<td>Maximum</td>
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<td>Average</td>
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<td>Std. Dev</td>
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<td>Maximum</td>
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M1 Study B on 19 July, 1990 (Hazy 9:00-12:00, Overcast 12:00-15:00)

M1 LUMINANCE AT 10:05
RANGE = 36 FEET
19 JULY 1990

M1 LUMINANCE AT 10:35
RANGE = 36 FEET
19 JULY 1990

M1 LUMINANCE AT 11:05
RANGE = 36 FEET
19 JULY 1990

M1 LUMINANCE AT 11:35
RANGE = 36 FEET
19 JULY 1990

Figure 43
Figure 44
Figure 45
Figure 46
M1 Study B on 19 July, 1990 (Hazy 9:00-12:00, Overcast 12:00-15:00)

M1 LUMINANCE AT 12:05
RANGE = 36 FEET
19 JULY 1990

M1 LUMINANCE AT 12:35
RANGE = 36 FEET
19 JULY 1990

M1 LUMINANCE AT 13:05
RANGE = 36 FEET
19 JULY 1990

M1 LUMINANCE AT 13:35
RANGE = 36 FEET
19 JULY 1990

Figure 47

Figure 48

Figure 49

Figure 50
M1 Study B on 19 July, 1990 (Hazy 9:00-12:00, Overcast 12:00-15:00)

**M1 Luminance at 14:05**

**M1 Luminance at 14:35**

**M1 Luminance at 15:05**

**Average M1 Luminance**

---

**Figure 51**

**Figure 52**

**Figure 53**

**Figure 54**

---

35
M1 Study on 19 July, 90 (Hazy 9:00-12:00, Overcast 12:00-15:00)

M1 CONTRAST
TREE BACKGROUND
STUDY A

AVERAGE CONTRAST OF M1
RANGE = 36 FEET
STUDY B

M1 LUMINANCE
RANGE = 36 FEET
STUDY B

Figure 55

Figure 56

Figure 57

36
Study 1 August, 1990  Clear skies 10:00 - 15:30

Figure 58 shows the position and surroundings of the M1 used for studies 1 August, 1990 and 6 August, 1990. The M1 and tree line were facing east. The LS-100 meter was pointed west while luminance data was collected.

Luminance readings were acquired for the M1 and tree line using four different ranges from the M1: 36 feet, 100 feet, 200 feet and 330 feet. Figure 59, Figure 60,...Figure 62 show the approximate M1 measurement area for these four ranges.

Fifty different luminance readings were selected from the tree line between the poles in Figure 58. Readings were acquired from left to right using an up-down scanning pattern.

Figure 58

Position and surroundings of the M1 used for studies 1 August, 1990 and 6 August, 1990. The M1 and tree line were facing east. The LS-100 meter was pointed west while luminance data was collected.
Figure 59

Approximate M1 Measurement Area for 5 August and 6 August, 1990.
Range = 86 feet

Figure 60

Approximate M1 Measurement Area for 7 August and 6 August, 1990.
Range = 100 feet

As the LS-100 Luminance Meter was moved farther from the M1, the Luminance area measured on the M1 increased. The Luminance area increases as the square of the range. If the range is doubled, the measurement area increases by a factor of four.
When the word "average" occurs in the title for the graphs that follow, it will indicate that the average luminance was used for constructing the graph.

All graphs involving the tree line were constructed using the average luminance of fifty random tree line luminance readings.
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)

M1 LUMINANCE AT 14:00
RANGE = 36 FEET
1 AUGUST, 1990

M1 LUMINANCE AT 15:00
RANGE = 36 FEET
1 AUGUST, 1990

AVERAGE M1 LUMINANCE
RANGE = 36 FEET
1 AUGUST, 1990; 10:00 - 15:00

Figure 67

Figure 68

Figure 69
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)

**M1 LUMINANCE AT 10:10**
RANGE = 100 FEET
1 AUGUST, 1990

![Graph](image1)

**Figure 70**

**M1 LUMINANCE AT 11:10**
RANGE = 100 FEET
1 AUGUST, 1990

![Graph](image2)

**Figure 71**

**M1 LUMINANCE AT 12:10**
RANGE = 100 FEET
1 AUGUST, 1990

![Graph](image3)

**Figure 72**

**M1 LUMINANCE AT 13:10**
RANGE = 100 FEET
1 AUGUST, 1990

![Graph](image4)

**Figure 73**
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)

**M1 LUMINANCE AT 14:10**
RANGE = 100 FEET
1 AUGUST, 1990

**M1 LUMINANCE AT 15:10**
RANGE = 100 FEET
1 AUGUST, 1990

---

**AVERAGE M1 LUMINANCE**
RANGE = 100 FEET
1 AUGUST, 1990: 10:10 - 15:10

---

Figure 74

Figure 75

Figure 76
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)

AVERAGE LUMINANCE OF M1
DIFFERENT RANGES

![Graph showing average luminance of M1 for different ranges over time.](image)

AVERAGE LUMINANCE OF TREES
DIFFERENT RANGES

![Graph showing average luminance of trees for different ranges over time.](image)

LUMINANCE OF GRASS
DIFFERENT RANGES

![Graph showing luminance of grass for different ranges over time.](image)

LUMINANCE OF SKY
DIFFERENT RANGES

![Graph showing luminance of sky for different ranges over time.](image)

Figure 77

Figure 78

Figure 79

Figure 30
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)

AVERAGE CONTRAST OF M1
AVERAGE TREE BACKGROUND
DIFFERENT RANGES

AVERAGE CONTRAST OF M1
GRASS BACKGROUND
DIFFERENT RANGES

Figure 81

Figure 82

AVERAGE CONTRAST OF M1
SKY BACKGROUND
DIFFERENT RANGES

Figure 83
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)

AVERAGE CONTRAST OF M1
RANGE = 36 FEET

AVERAGE CONTRAST OF M1
RANGE = 100 FEET

Figure 84

Figure 85

AVERAGE CONTRAST OF M1
RANGE = 100 FEET

AVERAGE CONTRAST OF M1
RANGE = 330 FEET

Figure 86

Figure 87
M1 Study on 1 August, 1990 (Clear Skies 10:00-15:30)

Figure 88
10:00 1 August, 1990

Figure 89
11:00 1 August, 1990

Figure 90
12:00 1 August, 1990

Figure 91
13:00 1 August, 1990

Figure 92
14:00 1 August, 1990

Figure 93
15:00 1 August, 1990

47
Table 13. M1 Area Luminance Analysis For Times 10:00 - 15:00 on 1 August, 1990

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Avg. 1692  932
St. Dev. 616  301

| Avg.   | 1952   | 1060 |
| St. Dev. | 325    | 311  |
Table 14. M1 Area Luminance Analysis For Times 10:00 - 15:00 on 1 August, 1990
Clear Skies All Day.

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<td>Avg.</td>
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The column heading 'Avg.' in Table 13 and Table 14 refers to the averages of six luminance readings acquired between the times 10:00 and 15:00 for each measurement area.

The column heading 'St. Dev.' refers to the standard deviation.

Table 13 relates to Figure 59 and Figure 60. Table 14 relates to Figure 61 and Figure 62.

Table 15. Average Tree Line Luminance (cd/m²) on 1 August, 1990

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<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
<th>Avg.</th>
</tr>
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<tbody>
<tr>
<td>36'</td>
<td>1113</td>
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<td>888</td>
<td>901</td>
<td>849</td>
<td>363</td>
<td>956</td>
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<tr>
<td>100'</td>
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<td>1226</td>
<td>979</td>
<td>991</td>
<td>899</td>
<td>786</td>
<td>1016</td>
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<tr>
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<td>1291</td>
<td>1150</td>
<td>995</td>
<td>928</td>
<td>906</td>
<td>837</td>
<td>1018</td>
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<tr>
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<td>961</td>
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<td>907</td>
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Table 16. Summary of Diurnal Luminance Averages (cd/m²) for 1 August, 1990
Clear Skies All Day.

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<th>Grass</th>
<th>Sky</th>
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<td>901</td>
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<td>777</td>
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<td>956</td>
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<tr>
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<td>3327</td>
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<tr>
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<tr>
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<td>745</td>
<td>899</td>
<td>2703</td>
<td>5576</td>
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<tr>
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<td>780</td>
<td>2307</td>
<td>7072</td>
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<tr>
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<td>1016</td>
<td>2986</td>
<td>5241</td>
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<tr>
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<tr>
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<td>1150</td>
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<td>5242</td>
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<tr>
<td>200 feet</td>
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<td>995</td>
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<td>4922</td>
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<tr>
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<td>4864</td>
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<tr>
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<td>653</td>
<td>906</td>
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<tr>
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<tr>
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<tr>
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<tr>
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<td>1206</td>
<td>1024</td>
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<td>2805</td>
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<td>828</td>
<td>130</td>
<td>414</td>
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Table 17. Analysis of M1 Turret Luminance Readings (cd/m²) on 1 August, 1990
Range = 36 feet. Clear Skies All Day.

<table>
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<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
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</table>

| Avg    | 3768  | 3682  | 3221  | 2653  | 1960  | 1266  | 2758 | 947    |
| St. Dev| 744   | 723   | 848   | 1154  | 1013  | 625   | 789  | 255    |

Table 18. Analysis of M1 Turret Luminance Readings (cd/m²) on 1 August, 1990
Range = 100 feet. Clear Skies All Day.

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</table>

| Avg    | 3470  | 3269  | 2696  | 2159  | 1713  | 1126  | 2406 | 842      |
| St. Dev.| 325   | 358   | 463   | 662   | 573   | 376   | 426  | 156      |

51
Table 19. Analysis of M1 Skirt Luminance Readings (cd/m²) on 1 August, 1990
Range = 36 feet. Clear Skies All Day.

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<td>1933 1273</td>
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<td>2584</td>
<td>1690</td>
<td>528</td>
<td>489</td>
<td>2165 1393</td>
</tr>
</tbody>
</table>

| Avg.  | 3791  | 3439  | 2403  | 1527  | 488   | 448   | 2016 1314     |
| St. Dev. | 172  | 174   | 111   | 83    | 19    | 13    | 90    65       |

Table 20. Analysis of M1 Skirt Luminance Readings (cd/m²) on 1 August, 1990
Range = 100 feet. Clear Skies All Day.

<table>
<thead>
<tr>
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<td>456</td>
<td>1851 1229</td>
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<td>2088</td>
<td>1197</td>
<td>498</td>
<td>438</td>
<td>1800 1190</td>
</tr>
</tbody>
</table>

| Avg.  | 3595  | 3206  | 2130  | 1309  | 488   | 460   | 1865 1228     |
| St. Dev. | 109  | 82    | 49    | 55    | 7     | 23    | 45    39       |
Study 6 August, 1990  Overcast skies 10:00 - 15:30.

The only difference between this study and Study 1 conducted on August, 1990 is sky condition. The overcast sky condition during this study produced no sharp shadows.

Figure 58 shows the M1 position and its background. The M1's position and orientation was not altered during the time interval between the Study 1 on August, 1990 and the Study 6 on August, 1990.

Figure 59, Figure 60,...Figure 62 show the approximate M1 measurement areas used for this study.
M1 Study on 6 August, 1990 (Overcast 10:00-15:30)

M1 Luminance at 10:00
Range: 36 Feet
6 August, 1990

M1 Luminance at 11:00
Range: 36 Feet
6 August, 1990

M1 Luminance at 12:00
Range: 36 Feet
6 August, 1990

M1 Luminance at 13:00
Range: 36 Feet
6 August, 1990

Figure 94
Figure 95
Figure 96
Figure 97
M1 Study on 6 August, 1990 (Overcast 10:00-15:30)

M1 LUMINANCE AT 14:00
RANGE = 36 FEET
6 AUGUST, 1990

![Graph of M1 Luminance at 14:00](image)

Figure 98

M1 LUMINANCE AT 15:00
RANGE = 36 FEET
6 AUGUST, 1990

![Graph of M1 Luminance at 15:00](image)

Figure 99

AVERAGE M1 LUMINANCE
RANGE = 36 FEET
6 AUGUST, 1990; 10:00 - 15:00

![Graph of Average M1 Luminance](image)

Figure 100

55
M1 Study on 6 August, 1990 (Overcast 10:00-15:30)

**M1 LUMINANCE AT 10:10**
RANGE • 100 FEET
6 AUGUST, 1990

![Figure 101](image1)

**M1 LUMINANCE AT 11:10**
RANGE • 100 FEET
6 AUGUST, 1990

![Figure 102](image2)

**M1 LUMINANCE AT 12:10**
RANGE • 100 FEET
6 AUGUST, 1990

![Figure 103](image3)

**M1 LUMINANCE AT 13:10**
RANGE • 100 FEET
6 AUGUST, 1990

![Figure 104](image4)
M1 Study on 6 August, 1990 (Overcast 10:00-15:30)

M1 LUMINANCE AT 14:10
RANGE = 100 FEET
6 AUGUST, 1990

Figure 105

M1 LUMINANCE AT 15:10
RANGE = 100 FEET
6 AUGUST, 1990

Figure 106

AVERAGE M1 LUMINANCE
RANGE = 100 FEET
6 AUGUST, 1990

Figure 107
M1 Study on 6 August, 1990 (Overcast 10:00-15.30)

**Figure 108**

**Figure 109**

**Figure 110**

**Figure 111**
M1 Study on 6 August, 1990 (Overcast 10:00-15:30)

AVERAGE CONTRAST OF M1
AVERAGE TREE BACKGROUND
DIFFERENT RANGES

Figure 112

AVERAGE CONTRAST OF M1
SKY BACKGROUND
DIFFERENT RANGES

Figure 114

AVERAGE CONTRAST OF M1
GRASS BACKGROUND
DIFFERENT RANGES

Figure 113
M1 Study on 6 August, 1990 (Overcast 10:00-15:30)

AVERAGE CONTRAST OF M1
RANGE = 36 FEET

AVERAGE CONTRAST OF M1
RANGE = 100 FEET

Figure 115

Figure 116

AVERAGE CONTRAST OF M1
RANGE = 200 FEET

AVERAGE CONTRAST OF M1
RANGE = 330 FEET

Figure 117

Figure 118

60
Table 21. M1 Area Luminance Analysis For Times 10:00 - 15:30 on 6 August, 1990

<table>
<thead>
<tr>
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<td>273</td>
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</table>

Avg.  506  264
St. Dev. 210  116

Avg.  487  257
St. Dev. 154  83
Table 22. MI Area Luminance Analysis For Times 10:00 - 15:30 on 6 August, 1990
Overcast 10:00 - 15:30.

<table>
<thead>
<tr>
<th>Range - 200 feet</th>
<th>Range - 330 feet</th>
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<tbody>
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<td>2</td>
<td>628</td>
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<tr>
<td>3</td>
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<td>8</td>
<td>567</td>
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<tr>
<td>9</td>
<td>583</td>
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<tr>
<td>Avg.</td>
<td>577</td>
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<tr>
<td>St. Dev.</td>
<td>86</td>
</tr>
</tbody>
</table>

The column heading 'Avg.' in Table 21 and Table 22 refers to the averages of six luminance readings acquired between the times 10:00 and 15:00 for each measurement area.

The column heading 'St. Dev.' refers to the standard deviation.

Table 21 relates to Figure 59 and Figure 60. Table 22 relates to Figure 61 and Figure 62.

Table 23. Average Tree Line Luminance (cd/m²) on 6 August, 1990

<table>
<thead>
<tr>
<th>Range</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
<th>Avg.</th>
<th>S. D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>36'</td>
<td>162</td>
<td>446</td>
<td>129</td>
<td>399</td>
<td>510</td>
<td>177</td>
<td>304</td>
<td>170</td>
</tr>
<tr>
<td>100'</td>
<td>236</td>
<td>546</td>
<td>131</td>
<td>332</td>
<td>647</td>
<td>220</td>
<td>352</td>
<td>170</td>
</tr>
<tr>
<td>200'</td>
<td>461</td>
<td>778</td>
<td>150</td>
<td>259</td>
<td>332</td>
<td>638</td>
<td>438</td>
<td>170</td>
</tr>
<tr>
<td>330'</td>
<td>585</td>
<td>722</td>
<td>188</td>
<td>255</td>
<td>428</td>
<td>436</td>
<td>436</td>
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<td>623</td>
<td>150</td>
<td>314</td>
<td>479</td>
<td>368</td>
<td>382</td>
<td>170</td>
</tr>
<tr>
<td>S. D.</td>
<td>170</td>
<td>133</td>
<td>24</td>
<td>57</td>
<td>116</td>
<td>184</td>
<td>66</td>
<td>170</td>
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</table>
Table 24. Summary of Diurnal Luminance Averages (cd/m²) for 6 August, 1990
Overcast 10:00 - 15:30.

<table>
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<tr>
<th>Range</th>
<th>Time</th>
<th>Avg. M1</th>
<th>Avg. Ms</th>
<th>Gross</th>
<th>Sky</th>
</tr>
</thead>
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<tr>
<td>36 feet</td>
<td>10:00</td>
<td>299</td>
<td>162</td>
<td>679</td>
<td>7824</td>
</tr>
<tr>
<td>36 feet</td>
<td>11:00</td>
<td>598</td>
<td>446</td>
<td>1214</td>
<td>5463</td>
</tr>
<tr>
<td>36 feet</td>
<td>12:00</td>
<td>715</td>
<td>129</td>
<td>294</td>
<td>2238</td>
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<tr>
<td>36 feet</td>
<td>13:00</td>
<td>924</td>
<td>399</td>
<td>946</td>
<td>4446</td>
</tr>
<tr>
<td>36 feet</td>
<td>14:00</td>
<td>930</td>
<td>510</td>
<td>382</td>
<td>5046</td>
</tr>
<tr>
<td>36 feet</td>
<td>15:00</td>
<td>291</td>
<td>177</td>
<td>1237</td>
<td>14190</td>
</tr>
<tr>
<td>36 feet</td>
<td>Average</td>
<td>506</td>
<td>304</td>
<td>796</td>
<td>5335</td>
</tr>
<tr>
<td>36 feet</td>
<td>Std. Dev.</td>
<td>255</td>
<td>152</td>
<td>373</td>
<td>3796</td>
</tr>
</tbody>
</table>

| 100 feet | 10:00 | 284     | 226     | 985   | 7526|
| 100 feet | 11:00 | 852     | 546     | 1717  | 10410|
| 100 feet | 12:00 | 196     | 131     | 376   | 2070|
| 100 feet | 13:00 | 335     | 332     | 907   | 3123|
| 100 feet | 14:00 | 786     | 447     | 688   | 5384|
| 100 feet | 15:00 | 271     | 220     | 2139  | 9160|
| 100 feet | Average | 467     | 352     | 1135  | 6279|
| 100 feet | Std. Dev. | 257     | 185     | 605   | 3039|

| 200 feet | 10:00 | 515     | 461     | 1176  | 7285|
| 200 feet | 11:00 | 1118    | 778     | 2136  | 4435|
| 200 feet | 12:00 | 207     | 150     | 482   | 2032|
| 200 feet | 13:00 | 409     | 269     | 773   | 2282|
| 200 feet | 14:00 | 346     | 332     | 1046  | 5193|
| 200 feet | 15:00 | 845     | 638     | 2014  | 5731|
| 200 feet | Average | 577     | 438     | 1271  | 4826|
| 200 feet | Std. Dev. | 210     | 216     | 610   | 1994|

| 330 feet | 10:00 | 645     | 585     | 1195  | 7301|
| 330 feet | 11:00 | 1045    | 722     | 1873  | 6453|
| 330 feet | 12:00 | 239     | 188     | 517   | 2057|
| 330 feet | 13:00 | 385     | 255     | 725   | 2481|
| 330 feet | 14:00 | 481     | 428     | 1378  | 5353|
| 330 feet | 15:00 | 627     | 434     | 1759  | 5547|
| 330 feet | Average | 612     | 426     | 1249  | 4865|
| 330 feet | Std. Dev. | 283     | 182     | 601   | 1946|

63
Table 25. Analysis of M1 Turret Luminance Readings (cd/\text{m}^2) on 6 August, 1990
Range = 36 feet. Overcast 10:00 - 15:30.

<table>
<thead>
<tr>
<th>Area #</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
<th>Avg.</th>
<th>St. Dev.</th>
</tr>
</thead>
<tbody>
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<td>845</td>
<td>295</td>
<td>1477</td>
<td>1101</td>
<td>455</td>
<td>767</td>
<td>420</td>
</tr>
<tr>
<td>2</td>
<td>518</td>
<td>982</td>
<td>338</td>
<td>1735</td>
<td>1310</td>
<td>547</td>
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<td>958</td>
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<td>1573</td>
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<td>464</td>
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<td>842</td>
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<td>1522</td>
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<td>442</td>
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<td>435</td>
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<td>10</td>
<td>261</td>
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<td>537</td>
<td>1011</td>
<td>340</td>
<td>1756</td>
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<td>526</td>
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<td>1000</td>
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<td>1290</td>
<td>516</td>
<td>906</td>
<td>497</td>
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<td>13</td>
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<td>383</td>
<td>1712</td>
<td>1374</td>
<td>561</td>
<td>948</td>
<td>476</td>
</tr>
</tbody>
</table>

| Avg.   | 440   | 817   | 285   | 1426  | 1075  | 444   | 748  | 404      |
| St. Dev.| 105   | 192   | 62    | 337   | 252   | 95    | 172  | 96       |

Table 26. Analysis of M1 Turret Luminance Readings (cd/\text{m}^2) on 6 August, 1990
Range = 100 feet. Overcast 10:00 - 15:30.

<table>
<thead>
<tr>
<th></th>
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<td>320</td>
<td>594</td>
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<td>864</td>
<td>202</td>
<td>560</td>
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<td>1059</td>
<td>1502</td>
<td>503</td>
<td>896</td>
<td>478</td>
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</tbody>
</table>

| Avg.   | 371   | 1128  | 260   | 794   | 1072  | 360   | 664  | 352      |
| St. Dev.| 75    | 228   | 50    | 163   | 252   | 80    | 140  | 78       |

64
Table 27. Analysis of M1 Skirt Luminance Readings (cd/m²) on 6 August, 1990
Range = 36 feet. Clear Skies All Day.

<table>
<thead>
<tr>
<th>Area #</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
<th>Avg.</th>
<th>St. Dev.</th>
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<td>294</td>
<td>551</td>
<td>181</td>
<td>846</td>
<td>692</td>
<td>277</td>
<td>474</td>
<td>241</td>
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<tr>
<td>19</td>
<td>313</td>
<td>608</td>
<td>196</td>
<td>935</td>
<td>760</td>
<td>300</td>
<td>519</td>
<td>269</td>
</tr>
<tr>
<td>20</td>
<td>322</td>
<td>632</td>
<td>209</td>
<td>995</td>
<td>802</td>
<td>317</td>
<td>546</td>
<td>286</td>
</tr>
<tr>
<td>21</td>
<td>325</td>
<td>644</td>
<td>207</td>
<td>996</td>
<td>804</td>
<td>316</td>
<td>549</td>
<td>287</td>
</tr>
<tr>
<td>22</td>
<td>317</td>
<td>628</td>
<td>201</td>
<td>983</td>
<td>791</td>
<td>311</td>
<td>539</td>
<td>284</td>
</tr>
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<td>23</td>
<td>318</td>
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<td>534</td>
<td>278</td>
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<td>301</td>
<td>611</td>
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<td>663</td>
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<tr>
<td>29</td>
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<td>533</td>
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<tr>
<td>30</td>
<td>315</td>
<td>659</td>
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<td>973</td>
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<td>297</td>
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<td>281</td>
</tr>
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<td>224</td>
<td>900</td>
<td>789</td>
<td>297</td>
<td>543</td>
<td>273</td>
</tr>
</tbody>
</table>

| Avg.  | 316   | 648   | 207   | 968   | 775   | 302   | 536  | 280      |
| St. Dev. | 10   | 39    | 10    | 48    | 30    | 11    | 21   | 13       |

Table 28. Analysis of M1 Skirt Luminance Readings (cd/m²) on 6 August, 1990
Range = 100 feet. Clear Skies All Day.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<td>880</td>
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<td>534</td>
<td>285</td>
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<td>529</td>
<td>283</td>
</tr>
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<td>949</td>
<td>216</td>
<td>558</td>
<td>869</td>
<td>295</td>
<td>534</td>
<td>286</td>
</tr>
<tr>
<td>21</td>
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<td>212</td>
<td>540</td>
<td>863</td>
<td>292</td>
<td>524</td>
<td>232</td>
</tr>
<tr>
<td>22</td>
<td>304</td>
<td>955</td>
<td>206</td>
<td>536</td>
<td>830</td>
<td>282</td>
<td>509</td>
<td>270</td>
</tr>
<tr>
<td>23</td>
<td>314</td>
<td>907</td>
<td>212</td>
<td>547</td>
<td>843</td>
<td>289</td>
<td>519</td>
<td>272</td>
</tr>
<tr>
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<td>307</td>
<td>899</td>
<td>206</td>
<td>543</td>
<td>927</td>
<td>287</td>
<td>512</td>
<td>270</td>
</tr>
</tbody>
</table>

| Avg.  | 307   | 920   | 209   | 548   | 842   | 290   | 519  | 277      |
| St. Dev. | 7    | 24    | 4     | 21    | 23    | 6     | 13   | 8        |

65
SUMMARY OF M1 STUDIES

One of the more important results of the M1 studies is that the M1 has three distinguishing luminance areas: the turret, the skirt and the track and suspension areas. The graphs of Figure 119, Figure 120 and Figure 121 support this idea.

Figure 119 relates to the M1 side facing north and metering toward the south on a hazy, overcast day. Figure 120 and Figure 121 relate to the M1 side facing east and metering toward the west. Figure 120 relates to a clear day. Figure 121 relates to an overcast day. Note: Figure 59 relates the measurement area code to the position on the M1.

The turret, skirt and track and suspension areas remain distinguishing features regardless of M1 orientation, time of daylight or sky condition.

Table 29. M1 Luminance Averages for Turret, Skirt and Tractor Areas (cd/m²).

<table>
<thead>
<tr>
<th>M1 Area</th>
<th>Hazy-Overcast 19 July, 1990</th>
<th>Clear Skies 1 August, 1990</th>
<th>Overcast 6 August, 1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turret</td>
<td>1104</td>
<td>2758</td>
<td>748</td>
</tr>
<tr>
<td>Skirt</td>
<td>719</td>
<td>2016</td>
<td>536</td>
</tr>
<tr>
<td>Wheels</td>
<td>340</td>
<td>804</td>
<td>260</td>
</tr>
</tbody>
</table>

THE TURRET

The turret, which is the most elevated M1 region, produces the largest luminance readings. It consists of beveled, flat areas and obtuse corners which join together to form a three-dimensional figure. Also, there are areas (area #4 and area #9 of Figure 59) which extend out from other areas. These extensions produce shadows and undergo strong specular reflection at different times than other turret areas. The photographs of Figure 88, Figure 89... Figure 93 illustrate the diurnal changes in luminance which result from the turret geometry.

Table 30 also illustrates that luminance readings from the turret areas show large variances in luminance compared to other areas of the M1. The standard deviation for luminance of turret areas between 10:00 and 15:00 on 19 July, 1990 varied from 21 percent to 34 percent of the average luminance. On 1 August, 1990 it varied from 20 percent to 52 percent of the average luminance. On 6 August, 1990 the standard deviation varied from 21 percent to 24 percent of the average luminance. Even on an overcast day, turret areas show large variances in luminance compared to other areas of the M1.
AVERAGE M1 LUMINANCE
RANGE = 36 FEET
19 JULY 1990; 10:05 - 15:05
METERING SOUTH HAZY-OVERCAST

Figure 119

AVERAGE M1 LUMINANCE
RANGE = 36 FEET
1 AUGUST, 1990; 10:00 - 15:00
METERING WEST CLEAR SKIES

Figure 120

AVERAGE M1 LUMINANCE
RANGE = 36 FEET
6 AUGUST, 1990; 10:00 - 15:00
METERING WEST OVERCAST

Figure 121
The greatest variance in luminance occurred for turret area #13 (Figure 59) during Study B on 19 July, 1990. Figure 49 and Figure 50 illustrate the dramatic diurnal changes in luminance for area #13.

The lowest luminance reading from the M1 turret was 192 cd/m². This was acquired from area #10 (Figure 59) during overcast skies, range 36 feet, at 12:00 on 6 August, 1990.

The largest luminance reading from the M1 turret was 4,618 cd/m². This was acquired from area #11 (Figure 59) during clear skies, range 36 feet, at 10:00 on 1 August, 1990.

Table 30. Summary Analysis of M1 Turret Luminance Readings (cd/m²).

Note:
\[
\% \text{ of Average} = \frac{\text{Standard Deviation}}{\text{Average}} \times 100
\]

<table>
<thead>
<tr>
<th>19 July, 1990. Hazy - Overcast. Range = 36 feet</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
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<td>1084</td>
<td>1173</td>
<td>859</td>
<td>941</td>
<td>441</td>
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<td>Standard Dev.</td>
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<td>358</td>
<td>343</td>
<td>262</td>
<td>252</td>
<td>91</td>
</tr>
<tr>
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<td>33</td>
<td>29</td>
<td>31</td>
<td>27</td>
<td>21</td>
</tr>
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</table>

<table>
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<th>1 August, 1990. Clear Skies All Day. Range = 36 feet</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
</tr>
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<tr>
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<td>3682</td>
<td>3221</td>
<td>2653</td>
<td>1960</td>
<td>1266</td>
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<td>Standard Dev.</td>
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<td>1154</td>
<td>1013</td>
<td>625</td>
</tr>
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<td>20</td>
<td>26</td>
<td>44</td>
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<thead>
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<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>440</td>
<td>817</td>
<td>285</td>
<td>1426</td>
<td>1075</td>
<td>444</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td>105</td>
<td>192</td>
<td>62</td>
<td>337</td>
<td>252</td>
<td>95</td>
</tr>
<tr>
<td>% of Average</td>
<td>24</td>
<td>24</td>
<td>22</td>
<td>24</td>
<td>23</td>
<td>21</td>
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</tbody>
</table>
THE SKIRT

The skirt areas produce luminance readings between the turret and track and suspension areas.

The skirt of the M1 is essentially a vertical plane. Two areas of measurement on the skirt (area #25 and area #26) differed from all other skirt areas. Area #25 is partly on the skirt and partly on the idler wheel. Area #26 is a square opening in the skirt which exposes a part of the track and suspension area. The luminance from these two areas was significantly lower than other skirt areas.

The luminance readings from the skirt areas show small variances in luminance compared to the M1 turret. Points on the diurnal luminance graphs (Figure 119, Figure 120 and Figure 121), which correspond to the skirt areas, form nearly horizontal segments on the graphs.

Table 31 also illustrates that luminance readings from the skirt areas show small variances in luminance compared to the turret areas of the M1. The standard deviation for luminance of skirt areas between 10:00 and 15:00 on 19 July, 1990 varied from 4 percent to 18 percent of the average luminance. On 1 August, 1990 it varied from 3 percent to 5 percent of the average luminance. On 6 August, 1990 the standard deviation varied from 3 percent to 6 percent of the average luminance.

Table 31. Summary Analysis of M1 Skirt Luminance Readings (cd/m²).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
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<td>11:00</td>
<td>12:00</td>
<td>13:00</td>
<td>14:00</td>
<td>15:00</td>
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<td>Average</td>
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<td>32</td>
<td>26</td>
<td>28</td>
<td>144</td>
<td>40</td>
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<tr>
<td>% of Average</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>18</td>
<td>6</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>1 August, 1990. Clear Skies All Day. Range = 36 feet</th>
<th></th>
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<tr>
<td>10:00</td>
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<td>12:00</td>
<td>13:00</td>
<td>14:00</td>
<td>15:00</td>
</tr>
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<td>Average</td>
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<td>174</td>
<td>111</td>
<td>83</td>
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<td>% of Average</td>
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<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
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</tbody>
</table>

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<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>10:00</td>
<td>11:00</td>
<td>12:00</td>
<td>13:00</td>
<td>14:00</td>
<td>15:00</td>
</tr>
<tr>
<td>Average</td>
<td>316</td>
<td>648</td>
<td>207</td>
<td>968</td>
<td>755</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td>10</td>
<td>39</td>
<td>10</td>
<td>48</td>
<td>30</td>
</tr>
<tr>
<td>% of Average</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>
TRACK AND SUSPENSION

The only track and suspension areas studied were the road wheels. These areas are the lowest areas on the M1 and produced the lowest luminance readings. As Figure 88, Figure 89,... Figure 93 illustrate, they are very susceptible to shading from areas above them.

The luminance readings from the road wheel areas show small variances in luminance compared to the M1 turret. Points on the diurnal luminance graphs which correspond to the wheel areas form nearly horizontal segments on the graphs.

Table 32 also illustrates that luminance readings from the wheel areas show small variances in luminance compared to the turret areas of the M1. The standard deviation for luminance of wheel areas between 10:00 and 15:00 on 19 July, 1990 varied from 4 percent to 5 percent of the average luminance. On 1 August, 1990 it varied from 3 percent to 16 percent of the average luminance. On 6 August, 1990 the standard deviation varied from 3 percent to 5 percent of the average luminance.

Table 32. Summary Analysis of M1 Road Wheel Luminance Readings (cd/m²).

<table>
<thead>
<tr>
<th>Date</th>
<th>Hazy - Overcast</th>
<th>Range - 36 feet</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
<th>15:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 July, 1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>351</td>
<td>330</td>
<td>370</td>
<td>438</td>
<td>343</td>
<td>107</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td></td>
<td></td>
<td>18</td>
<td>14</td>
<td>15</td>
<td>19</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>% of Average</td>
<td></td>
<td></td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1 August, 1990</td>
<td>Clear Skies All Day</td>
<td>Range - 36 feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>2425</td>
<td>1185</td>
<td>258</td>
<td>325</td>
<td>286</td>
<td>244</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td></td>
<td></td>
<td>107</td>
<td>186</td>
<td>14</td>
<td>13</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>% of Average</td>
<td></td>
<td></td>
<td>4</td>
<td>16</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6 August, 1990</td>
<td>Overcast</td>
<td>Range - 36 feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>149</td>
<td>347</td>
<td>102</td>
<td>422</td>
<td>389</td>
<td>149</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td></td>
<td></td>
<td>6</td>
<td>16</td>
<td>4</td>
<td>14</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>% of Average</td>
<td></td>
<td></td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
LUMINANCE DURING CLEAR SKIES

The study of 1 August, 1990 was the only M1 study conducted during clear skies. This study is very important since cloud conditions do not muddle analysis. One of the interesting results of this study is that average M1 luminance, average tree luminance and grass luminance readings can be described by linear equations. As will be seen in a later study (Study 24 July, 1990), similar results were obtained for the LAV25 during clear skies.

Table 33 provides expressions for luminance (L) in terms of time (t = 0 corresponds to 10:00) for different ranges. Correlation coefficients are included to show how close the relationships fit collected data.

Figure 77, Figure 78 and Figure 79 show the collected data in graphical form.

Table 33. M1, Tree and Grass Luminance Analysis for 1 August, 1990 (Clear Skies)
Note: t in hours. Metering toward the west.

<table>
<thead>
<tr>
<th>Range</th>
<th>Luminance (cd/m²)</th>
<th>Corr. Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>L - 3303 - 583 t</td>
<td>0.9912</td>
</tr>
<tr>
<td>100 feet</td>
<td>L - 3019 - 550 t</td>
<td>0.9887</td>
</tr>
<tr>
<td>200 feet</td>
<td>L - 2809 - 497 t</td>
<td>0.9840</td>
</tr>
<tr>
<td>330 feet</td>
<td>L - 2816 - 476 t</td>
<td>0.9850</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Range</th>
<th>Luminance (cd/m²)</th>
<th>Corr. Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>L - 1102 - 59 t</td>
<td>0.8696</td>
</tr>
<tr>
<td>100 feet</td>
<td>L - 1237 - 89 t</td>
<td>0.9532</td>
</tr>
<tr>
<td>200 feet</td>
<td>L - 1237 - 88 t</td>
<td>0.9604</td>
</tr>
<tr>
<td>330 feet</td>
<td>L - 1281 - 56 t</td>
<td>0.7391</td>
</tr>
</tbody>
</table>

Grass Luminance Analysis for 1 August, 1990 (10:00 to 15:00)

<table>
<thead>
<tr>
<th>Range</th>
<th>Luminance (cd/m²)</th>
<th>Corr. Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>L - 2850 - 93 t</td>
<td>0.8843</td>
</tr>
<tr>
<td>100 feet</td>
<td>L - 3654 - 254 t</td>
<td>0.9918</td>
</tr>
<tr>
<td>200 feet</td>
<td>L - 3754 - 294 t</td>
<td>0.9946</td>
</tr>
<tr>
<td>330 feet</td>
<td>L - 3398 - 237 t</td>
<td>0.9801</td>
</tr>
</tbody>
</table>
It was shown earlier that the M1 has three distinguishing luminance areas: the turret, the skirt and the track and suspension areas. During clear skies, there are time intervals for which the luminance of these areas can be described by linear equations. Table 34 (range 36 feet) and Table 35 (range 100 feet) introduce these equations and the times for which they are appropriate. Correlation coefficients are also included.

Figure 125 (range 36 feet) and Figure 129 (range 100 feet) show the collected data in graphical form. The very abrupt change in luminance of the road wheels after 12:00 is clearly due to shading by areas above the track and suspension area as can be seen in the photographs of Figure 88, Figure 89,...Figure 93. These photographs also support the data of Figure 125 and Figure 129 with regard to the abrupt change in luminance of the skirt area after 14:00.

The equations for average luminance from Table 34 show that the rate at which average luminance decreases for the turret (609 cd/m²/hr) is approximately 40 percent less than the rate at which luminance decreases for the skirt (972 cd/m²/hr) and road wheels (1033 cd/m²/hr).

| Table 34. Average Turret, Skirt and Road Wheel Luminance Analysis for 1 August, 1990.
| Clear Skies. Range = 36 feet. | t in hours. Metering toward the west |
|--------------------------------|
| **M1 Area** | **Luminance (cd/m²)** | **Time Interval** | **Corr. Coeff.** |
| Turret | L = 3775 - 609 t | 11:00 - 15:00 | 0.9965 |
| Skirt | L = 3424 - 972 t | 11:00 - 14:00 | 0.9994 |
| Road Wheels | L = 2356 - 1033 t | 10:00 - 12:00 | 0.9934 |

The equations for average luminance from Table 35 show that the rate at which average luminance decreases for the turret (484 cd/m²/hr) is also approximately 40 percent less than the rate at which luminance decreases for the skirt area (811 cd/m²/hr).

| Table 35. Average Turret, Skirt and Road Wheel Luminance Analysis for 1 August, 1990.
| Clear Skies. Range = 100 feet. | t in hours. Metering toward the west |
|--------------------------------|
| **M1 Area** | **Luminance (cd/m²)** | **Time Interval** | **Corr. Coeff.** |
| Turret | L = 3614 - 484 t | 10:00 - 15:00 | 0.9941 |
| Skirt | L = 3767 - 811 t | 10:00 - 14:00 | 0.9929 |
| Road Wheels | L = 1720 - 570 t | 10:00 - 12:00 | 0.9981 |
M1 Turret, Skirt and Road Wheel Analysis for 1 August, 1990 (Range = 36 feet)

CONTRAST OF M1 TARGETS
TREE BACKGROUND
RANGE = 36 FEET

CLEAR SKIES

TIME OF DAY (1 AUG 1990)

Figure 122

CONTRAST OF M1 TARGETS
GRASS BACKGROUND
RANGE = 36 FEET

CLEAR SKIES

TIME OF DAY (1 AUG 1990)

Figure 123

CONTRAST OF M1 TARGETS
SKY BACKGROUND
RANGE = 36 FEET

CLEAR SKIES

TIME OF DAY (1 AUG 1990)

Figure 124

AVERAGE M1 LUMINANCE
RANGE = 36 FEET
CLEAR SKIES

TIME OF DAY (1 AUG 1990)

Figure 125

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M1 Turret, Skirt and Road Wheel Analysis for 1 August, 1990 (Range = 100 feet)

CONTRAST OF M1 TARGETS
TREE BACKGROUND
RANGE = 100 FEET
CLEAR SKIES

CONTRAST OF M1 TARGETS
GRASS BACKGROUND
RANGE = 100 FEET
CLEAR SKIES

CONTRAST OF M1 TARGETS
SKY BACKGROUND
RANGE = 100 FEET
CLEAR SKIES

AVERAGE M1 LUMINANCE
RANGE = 100 FEET
CLEAR SKIES

Figure 126

Figure 127

Figure 128

Figure 129

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CONTRAST DURING CLEAR SKIES

Since both the average luminance of the M1 and the background can be expressed as linear equations during clear skies, it would appear that contrast between the M1 and background would not result in a linear equation since

\[ \text{CONTRAST} = \frac{L_T - L_B}{L_B} \]

where \( L_T \) = luminance of M1 and \( L_B \) = luminance of background.

The ratio of two linear equations cannot, in general, be a linear equation. However, since the luminance of tree and grass backgrounds is nearly constant (small coefficients of the first degree term), contrast between the M1 and trees and between the M1 and grass, during clear skies, can be expressed as linear equations to a high degree of precision. Table 36 provides expressions for contrast (C) in terms of time (t = 0 corresponds to 10:00) for different ranges. Correlation coefficients are included to show how close the relationships fit collected data.

Figure 81 and Figure 82 show the collected data in graphical form.

Table 36. M1 Contrast for Tree and Grass Backgrounds on 1 August, 1990 (Clear Skies)

<table>
<thead>
<tr>
<th>Note: t in hours. Metering toward the west.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Range</th>
<th>Contrast</th>
<th>Corr. Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>( C = 2.06 - 0.487 \ t )</td>
<td>0.9861</td>
</tr>
<tr>
<td>100 feet</td>
<td>( C = 1.53 - 0.384 \ t )</td>
<td>0.9882</td>
</tr>
<tr>
<td>200 feet</td>
<td>( C = 1.34 - 0.353 \ t )</td>
<td>0.9802</td>
</tr>
<tr>
<td>330 feet</td>
<td>( C = 1.21 - 0.333 \ t )</td>
<td>0.9959</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Range</th>
<th>Contrast</th>
<th>Corr. Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>( C = 0.376 - 0.198 \ t )</td>
<td>0.9926</td>
</tr>
<tr>
<td>100 feet</td>
<td>( C = 0.021 - 0.138 \ t )</td>
<td>0.9861</td>
</tr>
<tr>
<td>200 feet</td>
<td>( C = 0.106 - 0.116 \ t )</td>
<td>0.9837</td>
</tr>
<tr>
<td>330 feet</td>
<td>( C = 0.028 - 0.121 \ t )</td>
<td>0.9873</td>
</tr>
</tbody>
</table>
During clear skies, there are time intervals for which the contrast of the turret, skirt and road wheels can be described by linear equations. Table 37 (range 36 feet) and Table 38 (range = 100 feet) introduce these equations and the times for which they are appropriate. Correlation coefficients are also included. Figure 122, Figure 123, Figure 124, Figure 126, Figure 127 and Figure 128 show the collected data in graphical form.

Table 37. Contrast Analysis of M1 Turret, Skirt and Road Wheels on 1 August, 1990
Clear Skies. Range = 36 feet. Metering toward the west. t in hours

<table>
<thead>
<tr>
<th>M1 Area</th>
<th>Contrast</th>
<th>Time Interval</th>
<th>Corr. Coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turret</td>
<td>C - 2.65 - 0.71 t</td>
<td>12:00 - 15:00</td>
<td>0.9982</td>
</tr>
<tr>
<td>Skirt</td>
<td>C - 1.73 - 1.07 t</td>
<td>12:00 - 14:00</td>
<td>0.9996</td>
</tr>
<tr>
<td>Road Wheels</td>
<td>C - 1.10 - 0.89 t</td>
<td>10:00 - 12:00</td>
<td>0.9891</td>
</tr>
</tbody>
</table>

Table 38. Contrast Analysis of M1 Turret, Skirt and Road Wheels on 1 August, 1990
Clear Skies. Range = 100 feet. Metering toward the west. t in hours

<table>
<thead>
<tr>
<th>M1 Area</th>
<th>Contrast</th>
<th>Time Interval</th>
<th>Corr. Coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turret</td>
<td>C - 1.70 - 0.42 t</td>
<td>12:00 - 15:00</td>
<td>0.9916</td>
</tr>
<tr>
<td>Skirt</td>
<td>C - 1.16 - 0.21 t</td>
<td>12:00 - 14:00</td>
<td>0.9996</td>
</tr>
<tr>
<td>Road Wheels</td>
<td>C - 0.40 - 0.41 t</td>
<td>10:00 - 12:00</td>
<td>0.9862</td>
</tr>
</tbody>
</table>
M1 Turret, Skirt and Road Wheel Analysis for 19 July, 1990 (Range = 36 feet)
M1 Turret, Skirt and Road Wheel Analysis for 6 August, 1990 (Range = 36 feet)

**CONTRAST OF M1 TARGETS**

**TREE BACKGROUND**

**RANGE = 36 FEET**

**OVERCAST**

![Graph](image1)

**CONTRAST OF M1 TARGETS**

**GRASS BACKGROUND**

**RANGE = 36 FEET**

**OVERCAST**

![Graph](image2)

**CONTRAST OF M1 TARGETS**

**SKY BACKGROUND**

**RANGE = 36 FEET**

**OVERCAST**

![Graph](image3)

**AVERAGE M1 LUMINANCE**

**RANGE = 36 FEET**

**OVERCAST**

![Graph](image4)

Figure 134

Figure 135

Figure 136

Figure 137
The average luminance of the M1, as measured from ranges of 36, 100, 200 and 330 feet, is represented by the graph of Figure 77 and Table 33. There is very little difference in the average M1 luminance readings using different ranges. As Table 33 illustrates, the expression for average luminance at 36 feet, using 45 M1 luminance readings, is nearly the same as the expression for average luminance at 330 feet where only three M1 luminance readings were used. As Table 33 also illustrates, there is a small change in the rate at which average M1 luminance decreases when the range increases. This is due to more recessed areas being included in the measurement area at greater ranges (see Figure 59, Figure 60,... Figure 62).

During clear skies, the rate at which average contrast decreases for the M1 (Table 36) also changes slightly for different ranges. The reason for this small decrease in the rate at which contrast decreases for increasing ranges is the same as given above.

Table 39. Average Luminance (cd/m²) for the Day of 1 August, 1990 for Different Ranges. Clear Skies. Averages based on the time interval from 10:00 to 15:00.

<table>
<thead>
<tr>
<th>Measurement Area</th>
<th>Range 36 feet</th>
<th>Range 100 feet</th>
<th>Range 200 feet</th>
<th>Range 330 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>1845</td>
<td>1693</td>
<td>1567</td>
<td>1626</td>
</tr>
<tr>
<td>Trees</td>
<td>956</td>
<td>1016</td>
<td>1018</td>
<td>1140</td>
</tr>
<tr>
<td>Grass</td>
<td>2619</td>
<td>2986</td>
<td>3018</td>
<td>2805</td>
</tr>
<tr>
<td>Sky</td>
<td>4796</td>
<td>5241</td>
<td>5710</td>
<td>5923</td>
</tr>
</tbody>
</table>

Table 40. Average Contrast of M1 for the Day of 1 August, 1990 for Different Ranges. Clear Skies. Averages based on the time interval from 10:00 to 15:00.

<table>
<thead>
<tr>
<th>Background</th>
<th>Range 36 feet</th>
<th>Range 100 feet</th>
<th>Range 200 feet</th>
<th>Range 330 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees</td>
<td>0.847</td>
<td>0.571</td>
<td>0.453</td>
<td>0.377</td>
</tr>
<tr>
<td>Grass</td>
<td>-0.315</td>
<td>-0.463</td>
<td>-0.514</td>
<td>-0.450</td>
</tr>
<tr>
<td>Sky</td>
<td>-0.592</td>
<td>-0.652</td>
<td>-0.708</td>
<td>-0.707</td>
</tr>
</tbody>
</table>
PHOTOGRAPHIC DECEPTION

Figure 88, Figure 89,...Figure 93 show photographs of the M1 for the six times luminance readings were made on 1 August, 1990. It was discovered that these photographs are very misleading with regard to how the luminance of the M1 changes with time.

Note:

Figure 88, Figure 89,...Figure 93 were taken with a Canon A1 set for automatic exposure. The camera was loaded with Kodak TMAX 400 film. The pictures were developed consecutively on the same day, using the same paper stock and the same chemicals. The enlarger was not changed for any of the exposures and the same time was used for all prints.

Example 1: It appears that the luminance of the turret increases from 10:00 to 13:00. In fact, as Figure 129 illustrates, the luminance of the turret decreases continuously throughout this time interval.

Example 2: It appears that Figure 92 and Figure 93 should be switched. The average luminance of the M1 appears to be greater at 15:00 than at 14:00. In fact, as Figure 77 illustrates, the average M1 luminance continuously decreases from 10:00 to 15:00.

Evidently, in Example 1, the rate of decrease in luminance of the turret areas was less than the rate of decrease in the average luminance for the entire scene. The luminance of the turret areas was progressively greater than the average luminance of the scene as the day progressed from 10:00 to 13:00. It can be seen from Table 34 that the rate of decrease in luminance of the skirt and road wheels is greater than the turret.

All objects in a scene with average luminance are printed as middle gray. The turret was printed progressively lighter than middle gray since its luminance was greater than the average luminance of the scene.

The explanation of the deception in Example 2 is illustrated in Figure 138 and Figure 139. When the photographs of Figure 92 and Figure 93 were taken, the camera was inadvertently positioned to include more sky background in Figure 92 than in Figure 93. This produced a higher average luminance for Figure 92 than for Figure 93. Therefore, since there are areas on the M1 with luminance below the average luminance of the scene, those areas on the M1 printed darker in Figure 92 than in Figure 93.
Figure 138
Complete, Uncropped Scene of Figure 92

Figure 139
Complete, Uncropped Scene of Figure 93
Whenever a reflected light exposure meter of a camera is used to obtain an exposure setting of an evenly illuminated single toned surface, the resultant camera setting will produce a negative density which will produce a "middle gray" in the print. A photograph of a completely black or completely white card will produce a print which is completely "middle gray."

Figure 140, Figure 141,...Figure 143 illustrate this idea. Figure 140 was produced using a laser printer. Figure 141 is a photograph of Figure 140. It was obtained using a reflected light exposure meter. The black squares appear black and the white squares appear white. The white squares had a luminance far above the average luminance for the scene (Figure 140). Therefore, the white squares printed much lighter than "middle gray." The black squares had a luminance far below the average luminance for the scene (Figure 140). Therefore, the black squares printed much darker than "middle gray."

Figure 142 was also produced using a laser printer. Figure 143 is a photograph of Figure 142. This photograph was obtained using the same reflected light exposure meter as was used for Figure 141. The black squares appear very black but the white squares appear gray. Since Figure 142 contains many more white squares than black squares, the average luminance for this scene is higher than for Figure 140. The white squares had a luminance close to the average luminance for the scene (Figure 142). Therefore, the white squares printed a little lighter than "middle gray." The black squares had a luminance far below the average luminance for the scene (Figure 142). Therefore, the black squares printed much darker than "middle gray."

Both pictures, Figure 141 and Figure 143, were developed consecutively on the same day, using the same paper stock and the same chemicals. The enlarger was not changed for either exposure and the same time was used for both prints.
Figure 140
Checker Board Grid with Equal Number of Black and White Squares

Figure 141
Photograph of Figure 140
Figure 142
Checker Board Grid with Three Black Squares and Thirty Three White Squares

Figure 143
Photograph of Figure 142

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LAV25 STUDIES

Figure 144 shows the position and surroundings of the LAV25 used for all studies of the LAV25. The LAV25 and tree line were facing east. The LS-100 meter was pointed west while luminance data was collected.

Luminance readings were acquired for the LAV25 and tree line using four different ranges from the LAV25: 36 feet, 100 feet, 200 feet and 330 feet. Figure 145, Figure 146, ... Figure 148 show the approximate LAV25 measurement area for these four ranges.

When the word "average" occurs in the title for the graphs that follow, the average luminance was used for constructing the graph.

All graphs involving the tree line were constructed using the average luminance of 50 random tree line luminance readings between the poles in Figure 144. Tree line luminance readings were acquired from left to right using an up-down scanning pattern.

Figure 144
Position and Surroundings of the LAV25.
Metering Toward the West.
Figure 145
Approximate LAV25 Measurement Area. Range = 36 feet.

Figure 146
Approximate LAV25 Measurement Area. Range = 100 feet.
Figure 147
Approximate LAV25 Measurement Area. Range = 200 feet.

Figure 148
Study 23 July, 1990  Clear Skies 10:00-11:00, Cloudy 11:00-15:00

LAV25 LUMINANCE AT 10:00
METERING WEST AT 36 FEET
23 JULY, 1990; CLEAR SKIES

LAV25 LUMINANCE AT 10:30
METERING WEST AT 36 FEET
23 JULY, 1990; CLEAR SKIES

LAV25 LUMINANCE AT 11:30
METERING WEST AT 36 FEET
23 JULY, 1990; CLOUDY

LAV25 LUMINANCE AT 12:45
METERING WEST AT 35 FEET
23 JULY, 1990; CLOUDY
Study 23 July, 1990  Clear Skies 10:00-11:00, Cloudy 11:00-15:00

LAV25 LUMINANCE AT 13:30
METEERING WEST AT 36 FEET
23 JULY, 1990; CLOUDY

Figure 153

LAV25 LUMINANCE AT 14:05
METEERING WEST AT 36 FEET
23 JULY, 1990; CLOUDY

Figure 154

AVERAGE LUMINANCE
METEERING AT 36 FEET

Figure 155

AVERAGE LAV25 CONTRAST
TREE BACKGROUND
METEERING WEST AT 36 FEET

Figure 156
Study 23 July, 1990  Clear Skies 10:00-11:00, Cloudy 11:00-15:00

LAV25 LUMINANCE AT 10:45
METERING WEST AT 100 FEET
23 JULY, 1990; CLEAR SKIES

LAV25 LUMINANCE AT 11:45
METERING WEST AT 100 FEET
23 JULY, 1990; CLOUDY

LAV25 LUMINANCE AT 13:00
METERING WEST AT 100 FEET
23 JULY, 1990; CLOUDY

LAV25 LUMINANCE AT 13:30
METERING WEST AT 100 FEET
23 JULY, 1990; CLOUDY

Figure 157

Figure 158

Figure 159

Figure 160
Study 23 July, 1990  Clear Skies 10:00-11:00, Cloudy 11:00-15:00

**LAV25 LUMINANCE AT 14:15**
METERING WEST AT 100 FEET
23 JULY, 1990; CLOUDY

**LAV25 AVERAGE LUMINANCE**
METERING WEST
CLEAR UNTIL 11:00, CLOUDY AFTER 11:00

Figure 161

Figure 162
Study 24 July, 1990  Clear Skies

**LAV25 LUMINANCE AT 9:00**
METERING WEST AT 36 FEET
24 JULY, 1990; CLEAR SKIES

![Graph](image1)

Figure 163

**LAV25 LUMINANCE AT 9:30**
METERING WEST AT 36 FEET
24 JULY, 1990; CLEAR SKIES

![Graph](image2)

Figure 164

**LAV25 LUMINANCE AT 10:00**
METERING WEST AT 36 FEET
24 JULY, 1990; CLEAR SKIES

![Graph](image3)

Figure 165

**LAV25 LUMINANCE AT 10:30**
METERING WEST AT 36 FEET
24 JULY, 1990; CLEAR SKIES

![Graph](image4)

Figure 166
Study 24 July, 1990  Clear Skies

LAV25 LUMINANCE AT 11:00
METERING WEST AT 36 FEET
24 JULY, 1990; CLEAR SKIES

Average Luminance
Metering at 36 Feet
Clear Skies

Tree Line Luminance
Clear Skies

Average LAV25 Contrast
Metering at 36 Feet
Clear Skies

Figure 167
Figure 168
Figure 169
Figure 170
Study 24 July, 1990 Clear Skies

LAV25 LUMINANCE AT 9:15
METERING WEST AT 100 FEET
24 JULY, 1990; CLEAR SKIES

LAV25 LUMINANCE AT 9:45
METERING WEST AT 100 FEET
24 JULY, 1990; CLEAR SKIES

Figure 171

LAV25 LUMINANCE AT 10:15
METERING WEST AT 100 FEET
24 JULY, 1990; CLEAR SKIES

LAV25 LUMINANCE AT 10:45
METERING WEST AT 100 FEET
24 JULY, 1990; CLEAR SKIES

Figure 173

Figure 172

Figure 174
Study 24 July, 1990 Clear Skies

LAV25 LUMINANCE AT 11:15
METERING WEST AT 100 FEET
24 JULY, 1990; CLEAR SKIES

AVERAGE LAV25 LUMINANCE
CLEAR SKIES

Figure 175

Figure 176

AVERAGE LAV25 CONTRAST
TREE BACKGROUND
CLEAR SKIES

Figure 177

95
Study 26 July, 1990  Hazy 9:30-12:30, Cloudy 12:30-14:30

LAV25 LUMINANCE AT 9:30
METERING WEST AT 36 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30 - 14:30

LAV25 LUMINANCE AT 10:30
METERING WEST AT 36 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30 - 14:30

LAV25 LUMINANCE AT 11:30
METERING WEST AT 36 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30 - 14:30

LAV25 LUMINANCE AT 12:30
METERING WEST AT 36 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30 - 14:30

Figure 178

Figure 179

Figure 180

Figure 181
Study 26 July, 1990  Hazy 9:30-12:30, Cloudy 12:30-14:30

LAV25 LUMINANCE AT 9:40
METERING WEST AT 100 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30-14:30

![Figure 186](image1)

LAV25 LUMINANCE AT 10:40
METERING WEST AT 100 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30-14:30

![Figure 187](image2)

LAV25 LUMINANCE AT 11:40
METERING WEST AT 100 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30-14:30

![Figure 188](image3)

LAV25 LUMINANCE AT 12:40
METERING WEST AT 100 FEET
26 JULY, 1990
HAZY, CLOUDY 12:30-14:30

![Figure 189](image4)
Study 26 July, 1990  Hazy 9:30-12:30, Cloudy 12:30-14:30

Figure 190

Figure 191

Figure 192

Figure 193
Study 26 July, 1990  Hazy 9:30-12:30, Cloudy 12:30-14:30

**AVERAGE LAV25 CONTRAST**
Trees Background
Hazy, Cloudy 12:30-14:30

**AVERAGE LAV25 CONTRAST**
Grass Background
Hazy, Cloudy 12:30-14:30

**AVERAGE LAV25 CONTRAST**
Sky Background
Hazy, Cloudy 12:30-14:30

**AVERAGE LAV25 CONTRAST**
Concrete Background
Hazy, Cloudy 12:30-14:30

Figure 194

Figure 195

Figure 196

Figure 197
LAV25 Study on 26 July, 1990 (Hazy 9:00-12:30, Cloudy 12:30-14:30; Viewing Toward West)

Figure 198
LAV25 at 9:30

Figure 199
LAV25 at 10:30

Figure 200
LAV25 at 11:30

Figure 201
LAV25 at 12:30

Figure 202
LAV25 at 13:30

Figure 203
LAV25 at 14:30
SUMMARY OF LAV25 STUDIES

All LAV25 studies were conducted with the vehicle oriented along a north-south line with luminance metering toward the west. Figure 144 shows the position of the vehicle and its surroundings during the times measurements were acquired. All conclusions in this study are based on this vehicle orientation and setup.

Luminance readings were acquired from four different ranges: 36, 100, 200 and 330 feet. The approximate measurement areas on the LAV25 for these ranges are shown in Figure 145, Figure 146,...Figure 148.

WHEEL AREAS

The most obvious luminance feature of the LAV25 relates to the vehicle's wheels and the surrounding wheel areas. In terms of luminance, the LAV25 is a bi-sectional vehicle. Its high stature, when positioned on the ground, produces significant shading of the wheel areas between 10:30 and 14:30. The photographs of Figure 198, Figure 199,...Figure 203 illustrate how shading and shadows develop between 9:30 and 14:30. Shadows in the wheel areas begin at 10:30 and complete shading occurs at 14:30.

The graphs of Figure 149, Figure 150,...Figure 154 (range = 36 feet) illustrate clearly the bi-sectional luminance nature of the LAV25. The variance in luminance for measurement areas 34-50 (wheel areas) is greater than for measurement areas 1-33. As time elapses, the two sections graphically separate.

The graphs of Figure 157, Figure 158,...Figure 161 (range = 100 feet) also illustrate clearly the bi-sectional luminance nature of the LAV25. The variance in luminance for measurement areas 13-20 (wheel areas) is much greater than for measurement areas 1-12. As time elapses, the two sections graphically separate.

The graphs of Figure 204, Figure 205,...Figure 215 compare the average luminance of the wheel areas to the average luminance of those areas above them for ranges of 36 feet and 100 feet. At approximately 9:00, the average luminance of both areas is approximately 1700 cd/m². At approximately 12:00, the average luminance of the wheel areas is approximately 50 percent of the average luminance of the area above the wheels. The ratio of the average luminance of the wheel areas to the average luminance of the area above the wheels decreases at the approximate rate of 0.15 per hr.

Table 41 gives the luminance of the LAV25 wheels, the luminance of the immediate surrounding areas and the contrast between them. There is considerable contrast between the LAV25 wheels and the immediate LAV25 surrounding areas. The average contrast between the LAV25 and tree background is approximately 0.6 (Figure 156, Figure 170 and Figure 194). However, the contrast between the LAV25 wheels and the immediate surrounding LAV25 areas varies from 0.57 to 2.61.
Study 23 July, 1990  Clear Skies 10:00-11:00, Cloudy 11:00-15:00

AVERAGE LAV25 LUMINANCE
METERING WEST AT 36 FEET
CLEAR UNTIL 11:00 CLOUDY AFTER 11:00

![Graph of Luminance vs Time of Day (Clear and Cloudy)]

Figure 204

AVERAGE LUMINANCE RATIOS
METERING WEST AT 36 FEET
CLEAR UNTIL 11:00 CLOUDY AFTER 11:00

![Graph of Luminance Ratio vs Time of Day (Clear and Cloudy)]

Figure 205

AVERAGE LAV25 LUMINANCE
METERING WEST AT 100 FEET
CLEAR UNTIL 11:00 CLOUDY AFTER 11:00

![Graph of Luminance vs Time of Day (Clear and Cloudy)]

Figure 206

AVERAGE LUMINANCE RATIOS
METERING WEST AT 100 FEET
CLEAR UNTIL 11:00 CLOUDY AFTER 11:00

![Graph of Luminance Ratio vs Time of Day (Clear and Cloudy)]

Figure 207
Study 24 July, 1990  Clear Skies

AVERAGE LAV25 LUMINANCE
METERING WEST AT 36 FEET
CLEAR SKIES UNTIL 11:00

AVERAGE LUMINANCE RATIOS
METERING WEST AT 36 FEET
CLEAR SKIES UNTIL 11:00

Figure 208

AVERAGE LAV25 LUMINANCE
METERING WEST AT 100 FEET
CLEAR SKIES UNTIL 11:00

AVERAGE LUMINANCE RATIOS
METERING WEST AT 100 FEET
CLEAR SKIES UNTIL 11:00

Figure 209

Figure 210

Figure 211

104
Study 26 July, 1990  Hazy 9:30-12:30, Cloudy 12:30-14:30

AVERAGE LAV25 LUMINANCE
METERING WEST AT 36 FEET
HAZY, CLOUDY 12:30-14:30

AVERAGE LUMINANCE RATIOS
METERING WEST AT 36 FEET
HAZY, CLOUDY 12:30-14:30

Figure 212

AVERAGE LAV25 LUMINANCE
METERING WEST AT 100 FEET
HAZY, CLOUDY 12:30-14:30

AVERAGE LUMINANCE RATIOS
METERING WEST AT 100 FEET
HAZY, CLOUDY 12:30-14:30

Figure 214

Figure 213

Figure 215
Table 41. Contrast of LAV25 Wheels Using Surrounding Wheel Area as Background.

23 July, 1990. Range = 36 feet. Clear Until 11:00, Cloudy after 11:00

<table>
<thead>
<tr>
<th>Area #</th>
<th>10:00</th>
<th>10:30</th>
<th>11:30</th>
<th>11:45</th>
<th>13:30</th>
<th>14:00</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1924</td>
<td>2090</td>
<td>1718</td>
<td>1118</td>
<td>753</td>
<td>432</td>
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<td>1760</td>
<td>1590</td>
<td>1349</td>
<td>862</td>
<td>625</td>
<td>378</td>
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<tr>
<td>39</td>
<td>2123</td>
<td>2011</td>
<td>1578</td>
<td>813</td>
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<td>403</td>
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<td>40</td>
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<tr>
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<td>2014</td>
<td>1756</td>
<td>1619</td>
<td>701</td>
<td>724</td>
<td>396</td>
</tr>
<tr>
<td>44</td>
<td>1274</td>
<td>1264</td>
<td>1068</td>
<td>679</td>
<td>481</td>
<td>271</td>
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<tr>
<td>46</td>
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<td>2047</td>
<td>2109</td>
<td>1036</td>
<td>892</td>
<td>495</td>
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<td>47</td>
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<td>1741</td>
<td>1263</td>
<td>1016</td>
<td>641</td>
<td>380</td>
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<tr>
<td>Average</td>
<td>1860</td>
<td>1721</td>
<td>1474</td>
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<td>649</td>
<td>383</td>
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</table>

<table>
<thead>
<tr>
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<th>10:00</th>
<th>10:30</th>
<th>11:30</th>
<th>11:45</th>
<th>13:30</th>
<th>14:00</th>
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<tbody>
<tr>
<td>34</td>
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<td>800</td>
<td>721</td>
<td>454</td>
<td>270</td>
<td>222</td>
</tr>
<tr>
<td>35</td>
<td>914</td>
<td>732</td>
<td>328</td>
<td>307</td>
<td>303</td>
<td>266</td>
</tr>
<tr>
<td>38</td>
<td>256</td>
<td>251</td>
<td>260</td>
<td>222</td>
<td>220</td>
<td>206</td>
</tr>
<tr>
<td>41</td>
<td>398</td>
<td>383</td>
<td>366</td>
<td>345</td>
<td>341</td>
<td>308</td>
</tr>
<tr>
<td>42</td>
<td>374</td>
<td>216</td>
<td>204</td>
<td>180</td>
<td>174</td>
<td>160</td>
</tr>
<tr>
<td>45</td>
<td>1367</td>
<td>1059</td>
<td>407</td>
<td>332</td>
<td>362</td>
<td>304</td>
</tr>
<tr>
<td>48</td>
<td>780</td>
<td>384</td>
<td>336</td>
<td>325</td>
<td>326</td>
<td>301</td>
</tr>
<tr>
<td>49</td>
<td>863</td>
<td>833</td>
<td>419</td>
<td>258</td>
<td>252</td>
<td>204</td>
</tr>
<tr>
<td>50</td>
<td>1003</td>
<td>934</td>
<td>631</td>
<td>375</td>
<td>256</td>
<td>224</td>
</tr>
<tr>
<td>Average</td>
<td>755</td>
<td>621</td>
<td>408</td>
<td>311</td>
<td>278</td>
<td>244</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area #</th>
<th>10:00</th>
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<th>11:30</th>
<th>11:45</th>
<th>13:30</th>
<th>14:00</th>
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<td>721</td>
<td>454</td>
<td>270</td>
<td>222</td>
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<tr>
<td>38</td>
<td>256</td>
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<td>41</td>
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<td>383</td>
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<td>341</td>
<td>308</td>
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<td>42</td>
<td>374</td>
<td>216</td>
<td>204</td>
<td>180</td>
<td>174</td>
<td>160</td>
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<td>45</td>
<td>1367</td>
<td>1059</td>
<td>407</td>
<td>332</td>
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<tr>
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<td>780</td>
<td>384</td>
<td>336</td>
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<td>326</td>
<td>301</td>
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<td>49</td>
<td>863</td>
<td>833</td>
<td>419</td>
<td>258</td>
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<td>204</td>
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<tr>
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<td>1003</td>
<td>934</td>
<td>631</td>
<td>375</td>
<td>256</td>
<td>224</td>
</tr>
<tr>
<td>Average</td>
<td>755</td>
<td>621</td>
<td>408</td>
<td>311</td>
<td>278</td>
<td>244</td>
</tr>
</tbody>
</table>

Luminance (cd/m²) of LAV25 Wheels

<table>
<thead>
<tr>
<th>Luminance of LAV25, Surrounding Wheel Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>38</td>
</tr>
<tr>
<td>41</td>
</tr>
<tr>
<td>42</td>
</tr>
<tr>
<td>45</td>
</tr>
<tr>
<td>48</td>
</tr>
<tr>
<td>49</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

Contrast

<table>
<thead>
<tr>
<th>Contrasts 1.47</th>
<th>1.77</th>
<th>2.61</th>
<th>1.78</th>
<th>1.33</th>
<th>0.57</th>
</tr>
</thead>
</table>

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AVERAGE LAV25 LUMINANCE

The LAV25 was made available for measurement for five days. Unfortunately, it rained one of the days and the cloud conditions were extremely variable on another. None of the days provided clear skies for the entire day. During those time periods for which the skies were not completely clear, luminance readings were only taken when the sun was not eclipsed by clouds. During the study of 26 July, the sky conditions after 12:30 were hazy, overcast and cloudy.

In all three studies of the LAV25, there are extended periods of time for which the average luminance of the LAV25 can be expressed by linear equations. Table 42 provides expressions for average luminance (L) in terms of time (t) for the three days data was acquired. Correlation coefficients (r) are included to show how close the relationships fit collected data. Figure 155, Figure 168 and Figure 184 show graphically the data used to obtain Table 42.

Table 42. LAV25 Average Luminance Analysis. Range = 36 feet

<table>
<thead>
<tr>
<th>t = 0</th>
<th>Time Range; Date</th>
<th>Luminance (cd/m²)</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00</td>
<td>10:00 - 13:30; 23 July</td>
<td>L = 1740 - 117 t</td>
<td>0.957</td>
</tr>
<tr>
<td>9:30</td>
<td>9:30 - 11:00; 24 July</td>
<td>L = 1767 - 52 t</td>
<td>0.837</td>
</tr>
<tr>
<td>10:30</td>
<td>10:30 - 14:30; 26 July</td>
<td>L = 1705 - 220 t</td>
<td>0.993</td>
</tr>
</tbody>
</table>

Table 43 gives the average luminance acquired for the LAV25 on 26 July, 1990 for different ranges. The far left column titled "Average" represents the average LAV25 luminance for a specific time. The row titled "Average" represents the average LAV25 luminance for the entire time period data was collected. Figure 184 shows the data in graphical form.

Table 43. Average LAV25 Luminance (cd/m²) on 26 July, 1990 for Different Ranges

<table>
<thead>
<tr>
<th>Range</th>
<th>36 feet</th>
<th>100 feet</th>
<th>200 feet</th>
<th>330 feet</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30</td>
<td>1649</td>
<td>1661</td>
<td>1476</td>
<td>1677</td>
<td>1616</td>
</tr>
<tr>
<td>10:30</td>
<td>1667</td>
<td>1585</td>
<td>1427</td>
<td>1646</td>
<td>1581</td>
</tr>
<tr>
<td>11:30</td>
<td>1494</td>
<td>1198</td>
<td>1273</td>
<td>1458</td>
<td>1356</td>
</tr>
<tr>
<td>12:30</td>
<td>1326</td>
<td>853</td>
<td>947</td>
<td>1121</td>
<td>1062</td>
</tr>
<tr>
<td>13:30</td>
<td>1052</td>
<td>935</td>
<td>851</td>
<td>926</td>
<td>941</td>
</tr>
<tr>
<td>14:30</td>
<td>789</td>
<td>657</td>
<td>625</td>
<td>734</td>
<td>701</td>
</tr>
<tr>
<td>Average</td>
<td>1330</td>
<td>1148</td>
<td>1100</td>
<td>1260</td>
<td>1209</td>
</tr>
</tbody>
</table>

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Table 44 provides expressions for average luminance (L) in terms of time (t) for four different ranges. Correlation coefficients (r) are included to show how close the relationships fit collected data.

Table 44. LAV25 Average Luminance Analysis for 26 July, 1990 (t = 0 at 9:30)

<table>
<thead>
<tr>
<th>Range</th>
<th>Luminance (cd/m²)</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>L = 1780 - 180 t</td>
<td>0.964</td>
</tr>
<tr>
<td>100 feet</td>
<td>L = 1670 - 209 t</td>
<td>0.960</td>
</tr>
<tr>
<td>200 feet</td>
<td>L = 1550 - 180 t</td>
<td>0.982</td>
</tr>
<tr>
<td>330 feet</td>
<td>L = 1775 - 206 t</td>
<td>0.983</td>
</tr>
<tr>
<td>Average</td>
<td>L = 1694 - 194 t</td>
<td>0.986</td>
</tr>
</tbody>
</table>

TREELINE LUMINANCE

The photograph of Figure 144 shows the surrounding treeline background used for the three studies conducted for the LAV25. All graphs and tables relating to the treeline were constructed using the average luminance of 50 random luminance readings between the poles shown in Figure 144.

Table 45 and Table 46 provide a summary and an analysis of the average treeline luminance readings acquired during the LAV25 studies. Figure 155, Figure 169 and Figure 185 show the results in graphical form.

Table 45. Average Treeline Luminance (cd/m²) for 23 July, 1990 and 24 July, 1990

<table>
<thead>
<tr>
<th>23 July; Range = 36'</th>
<th>24 July; Range = 36'</th>
<th>24 July; Range = 200'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Luminance</td>
<td>Time</td>
</tr>
<tr>
<td>------</td>
<td>-----------</td>
<td>------</td>
</tr>
<tr>
<td>10:15</td>
<td>1056</td>
<td>9:05</td>
</tr>
<tr>
<td>12:00</td>
<td>1057</td>
<td>9:35</td>
</tr>
<tr>
<td>13:15</td>
<td>934</td>
<td>10:05</td>
</tr>
<tr>
<td>14:00</td>
<td>849</td>
<td>10:35</td>
</tr>
<tr>
<td>Average</td>
<td>974</td>
<td>Average</td>
</tr>
<tr>
<td>L = 1091 - 55 t</td>
<td>L = 1053 - 7 t</td>
<td>L = 1279 - 44 t</td>
</tr>
<tr>
<td>r = 0.889</td>
<td>r = 0.086</td>
<td>r = 0.912</td>
</tr>
</tbody>
</table>
Table 46. Summary and Analysis of Average Treeline Luminance (cd/m²) for 26 July, 1990

<table>
<thead>
<tr>
<th>Time</th>
<th>Luminance R = 36'</th>
<th>Luminance R = 100'</th>
<th>Luminance R = 200'</th>
<th>Luminance R = 330'</th>
<th>Average Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30</td>
<td>1064</td>
<td>1224</td>
<td>1265</td>
<td>1397</td>
<td>1238</td>
</tr>
<tr>
<td>10:30</td>
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<td>1168</td>
<td>1263</td>
<td>1375</td>
<td>1212</td>
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<td>1055</td>
<td>1224</td>
<td>1054</td>
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</table>

The data in Table 45 and Table 46 indicate that the average diurnal treeline luminance can be expressed as linear equations. With one exception, range R = 330 feet, the correlation coefficients are above 0.92.

These tables also indicate that the average treeline luminance is greater for larger ranges. The reason for this is unknown. Some considerations are:

1. Approximately five minutes were required to transport and set up the equipment for each new range position. It also takes time to acquire the luminance readings for each range. Sun position and sky conditions can change during this time.

2. The treeline luminance averages were obtained from a random sampling of trees and bushes. Each average represents a different collection of targets.

3. The luminance measurement area becomes larger the farther the meter gets from the target.

This difference in treeline luminance for different ranges contributes significantly to contrast differences for the LAV25 when the treeline is used as a background for different ranges. The graph of Figure 177 shows an average contrast of approximately 0.6 for a range 36 feet. When the range was 200 feet, the average contrast was approximately 0.2. This significant contrast difference is also due to the difference in measurement areas (Figure 145 and Figure 147) used for the two ranges. The wheels of the LAV25, which increase the average luminance of the LAV25, were not included in the measurement areas for a range of 200 feet.
Table 47. Average Luminance and Contrast for Ranges of 36 feet and 200 feet on 24 July, 1990

<table>
<thead>
<tr>
<th>Range (feet)</th>
<th>Average LAV25 Luminance (cd/m²)</th>
<th>Average Treeline Luminance (cd/m²)</th>
<th>Average Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>1700</td>
<td>1046</td>
<td>0.62</td>
</tr>
<tr>
<td>200</td>
<td>1464</td>
<td>1235</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Similar results were obtained for the LAV25 study of 26 July, 1990. Figure 194 illustrates that a higher contrast is obtained at a range of 36 feet than is obtained for higher ranges at the same time of day.

CONTRAST

Four different backgrounds were used to acquire contrast values for the LAV25: grass, sky, concrete and trees. Of the three studies conducted for the LAV25, the study of 26 July, 1990 was the most extensive. This study involved all four backgrounds for four different ranges.

Table 48 gives a summary of the average contrasts obtained for the three LAV25 studies using a treeline as background. The following symbols are used: \( R = \) range in feet, \( C = \) contrast, \( r = \) correlation coefficient and \( t = \) time in hours (\( t = 0 \) at the start of the time interval). In those instances where the contrast was approximately constant, the average contrast is given for the time interval. For many time intervals the best fit curve through the data points is a straight line.

Table 48. Summary of Average LAV25 Contrast Using a Treeline as a Background

<table>
<thead>
<tr>
<th>( R ) (feet)</th>
<th>Time Interval</th>
<th>Date</th>
<th>Contrast Description</th>
<th>( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>10:30 - 12:30</td>
<td>23 July, 1990</td>
<td>( C = 0.56 )</td>
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<td>12:30 - 14:00</td>
<td>23 July, 1990</td>
<td>( C = 0.56 - 0.28 \ t )</td>
<td>1.000</td>
</tr>
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<td>9:00 - 11:00</td>
<td>24 July, 1990</td>
<td>( C = 0.63 )</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>9:30 - 12:30</td>
<td>26 July, 1990</td>
<td>( C = 0.55 )</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>12:30 - 14:30</td>
<td>26 July, 1990</td>
<td>( C = 0.57 - 0.31 \ t )</td>
<td>0.992</td>
</tr>
<tr>
<td>100</td>
<td>9:30 - 14:30</td>
<td>26 July, 1990</td>
<td>( C = 0.33 - 0.11 \ t )</td>
<td>0.839</td>
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<tr>
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<td>( C = 0.19 )</td>
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</tr>
<tr>
<td>200</td>
<td>9:30 - 14:30</td>
<td>26 July, 1990</td>
<td>( C = 0.25 - 0.09 \ t )</td>
<td>0.865</td>
</tr>
<tr>
<td>330</td>
<td>9:30 - 14:30</td>
<td>26 July, 1990</td>
<td>( C = 0.27 - 0.10 \ t )</td>
<td>0.813</td>
</tr>
</tbody>
</table>
Figure 198, Figure 199,...Figure 203 lend support to the results shown in Table 48. After 12:30 there is significant shading in the LAV25 wheels. Table 48 illustrates this for a range of 36 feet. Both studies, 23 July and 26 July, show a drastic change in the description of contrast after 12:30. The contrast is constant, approximately 0.55 until 12:30. After 12:30, the contrast is best described by the linear equation: \( C = 0.57 - 0.3 \, t \). Contrast decreases at the rate of 0.3/hour from 12:30 to 14:30 due to shading of the LAV25 wheels. Figure 156 and Figure 194 illustrate this graphically.

Table 49. Summary of Average LAV25 Contrast Using Grass as a Background.

<table>
<thead>
<tr>
<th>R (feet)</th>
<th>Time Interval</th>
<th>Date</th>
<th>Contrast</th>
<th>Description</th>
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<tr>
<td>36</td>
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<td>26 July, 1990</td>
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<tr>
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<td>C = - 0.41 - 0.06 t</td>
<td>0.978</td>
</tr>
<tr>
<td>200</td>
<td>9:30 - 14:30</td>
<td>26 July, 1990</td>
<td>C = - 0.56 - 0.03 t</td>
<td>0.966</td>
</tr>
<tr>
<td>300</td>
<td>9:30 - 14:30</td>
<td>26 July, 1990</td>
<td>C = - 0.47 - 0.04 t</td>
<td>0.966</td>
</tr>
</tbody>
</table>

Shading of the LAV25 wheels is also evident in the contrast calculations using a grass background. Table 49 gives two descriptions for the contrast of the LAV25 on 26 July when the range was 36 feet. From 9:30 to 12:30 the contrast is approximately constant (-0.31). From 12:30 to 14:30 the contrast is best described by: \( C = -0.41 - 0.06 \, t \). After 12:30 the contrast decreases at the rate of 0.06/hour. The negative contrast values obtained using a grass background indicate that the luminance of the grass was greater than the average luminance of the LAV25.

The description of contrast values acquired for the LAV25 using sky as a background were nearly the same for all ranges on 24 July (9:00 - 11:00) and 26 July, 1990 (9:30 - 14:30):

\[ C = -0.73 - 0.04 \, t \]

The contrast of the LAV25 using concrete as a background was nearly constant (\( C = -0.79 \)) for all ranges on 24 July (9:00 - 11:00) and also 26 July, 1990 (9:30 - 14:30).
Figure 198, Figure 199,...Figure 203 reveal those areas susceptible to diurnal shading. As these photographs illustrate, the wheel areas constitute more than 50 percent of the vehicle's side surface area and undergo the greatest amount of shading. As discussed in an earlier section, contrast variations are highest for the wheel areas.

The LAV turret also produces shading in the areas below it. In fact, the greatest contrast variation was obtained for measurement area #27 (see Figure 145). The range of luminance for this area was 3299 cd/m² (11:30, 23 July, 1990) to 516 cd/m² (14:00, 23 July, 1990).

Figure 216 shows an enlarged view of the turret area at 14:30 on 26 July, 1990. This photograph illustrates the extent of shading produced by the turret.

Figure 216
LAV Turret Area at 14:30 on 26 July, 1990
GLARE AND EDGE EFFECT

When two nonparallel surfaces of a vehicle meet, a rounded edge is formed. This edge may be formed by a single metal plate, a weld joint or a bend. In most instances, the width of this edge will be greater than several hundred microns. Under the right conditions, an edge may appear as a white line.

Arrow 1 and Arrow 3 in Figure 217 indicate places on the M113A3 where a white line occurs along an edge. Arrow 2 in Figure 217 indicates a place on the M113A3 where a white line is not visible along an edge.

Arrow 2 in Figure 218 indicates another edge on the M113A3 which shows a white line. Arrow 3 of Figure 218 indicates a shaded place along the top edge of the M113A3 where there is a break in the white line. Arrow 1 in Figure 218 indicates a place along a cylindrical rod which also produces a white line.

The white lines in the photographs are produced by a mirror like reflection called specular reflection. Because of the roundness of the edge, the white outline can be observed from many different directions, especially for edges near the top of the vehicle. Most of the light reflected off edges near the ground is reflected toward the ground and away from an observer.

Arrow 1, Arrow 2 and Arrow 3 in Figure 219 indicate places where glare occurs along an edge at the top of the M113A3. Figure 220 shows the same view using a polarizer in front of the camera lens. The polarizer is effective in reducing glare because the specularly reflected light from the edges is linearly polarized to a considerable extent. The degree of glare extinction depends on the angle between the transmission axis of the polarizer and the plane of polarization of the reflected light. The photograph of Figure 219 was obtained by rotating a polarizer in front of the camera lens until the glare from the edge, indicated by Arrow 3, was a minimum.

The painted metal objects, indicated by Arrow 1 and Arrow 2 of Figure 221, show significant glare along their edges and on their adjacent surfaces. Again, a polarizer is able to reduce the glare significantly as shown in Figure 222.

Arrow 1, Arrow 2 and Arrow 3 of Figure 221 indicate an edge that has been painted with three different colors, one of the colors being flat black. Figure 222 illustrates that the different colors of paint have little effect on the degree of glare. The entire illuminated edge appears white. Evidently, the glare is associated with light that has not interacted with the paint pigments.

An important consequence of the edge effect is an increase in contrast between the edge and surrounding surfaces. This increase in contrast increases the visibility of the vehicle.
Figure 217
M113A3. Viewing Toward the North.

Figure 218
M113A3. Viewing Toward the Southwest.
Figure 219
Photograph of Side of M113A3 - No Polaroid in Front of Camera.

Figure 220
Photograph of Side of M113A3 - Polaroid in Front of Camera.
Figure 221
Photograph of Top of M113A3 - No Polaroid in Front of Camera.

Figure 222
Photograph of Top of M113A3 - Polaroid in Front of Camera.
HORIZONTAL AND VERTICAL POLARIZATION OF THE M1A1

On June 20, 1991, diurnal luminance readings and photographs were acquired for the M1A1 turret area from 08:30 to 16:00. The M1A1 was positioned along a north-south line and metering was to the west. A Minolta LS-100 Luminance Meter was used to make the readings. Three different luminance readings were made at 30 minute time intervals. For the first reading, no polarizer was used in front of the LS-100. For the second reading, a polarizer was positioned in front of the LS-100 with its transmission axis vertical. For the third reading, a polarizer was positioned in front of the LS-100 with its transmission axis horizontal, as shown in Figure 223. The entire study was conducted under clear skies.

Figure 223
Positioning of Polarizer in Front of LS-100

Figure 224 shows the fifteen measurement areas for which diurnal luminance readings were acquired.

Figure 225, Figure 226,...Figure 240 show the diurnal photographs acquired for the M1A1.

Figure 224
Measurement Areas on M1A1

Figure 225
M1A1 at 08:30

Figure 226
M1A1 at 09:00

Figure 227
M1A1 at 09:30

Figure 228
M1A1 at 10:00

Figure 229
M1A1 at 10:30

Figure 230
M1A1 at 11:00

Figure 231  
M1A1 at 11:30

Figure 232  
M1A1 at 12:00

Figure 233  
M1A1 at 12:30

Figure 234
M1A1 at 13:00

Figure 235
M1A1 at 13:30

Figure 236
M1A1 at 14:00

Figure 237
M1A1 at 14:30

Figure 238
M1A1 at 15:00

Figure 239
M1A1 at 15:30

Figure 240
M1A1 at 16:00
Table 50, Table 51 and Table 52 give the results of the diurnal luminance readings.

Ln represents the luminance reading acquired when no polarizer was used.

Lv represents the luminance reading acquired when the transmission axis of the polarizer was vertical.

Lh represents the luminance reading acquired when the transmission axis of the polarizer was horizontal.

### Table 50. M1A1 Luminance Ln (No Polarizer) on 20 June, 1991. Clear Skies 8:30 - 16:00 M1A1 Positioned North-South. Metering toward the West.

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The graphs of Figure 241, Figure 242, ... Figure 256 show all the measurements graphically.

To ascertain the degree of vertical and horizontal polarization from the MIA1, the ratios \( L_v/L_n \) and \( L_h/L_n \) were calculated for all measurement areas and for all the measurement times. The results are given in Table 53 and Table 54. These ratios are a measure of the transmittance of the polarizer. The graphs of Figure 257, Figure 258, ... Figure 286 show the results graphically.

**Table 52. LUMINANCE \( L_h \) (Polarizer's Transmission Axis Horizontal) on 20 June, 1991. Clear Skies 8:30 - 16:00. MIA1 Positioned North-South. Metering West.**

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M1 LUMINANCE AT 08:30
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

M1 LUMINANCE AT 09:00
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

M1 LUMINANCE AT 09:30
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

M1 LUMINANCE AT 10:00
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

Figure 241

Figure 242

Figure 243

Figure 244
M1 LUMINANCE AT 10:30
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

M1 LUMINANCE AT 11:00
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

Figure 245

M1 LUMINANCE AT 11:30
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

M1 LUMINANCE AT 12:00
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

Figure 246

Figure 247

Figure 248
M1 LUMINANCE AT 14:30
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

M1 LUMINANCE AT 15:00
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

Figure 253

Figure 254

M1 LUMINANCE AT 15:30
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

M1 LUMINANCE AT 16:00
METERING WEST AT 36 FEET
20 JUNE, 1991; CLEAR SKIES

Figure 255

Figure 256
Table 53. Luminance Ratio (Lv/Ln).

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LUMINANCE RATIO (Lv/Ln)
MEASUREMENT AREA #1
METERING WEST; CLEAR SKIES

Figure 257

LUMINANCE RATIO (Lv/Ln)
MEASUREMENT AREA #2
METERING WEST; CLEAR SKIES

Figure 258

LUMINANCE RATIO (Lv/Ln)
MEASUREMENT AREA #3
METERING WEST; CLEAR SKIES

Figure 259

LUMINANCE RATIO (Lv/Ln)
MEASUREMENT AREA #4
METERING WEST; CLEAR SKIES

Figure 260

TIME OF DAY (20 JUNE 91)
Figure 261

Figure 262

Figure 263

Figure 264
LUMINANCE RATIO (Lv/Ln)  
MEASUREMENT AREA #9  
METERING WEST; CLEAR SKIES

Figure 265

LUMINANCE RATIO (Lv/Ln)  
MEASUREMENT AREA #10  
METERING WEST; CLEAR SKIES

Figure 266

LUMINANCE RATIO (Lv/Ln)  
MEASUREMENT AREA #11  
METERING WEST; CLEAR SKIES

Figure 267

LUMINANCE RATIO (Lv/Ln)  
MEASUREMENT AREA #12  
METERING WEST; CLEAR SKIES

Figure 268
LUMINANCE RATIO \( (L_v/L_n) \)
MEASUREMENT AREA #13
METERING WEST; CLEAR SKIES

Figure 269

LUMINANCE RATIO \( (L_v/L_n) \)
MEASUREMENT AREA #14
METERING WEST; CLEAR SKIES

Figure 270

LUMINANCE RATIO \( (L_v/L_n) \)
MEASUREMENT AREA #15
METERING WEST; CLEAR SKIES

Figure 271
Table 54. Luminance Ratio (Lh/Ln).

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LUMINANCE RATIO (Lh/Ln)
MEASUREMENT AREA #1
METERING WEST; CLEAR SKIES

LUMINANCE RATIO (Lh/Ln)
MEASUREMENT AREA #2
METERING WEST; CLEAR SKIES

LUMINANCE RATIO (Lh/Ln)
MEASUREMENT AREA #3
METERING WEST; CLEAR SKIES

LUMINANCE RATIO (Lh/Ln)
MEASUREMENT AREA #4
METERING WEST; CLEAR SKIES

TIME OF DAY (20 JUNE 91)

Figure 272

TIME OF DAY (20 JUNE 91)

Figure 273

TIME OF DAY (20 JUNE 91)

Figure 274

TIME OF DAY (20 JUNE 91)

Figure 275
LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #5
METERING WEST; CLEAR SKIES

Figure 276

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #6
METERING WEST; CLEAR SKIES

Figure 277

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #7
METERING WEST; CLEAR SKIES

Figure 278

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #8
METERING WEST; CLEAR SKIES

Figure 279
LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #9
METERING WEST; CLEAR SKIES

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #10
METERING WEST; CLEAR SKIES

Figure 280

Figure 281

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #11
METERING WEST; CLEAR SKIES

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #12
METERING WEST; CLEAR SKIES

Figure 282

Figure 283
Figure 284

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #13
METERING WEST; CLEAR SKIES

Figure 285

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #14
METERING WEST; CLEAR SKIES

Figure 286

LUMINANCE RATIO ($L_h/L_n$)
MEASUREMENT AREA #15
METERING WEST; CLEAR SKIES

Figure 286
Table 55 shows the difference in the amount of vertical and horizontal polarization. The graphs of Figure 287, Figure 288,...Figure 304 show the results graphically.

Table 55. Luminance Difference (Lh - Lv).

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Note: MINIMUM refers to the smallest difference obtained between 08:30 and 16:00. MAXIMUM refers to the largest difference obtained between 08:30 and 16:00. DIFFERENCE refers to the difference between MAXIMUM and MINIMUM. STD refers to the standard deviation of difference for each measurement area.
LUMINANCE DIFFERENCE (Lb - Lv)
MEASUREMENT AREA #1
METERING WEST; CLEAR SKIES

Figure 287

LUMINANCE DIFFERENCE (Lb - Lv)
MEASUREMENT AREA #2
METERING WEST; CLEAR SKIES

Figure 288

LUMINANCE DIFFERENCE (Lb - Lv)
MEASUREMENT AREA #3
METERING WEST; CLEAR SKIES

Figure 289

LUMINANCE DIFFERENCE (Lb - Lv)
MEASUREMENT AREA #4
METERING WEST; CLEAR SKIES

Figure 290

Figure 287

Figure 288

Figure 289

Figure 290
LUMINANCE DIFFERENCE ($L_h - L_v$)
MEASUREMENT AREA #5
METERING WEST; CLEAR SKIES

LUMINANCE DIFFERENCE ($L_h - L_v$)
MEASUREMENT AREA #6
METERING WEST; CLEAR SKIES

Figure 291

Figure 292

LUMINANCE DIFFERENCE ($L_h - L_v$)
MEASUREMENT AREA #7
METERING WEST; CLEAR SKIES

LUMINANCE DIFFERENCE ($L_h - L_v$)
MEASUREMENT AREA #8
METERING WEST; CLEAR SKIES

Figure 293

Figure 294
LUMINANCE DIFFERENCE ($L_b - L_v$)
MEASUREMENT AREA #9
METERING WEST; CLEAR SKIES

LUMINANCE DIFFERENCE ($L_b - L_v$)
MEASUREMENT AREA #10
METERING WEST; CLEAR SKIES

Figure 295

LUMINANCE DIFFERENCE ($L_b - L_v$)
MEASUREMENT AREA #11
METERING WEST; CLEAR SKIES

LUMINANCE DIFFERENCE ($L_b - L_v$)
MEASUREMENT AREA #12
METERING WEST; CLEAR SKIES

Figure 297

Figure 298
LUMINANCE DIFFERENCE (Lb - Lv)
MEASUREMENT AREA #13
METERING WEST; CLEAR SKIES

LUMINANCE DIFFERENCE (Lb - Lv)
MEASUREMENT AREA #14
METERING WEST; CLEAR SKIES

Figure 299

LUMINANCE DIFFERENCE (Lb - Lv)
MEASUREMENT AREA #15
METERING WEST; CLEAR SKIES

Figure 300

Figure 301
LUMINANCE DIFFERENCE (Lh - Lv)
LEFT SIDE OF M1 TURRET
METERING WEST; CLEAR SKIES

TIME OF DAY (20 JUNE 91)

--- #1
--- #7

--- #2
--- #8

--- #3

--- #15

Figure 302
146
LUMINANCE DIFFERENCE (Lh - Lv)
MIDDLE OF M1 TURRET
METERING WEST; CLEAR SKIES

![Graph showing luminance difference over time.](image)

**TIME OF DAY (20 JUNE 91)**

- - #4
- - #9
+ #5
⇒ #10
⇒ #15

Figure 303

147
LUMINANCE DIFFERENCE (Lh - Lv)
RIGHT SIDE OF M1 TURRET
METERING WEST; CLEAR SKIES

TIME OF DAY (20 JUNE 91)

- #11
- #12
- #13
- #14
- #15

Figure 304
148
ANALYSIS OF 20 JUNE, 1991 STUDY

An interesting photograph of the diurnal photographic study (Figure 225, Figure 226,..., Figure 240) is Figure 235. This photograph shows the MIA1 at 13:30. As Table 56 indicates, this is approximately the time the sun crosses the meridian (sun due south). Since the MIA1 was positioned along a north-south line, the angle of incidence of the sun's rays on the skirt areas (Area #15, slope 90°, azimuth 270°) is 90°. The sun does not radiate its energy directly on the skirt area shortly after 13:30. This explains why all the vertical areas oriented along a north-south line on the MIA1 give low luminance readings after 13:30. The luminance of these areas after 13:30 is due to skylight (and to a lesser extent other sources) and is approximately 700 cd/m² (Table 50, Figure 251, Figure 252,..., Figure 256).

The sun's rays make an angle of incidence of 90° with Area #12 (Figure 224, slope 60°, azimuth 270°) shortly after 15:30. The sun's rays make an angle of incidence of 90° with Area #13 (Figure 224, slope 60°, azimuth 204°) shortly after 16:00.

Table 56. Sun's Position and Angles of Incidence for 20 June, 1991

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NOTE: SOUTH = 0°, WEST = 90°, NORTH = 180°, EAST = 270°
At 8:30, the luminance of Area #12 and Area #15 are nearly equal, 3021 cd/m² and 3023 cd/m² respectfully, and the contrast between these two areas is zero. However, at 13:30, the luminance of Area #12 and Area #15 is 2760 cd/m² and 819 cd/m² respectfully and the contrast between these two areas is 2.4.

An important consequence of the shading of selected areas on a vehicle is contrast variation between different areas of the vehicle. The increase in contrast between Area #12 of the M1A1 (turret facet) and Area #15 of the M1A1 (skirt) at 13:30 compared to 8:30 increases the visibility of the vehicle and produces a visible signature.

At the conclusion of this study, it was initially thought that the polarization data of this study would be of little value. The vertical and horizontal positions of the transmission axis do not necessarily correspond to the minimum and maximum polarization readings. However, in a later study conducted on 15 July, 1991, it was found that the minimum and maximum polarization angles correspond very closely to the vertical and horizontal positions of the polarizer (Figure 305 and Figure 306). Also, there is a wealth of information contained in this polarization data that does not relate to minimum and maximum polarization angles.
The optical density of the polarizer used for this study was determined, using unpolarized light from a Macbeth TD 502 Densitometer, to be 0.6. This corresponds to a transmittance of 0.25. (See Appendix A for a discussion of optical density and transmittance.) However, the transmittance can be greater than 0.25 if polarized light is incident on the polarizer. As a matter of fact, if the transmittance is found to be greater than 0.25, it is reasonably certain that some of the light entering the polarizer is polarized light.

The ratio of a luminance reading with a polarizer in front of the meter to the luminance reading without a polarizer in front of the meter is equal to the transmittance of the polarizer. Any ratio greater than 0.25 corresponds to polarized light entering the polarizer. For example, virtually all the luminance ratios \( L_v/L_n \) (transmittance with the transmission axis of the polarizer vertical) for all fifteen areas of the M1A1 studied are 0.25 up to a time of 13:30. The ratios \( L_v/L_n \) at 13:30 and after are generally greater than 0.25 (Table 53, Figure 257, Figure 258, ..., Figure 270). Since the transmittance is greater than 0.25 at 13:30 and after, the amount of polarized light entering the polarizer increases after 13:30. But most of the M1A1 areas studied do not receive light directly from the sun after 13:30! The only other reasonable source for this polarized light is sky light.

The nature of the ratios \( L_h/L_n \) (transmittance with the transmission axis of the polarizer horizontal) are similar to the ratios \( L_v/L_n \). However, there are two distinct differences:

1. With a few minor exceptions, the ratios \( L_h/L_n \), for all fifteen areas studied, are greater than \( L_v/L_n \) for all times between 8:30 and 16:00 (Table 53, Table 54, Figure 257, Figure 258, ..., Figure 286).

2. Unlike \( L_v/L_n \), which has a near constant value of 0.25 from 8:30 to 13:30 and then increases after 13:30, \( L_h/L_n \) slowly increases from 8:30 to 13:30. The ratio \( L_h/L_n \) increases at a greater rate after 13:30 than it does before 13:30.

When the M1A1 is oriented along a north-south line and viewing of the M1A1 is toward the west, the azimuth range of the sky which can affect polarization measurements of the M1A1 is from 180° to 360° (south = 0°). In other words, only light from the eastern hemispherical region of the sky can affect polarization measurements.

The photographs of Figure 307 show how the polarization of light from the sky for this region changes with time from 10:30 to 16:00. These photographs were obtained by placing a polarization axis finder in front of a 100 mm macro lens fitted with an extension tube and attached to a 35 mm Canon A1 camera. The darker and broader the two opposing wedges appear, the greater the intensity of the polarized incident light. The polarization axis is along a line drawn through the center of the wedges. Appendix B gives a description of the polarization axis finder.
Figure 307

The Eastern Hemispherical Sky at 30° Altitude as Seen Through a Polarization Axis Finder

Note: Azimuth angles are displayed below the photographs.

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The sky photographs of Figure 307 illustrate clearly that the eastern hemispherical region of the sky produces an increasing amount of polarized light from 10:30 to 16:00. At 10:30, the polarization of this region is particularly strong to the north and very weak to the south. As the sun's position advances to the west, the polarization of the southern portion of the sky's eastern hemisphere increases.

Another trend in the polarization data of this study relates to the diurnal difference $\Delta L = L_h - L_v$. In general, for most of the M1A1 areas studied, $\Delta L$ increases from 8:30 to approximately 11:30 then decreases from 12:00 to 13:30. Although this phenomenon is on a small scale, ($\Delta L = 150 \text{ cd/m}^2$) it definitely exists and it is interesting because it appears to be related to the altitude of the sun and the polarization axis of sky light.

The maximum deviation of the polarization axis of sky light from the horizontal occurs at 90° to the sun's direction and is equal to the complement of the sun's altitude. The sun's altitude is approximately 45° at 11:00 (Table 56) and increases to a maximum 63° at 13:30.

**SUMMARY OF 20 JUNE, 1991 STUDY**

The following are the highlights of this study:

1. The maximum luminance acquired for the M1A1 was 3667 cd/m² (10:30, Area #12, slope 60°, azimuth 270°).

2. Large scale shading occurs when the sun's position creates a 90° angle of incidence for the skin area of the M1A1 (13:30, Area #15, slope 90°, azimuth 270°). This causes contrast variation (0 to 2.4), and increases the visibility of the vehicle and produces a visible signature.

3. The minimum and maximum polarization angles for light reflected from different areas of the M1A1 correspond closely to the vertical and horizontal positions of the transmission axis of a linear polarizer.

4. The transmittance of a polarizer is greater for polarized light than it is for unpolarized light.

5. The greatest degree of polarization from the M1A1 occurs when no direct light from the sun reaches its surfaces.

6. Sky light, which is partially polarized due to Rayleigh scattering, is a source of polarized light.

7. The degree of polarization of sky light for the eastern hemispherical sky increases from 8:30 to 16:00 from north to south.

8. The horizontal component of polarized light from the M1A1 is greater than the vertical component for almost every M1A1 area studied. The maximum difference occurs at approximately 11:30.
LUMINANCE, POLARIZATION AND CHROMATICITY STUDY ON 15 JULY, 1991

This study is similar to the 20 June, 1991 study with the following differences:

1. Only three M1A1 areas were metered, Area #12, Area #13 and Area #15 (Figure 224).

2. A linear polarizer (O.D. = 0.5) was rotated in front of the LS-100 luminance meter until a minimum reading was acquired. The polarization angle and luminance were both recorded.

3. The same polarizer was rotated in front of the LS-100 luminance meter until a maximum reading was acquired. The polarization angle and luminance were both recorded.

4. A Minolta CS-100 luminance meter was also used to acquire the three coordinates for the CIE Chromaticity Diagram. The same M1A1 areas (Figure 224, Area #12, Area #13 and Area #15) were metered with the CS-100 as with the LS-100. Also, a grass area (circle in Figure 309) and three different tree areas (numbered areas in Figure 310) were metered with the CS-100.

Figure 308
M1A1, LS-100 (right) and CS-100 (left) Positions for 15 July, 1991 Study
Figure 309
Location of the Grass Area Metered on 15 July, 1991

Figure 310
Location of the Three Tree Areas Metered on 15 July, 1991
Table 57. MIA1 Luminance and Polarization Data for Area #12 on 15 July, 1991

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<td>3442</td>
<td>1012</td>
<td>1069</td>
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<td>-12</td>
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<tr>
<td>09:30</td>
<td>3617</td>
<td>1039</td>
<td>1142</td>
<td>80</td>
<td>-10</td>
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<tr>
<td>10:00</td>
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<td>1033</td>
<td>1196</td>
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</tr>
<tr>
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<td>998</td>
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<tr>
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<td>3574</td>
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<td>-13</td>
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<tr>
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<td>3533</td>
<td>916</td>
<td>1235</td>
<td>74</td>
<td>-17</td>
</tr>
<tr>
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<td>3553</td>
<td>916</td>
<td>1247</td>
<td>78</td>
<td>-12</td>
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<tr>
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<td>903</td>
<td>1275</td>
<td>76</td>
<td>-20</td>
</tr>
<tr>
<td>13:00</td>
<td>3292</td>
<td>859</td>
<td>1236</td>
<td>80</td>
<td>-15</td>
</tr>
<tr>
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<td>2922</td>
<td>742</td>
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<td>80</td>
<td>-10</td>
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<tr>
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<td>2526</td>
<td>658</td>
<td>1008</td>
<td>80</td>
<td>-10</td>
</tr>
<tr>
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<td>1872</td>
<td>534</td>
<td>820</td>
<td>82</td>
<td>-8</td>
</tr>
</tbody>
</table>

Table 58. MIA1 Luminance and Polarization Data for Area #13 on 15 July, 1991

<table>
<thead>
<tr>
<th>TIME</th>
<th>Ln</th>
<th>Lmin</th>
<th>Lmax</th>
<th>&lt;min</th>
<th>&lt;max</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2785</td>
<td>793</td>
<td>814</td>
<td>-30</td>
<td>74</td>
</tr>
<tr>
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<td>2785</td>
<td>835</td>
<td>859</td>
<td>112</td>
<td>37</td>
</tr>
<tr>
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<td>2796</td>
<td>836</td>
<td>878</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
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<td>829</td>
<td>891</td>
<td>98</td>
<td>2</td>
</tr>
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<td>802</td>
<td>890</td>
<td>93</td>
<td>1</td>
</tr>
<tr>
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<td>737</td>
<td>855</td>
<td>83</td>
<td>-10</td>
</tr>
<tr>
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<td>2505</td>
<td>700</td>
<td>845</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
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<td>667</td>
<td>829</td>
<td>83</td>
<td>-8</td>
</tr>
<tr>
<td>12:00</td>
<td>2351</td>
<td>634</td>
<td>802</td>
<td>79</td>
<td>-5</td>
</tr>
<tr>
<td>12:30</td>
<td>2350</td>
<td>640</td>
<td>818</td>
<td>83</td>
<td>-5</td>
</tr>
<tr>
<td>13:00</td>
<td>2211</td>
<td>625</td>
<td>773</td>
<td>82</td>
<td>-4</td>
</tr>
<tr>
<td>13:30</td>
<td>1966</td>
<td>565</td>
<td>713</td>
<td>83</td>
<td>-2</td>
</tr>
<tr>
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<td>1851</td>
<td>545</td>
<td>646</td>
<td>87</td>
<td>-2</td>
</tr>
<tr>
<td>14:45</td>
<td>1685</td>
<td>480</td>
<td>581</td>
<td>88</td>
<td>-1</td>
</tr>
</tbody>
</table>

NOTES: Range - 36 feet. Minolta LS-100 Luminance meter

Clear Skies Until 12:00 (Light Overcast & Cloudy After 12:00)

Optical Density of linear polarizer = 0.50

Ln = Luminance reading with no polarizer
Lmin = Luminance reading with polarizer rotated to produce a minimum reading
Lmax = Luminance reading with polarizer rotated to produce a maximum reading

MIN < - The polarization angle which produces a minimum luminance reading
MAX < - The polarization angle which produces a maximum luminance reading
Table 59. M1A1 Luminance and Polarization Data for Area #15 on 15 July, 1991

<table>
<thead>
<tr>
<th>TIME</th>
<th>Ln</th>
<th>Lmin</th>
<th>Lmax</th>
<th>&lt;min</th>
<th>&lt;max</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00</td>
<td>3169</td>
<td>971</td>
<td>996</td>
<td>94</td>
<td>0</td>
</tr>
<tr>
<td>08:30</td>
<td>3313</td>
<td>1022</td>
<td>1037</td>
<td>42</td>
<td>135</td>
</tr>
<tr>
<td>09:00</td>
<td>3280</td>
<td>1036</td>
<td>1070</td>
<td>62</td>
<td>-18</td>
</tr>
<tr>
<td>09:30</td>
<td>3321</td>
<td>995</td>
<td>1056</td>
<td>82</td>
<td>-15</td>
</tr>
<tr>
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<td>3205</td>
<td>910</td>
<td>1014</td>
<td>82</td>
<td>-15</td>
</tr>
<tr>
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<td>3011</td>
<td>841</td>
<td>971</td>
<td>74</td>
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</tr>
<tr>
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<td>2742</td>
<td>788</td>
<td>945</td>
<td>73</td>
<td>-12</td>
</tr>
<tr>
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<td>2524</td>
<td>702</td>
<td>854</td>
<td>79</td>
<td>-17</td>
</tr>
<tr>
<td>12:00</td>
<td>2209</td>
<td>614</td>
<td>760</td>
<td>76</td>
<td>-17</td>
</tr>
<tr>
<td>12:30</td>
<td>1902</td>
<td>520</td>
<td>649</td>
<td>78</td>
<td>-5</td>
</tr>
<tr>
<td>13:00</td>
<td>1097</td>
<td>339</td>
<td>403</td>
<td>71</td>
<td>-18</td>
</tr>
<tr>
<td>13:30</td>
<td>637</td>
<td>209</td>
<td>229</td>
<td>76</td>
<td>-6</td>
</tr>
<tr>
<td>14:00</td>
<td>612</td>
<td>206</td>
<td>230</td>
<td>85</td>
<td>-9</td>
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<tr>
<td>14:45</td>
<td>641</td>
<td>188</td>
<td>221</td>
<td>73</td>
<td>-5</td>
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</table>
LUMINANCE OF AREA #12
M1A1 FACETS

TIME OF DAY (15 JULY 91)

LUMINANCE (cd/m²)

--- Ln --- Lmin --- Lmax

Figure 311
158
LUMINANCE OF AREA #13
M1A1 FACETS

Figure 312
159
LUMINANCE OF AREA #15
M1A1 FACETS

Figure 313
LUMINANCE OF M1A1 FACETS
CLEAR SKIES UNTIL 12:00
LIGHT OVERCAST & CLOUDY AFTER 12:00

Figure 314

161
MIN POLARIZATION ANGLE
M1A1 FACETS

Polarization Angle (degrees)

Time of Day (15 July 91)

- #12
- #13
- #15

Figure 315

162
MAX POLARIZATION ANGLE
M1A1 FACETS

Figure 316
### Table 60. MIA1 Luminance and Polarization Calculations for Area #12 on 15 July, 1991

<table>
<thead>
<tr>
<th>TIME</th>
<th>Lmin-Lmax</th>
<th>Lmin/Lmax</th>
<th>Lmin/Ln</th>
<th>Lmax/Ln</th>
<th>&lt;Diff</th>
<th>Deg of Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00</td>
<td>17</td>
<td>0.981</td>
<td>0.290</td>
<td>0.296</td>
<td>-85</td>
<td>0.009</td>
</tr>
<tr>
<td>08:30</td>
<td>17</td>
<td>0.983</td>
<td>0.294</td>
<td>0.299</td>
<td>75</td>
<td>0.009</td>
</tr>
<tr>
<td>09:00</td>
<td>57</td>
<td>0.947</td>
<td>0.294</td>
<td>0.311</td>
<td>92</td>
<td>0.027</td>
</tr>
<tr>
<td>09:30</td>
<td>103</td>
<td>0.910</td>
<td>0.287</td>
<td>0.316</td>
<td>90</td>
<td>0.047</td>
</tr>
<tr>
<td>10:00</td>
<td>163</td>
<td>0.864</td>
<td>0.283</td>
<td>0.328</td>
<td>89</td>
<td>0.073</td>
</tr>
<tr>
<td>10:30</td>
<td>192</td>
<td>0.839</td>
<td>0.276</td>
<td>0.329</td>
<td>90</td>
<td>0.088</td>
</tr>
<tr>
<td>11:00</td>
<td>236</td>
<td>0.792</td>
<td>0.266</td>
<td>0.336</td>
<td>93</td>
<td>0.116</td>
</tr>
<tr>
<td>11:30</td>
<td>290</td>
<td>0.765</td>
<td>0.264</td>
<td>0.346</td>
<td>91</td>
<td>0.133</td>
</tr>
<tr>
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<td>0.353</td>
<td>90</td>
<td>0.153</td>
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<td>0.256</td>
<td>0.361</td>
<td>96</td>
<td>0.171</td>
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<td>0.261</td>
<td>0.375</td>
<td>95</td>
<td>0.180</td>
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<tr>
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<td>348</td>
<td>0.681</td>
<td>0.254</td>
<td>0.373</td>
<td>90</td>
<td>0.190</td>
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<tr>
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<td>350</td>
<td>0.653</td>
<td>0.261</td>
<td>0.400</td>
<td>90</td>
<td>0.210</td>
</tr>
<tr>
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<td>286</td>
<td>0.651</td>
<td>0.285</td>
<td>0.438</td>
<td>90</td>
<td>0.211</td>
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</table>

### Table 61. MIA1 Luminance and Polarization Calculations for Area #13 on 15 July, 1991

<table>
<thead>
<tr>
<th>TIME</th>
<th>Lmin-Lmax</th>
<th>Lmin/Lmax</th>
<th>Lmin/Ln</th>
<th>Lmax/Ln</th>
<th>&lt;Diff</th>
<th>Deg of Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00</td>
<td>21</td>
<td>0.974</td>
<td>0.285</td>
<td>0.292</td>
<td>-104</td>
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<tr>
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<td>24</td>
<td>0.972</td>
<td>0.300</td>
<td>0.308</td>
<td>75</td>
<td>0.014</td>
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<tr>
<td>09:00</td>
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<td>0.952</td>
<td>0.299</td>
<td>0.314</td>
<td>83</td>
<td>0.025</td>
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<tr>
<td>09:30</td>
<td>62</td>
<td>0.930</td>
<td>0.295</td>
<td>0.317</td>
<td>96</td>
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<tr>
<td>10:00</td>
<td>88</td>
<td>0.901</td>
<td>0.294</td>
<td>0.326</td>
<td>92</td>
<td>0.052</td>
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<td>0.862</td>
<td>0.283</td>
<td>0.328</td>
<td>93</td>
<td>0.074</td>
</tr>
<tr>
<td>11:00</td>
<td>145</td>
<td>0.828</td>
<td>0.279</td>
<td>0.337</td>
<td>90</td>
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<td>162</td>
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<td>0.276</td>
<td>0.344</td>
<td>91</td>
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<td>0.117</td>
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<td>0.283</td>
<td>0.350</td>
<td>86</td>
<td>0.106</td>
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<tr>
<td>13:30</td>
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<td>0.792</td>
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<td>0.363</td>
<td>85</td>
<td>0.116</td>
</tr>
<tr>
<td>14:00</td>
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<td>0.294</td>
<td>0.349</td>
<td>89</td>
<td>0.085</td>
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<td>0.826</td>
<td>0.285</td>
<td>0.345</td>
<td>89</td>
<td>0.095</td>
</tr>
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</table>

**NOTES:**

- **Lmax-Lmin** = Difference between maximum and minimum luminance readings (Lmax - Lmin) using a rotated polarizer
- **Lmin/Lmax** = Ratio Lmin/Lmax
- **Lmin/Ln** = Ratio Lmin/Ln
- **Lmax/Ln** = Ratio Lmax/Ln
- **<Diff** = Difference between MAX < and MIN <
- **Deg. of Polar** = (Lmax - Lmin)/(Lmax + Lmin)
<table>
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<tr>
<th>TIME</th>
<th>Lmin-Lmax</th>
<th>Lmin/Lmax</th>
<th>Lmin/Ln</th>
<th>Lmax/Ln</th>
<th>&lt;Diff</th>
<th>Deg of Polar</th>
</tr>
</thead>
<tbody>
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<td>0.306</td>
<td>0.314</td>
<td>94</td>
<td>0.013</td>
</tr>
<tr>
<td>08:30</td>
<td>15</td>
<td>0.986</td>
<td>0.308</td>
<td>0.313</td>
<td>-93</td>
<td>0.007</td>
</tr>
<tr>
<td>09:00</td>
<td>34</td>
<td>0.968</td>
<td>0.316</td>
<td>0.326</td>
<td>80</td>
<td>0.016</td>
</tr>
<tr>
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<td>61</td>
<td>0.942</td>
<td>0.300</td>
<td>0.318</td>
<td>97</td>
<td>0.030</td>
</tr>
<tr>
<td>10:00</td>
<td>104</td>
<td>0.897</td>
<td>0.284</td>
<td>0.316</td>
<td>97</td>
<td>0.054</td>
</tr>
<tr>
<td>10:30</td>
<td>130</td>
<td>0.866</td>
<td>0.279</td>
<td>0.322</td>
<td>94</td>
<td>0.072</td>
</tr>
<tr>
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<td>157</td>
<td>0.834</td>
<td>0.287</td>
<td>0.345</td>
<td>85</td>
<td>0.091</td>
</tr>
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<td>152</td>
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<td>0.278</td>
<td>0.338</td>
<td>96</td>
<td>0.098</td>
</tr>
<tr>
<td>12:00</td>
<td>146</td>
<td>0.808</td>
<td>0.278</td>
<td>0.344</td>
<td>93</td>
<td>0.106</td>
</tr>
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<td>0.273</td>
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<td>0.110</td>
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<td>0.309</td>
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<td>13:30</td>
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<td>0.328</td>
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<td>0.337</td>
<td>0.376</td>
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<td>0.055</td>
</tr>
<tr>
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<td>33</td>
<td>0.851</td>
<td>0.293</td>
<td>0.345</td>
<td>78</td>
<td>0.081</td>
</tr>
</tbody>
</table>
Lmin/Ln POLARIZATION RATIO
M1A1 FACETS

TIME OF DAY (15 JULY 91)

LUMINANCE RATIO (cd/m²)

--- #12   --- #13   --*-- #15

Figure 317

166
Lmax/I.n POLARIZATION RATIO
M1A1 FACETS

TIME OF DAY (15 JULY 91)

#12       #13       #15

Figure 318

167
L_min/L_max POLARIZATION RATIO
M1A1 FACETS

Figure 319
DEGREE OF POLARIZATION
M1A1 FACETS

Figure 320

169
POLARIZATION MIN-MAX DIFFERENCE
M1A1 FACETS

LUMINANCE (cd/m²)

0 50 100 150 200 250 300 350 400

TIME OF DAY (15 JULY 91)

#12  #13  * #15

Figure 321

170
MIN-MAX POLARIZATION ANGLE DIFFERENCE
M1A1 FACETS

TIME OF DAY (15 JULY 91)

#12 #13 #15

Figure 322

171
MIN-MAX POLARIZATION ANGLE DIFFERENCE
M1A1 FACETS

Figure 323

TIME OF DAY (15 JULY 91)

→ #12  ← #13  * #15

172
### Table 63 Sun's Position and Angles of Incidence on 15 July, 1991

Clear Skies until 12:00, Light Overcast after 12:00

<table>
<thead>
<tr>
<th>TIME</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>AREA #12 SLOPE</th>
<th>AREA #13 SLOPE</th>
<th>AREA #15 SLOPE</th>
<th>EDST</th>
<th>ALTITUDE</th>
<th>AZIMUTH</th>
<th>AZIMUTH</th>
<th>AZIMUTH</th>
</tr>
</thead>
<tbody>
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<td>60</td>
<td>90</td>
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</tr>
<tr>
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<td>60</td>
<td>60</td>
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<td>60</td>
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<td>45.87</td>
<td>-90</td>
</tr>
</tbody>
</table>

**NOTES:**

- <1 = angle between sun's rays and the normal to an M1A1 facet (#12, #13 and #15)
- The facet represented by Area #15 was facing east. Azimuth is zero for a south orientation. Negative angles represent rotations eastward.
- The surface slopes represent angular displacements upward from the horizontal.
Table 64. Angles from Coordinate Axis for M1A1 Area #12 on 15 July, 1991

CLEAR SKIES UNTIL 12:00, LIGHT OVERCAST AFTER 12:00

AREA #12
FACET SLOPE: 60°
FACET AZIMUTH: -90° (EAST)

<table>
<thead>
<tr>
<th>INCIDENT RAY</th>
<th>REFLECTED RAY</th>
<th>ANGLE BETWEEN</th>
<th>ANGLE BETWEEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDST</td>
<td>+X</td>
<td>+Y</td>
<td>+Z</td>
</tr>
<tr>
<td>08:00</td>
<td>157.7</td>
<td>102.2</td>
<td>71.6</td>
</tr>
<tr>
<td>08:30</td>
<td>154.9</td>
<td>97.5</td>
<td>66.2</td>
</tr>
<tr>
<td>09:00</td>
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<td>60.7</td>
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<td>44.2</td>
</tr>
<tr>
<td>11:00</td>
<td>126.2</td>
<td>77.8</td>
<td>38.9</td>
</tr>
<tr>
<td>11:30</td>
<td>119.5</td>
<td>74.9</td>
<td>33.8</td>
</tr>
<tr>
<td>12:00</td>
<td>112.7</td>
<td>72.6</td>
<td>29.2</td>
</tr>
<tr>
<td>12:30</td>
<td>105.8</td>
<td>70.8</td>
<td>25.2</td>
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<td>22.3</td>
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<tr>
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<td>71.0</td>
<td>71.6</td>
<td>27.0</td>
</tr>
</tbody>
</table>

NOTES:

X, Y and Z refer to the angles between the incident or reflected rays and the X (west), Y (south) and Z (up) axes.

The angles between I and L or R and L refer to the angles between the incident or reflected rays and the LS-100 luminance meter. The LS-100 was pointing west when measurements were acquired.
Table 65. Angles from Coordinate Axis for M1A1 Area #13 on 15 July, 1991

CLEAR SKIES UNTIL 12:00, LIGHT OVERCAST AFTER 12:00

AREA #13
FACET SLOPE: 60°
FACET AZIMUTH: -156° (204)

<table>
<thead>
<tr>
<th>INCIDENT RAY</th>
<th>REFLECTED RAY</th>
<th>ANGLE BETWEEN</th>
<th>ANGLE BETWEEN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+X</td>
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<td>+Z</td>
</tr>
<tr>
<td>08:00</td>
<td>157.7</td>
<td>102.2</td>
<td>71.6</td>
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<td>08:30</td>
<td>154.9</td>
<td>97.5</td>
<td>66.2</td>
</tr>
<tr>
<td>09:00</td>
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<td>60.7</td>
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<tr>
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<td>88.7</td>
<td>55.2</td>
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<tr>
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<td>84.7</td>
<td>49.7</td>
</tr>
<tr>
<td>10:30</td>
<td>132.8</td>
<td>81.0</td>
<td>44.2</td>
</tr>
<tr>
<td>11:00</td>
<td>126.2</td>
<td>77.8</td>
<td>38.9</td>
</tr>
<tr>
<td>11:30</td>
<td>119.5</td>
<td>74.9</td>
<td>33.8</td>
</tr>
<tr>
<td>12:00</td>
<td>112.7</td>
<td>72.6</td>
<td>29.2</td>
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<td>98.8</td>
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<td>71.0</td>
<td>71.6</td>
<td>27.0</td>
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</table>
Table 66. Angles from Coordinate Axis for M1A1 Area #15 on 15 July, 1991

CLEAR SKIES UNTIL 12:00, LIGHT OVERCAST AFTER 12:00

AREA #15
FACET SLOPE: 90°
FACET AZIMUTH: -90° (270)

<table>
<thead>
<tr>
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<th>+X</th>
<th>+Y</th>
<th>+Z</th>
<th>+X</th>
<th>+Y</th>
<th>+Z</th>
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<th>R &amp; L</th>
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176
ALTITUDE AND AZIMUTH
EDST. LONG. = 83 W. LAT. = 42.5 N

TIME OF DAY (15 JULY 91)

— ALTITUDE       — AZIMUTH

Figure 324
177
ANGLE BETWEEN I AND METER
EDST. LONG. = 83 W. LAT. = 42.5 N

TIME OF DAY (15 JULY 91)

Figure 325

178
DIURNAL CHANGES IN $\angle i$ AND $\angle RL$
AREA #12: SLOPE = 60, AZIMUTH = -90
EDST. LONG. = 83 W LAT. = 42.5 N

TIME OF DAY (15 JULY 91)

$\angle i$ $\angle RL$

Figure 326

179
DIURNAL CHANGES IN $\langle i \rangle$ AND $\langle RL \rangle$

AREA #13: SLOPE = 60, AZIMUTH = -156
EDST. LONG. = 83 W LAT. = 42.5 N

TIME OF DAY (15 JULY 91)

Figure 327
180
DIURNAL CHANGES IN $\angle i$ AND $\angle RL$

AREA #15: SLOPE = 90, AZIMUTH = -90
EDST. LONG. = 83 W. LAT. = 42.5 N

Figure 328

131
LUMINANCE vs ANGLE RL
M1A1 AREAS; 8:00 - 14:00
15 JULY, 1991; CLEAR SKIES

Figure 329
182
LUMINANCE VS SUN-METER ANGLE
M1A1 AREAS; 8:00 - 14:00
15 JULY, 1991; CLEAR SKIES

Figure 330

183
LUMINANCE vs ANGLE OF INCIDENCE
M1A1 AREAS; 8:00 - 14:00
15 JULY 91; CLEAR SKIES

Figure 331

184
LUMINANCE vs COS i
M1A1 AREAS; 8:00 - 14:00
15 JULY 91; CLEAR SKIES

LUMINANCE (cd/m²)

COS i

AREA #12
AREA #13
AREA #15

Figure 332
185
Figure 333
LUMINANCE OF MIAI FACETS
CLEAR SKIES UNTIL 12:00
LIGHT OVERCAST & CLOUDY AFT. 12:00

LUMINANCE vs ANGLE OF INCIDENCE
MIAI AREAS; 9:00 - 14:00
15 JULY 91; CLEAR SKIES

LUMINANCE vs SUN-METER ANGLE
MIAI AREAS; 9:00 - 14:00
15 JULY, 1991; CLEAR SKIES

LUMINANCE vs ANGLE RL
MIAI AREAS; 9:00 - 14:00
15 JULY, '91; CLEAR SKIES

Figure 334

187
Figure 335
Table 67. CIE Coordinates for M1A1 Facets on 15 July, 1991

<table>
<thead>
<tr>
<th>TIME</th>
<th>M1A1 AREA #12</th>
<th>M1A1 AREA #13</th>
<th>M1A1 AREA #15</th>
</tr>
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<td>L X Y</td>
<td>L X Y</td>
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<td>3080 0.347 0.378</td>
<td>2770 0.341 0.371</td>
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<tr>
<td>14:45</td>
<td>1870 0.330 0.356</td>
<td>1770 0.323 0.349</td>
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</tr>
</tbody>
</table>

NOTES:

Readings from Minolta CS-100.

Clear Skies Until 12:00. Light Overcast & Cloudy After 12:00.

L - Luminance; X,Y - CIE Coordinates.


TEST CARD (FRESHLY PAINTED WITH 4 COATS OF WHITE TEMPRA PAINT):
L - 18,700 cd/m² X - 0.327 Y - 0.343
Table 68. CIE Coordinates for Grass and Trees on 15 July, 1991

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<th></th>
<th>TREE #1</th>
<th></th>
</tr>
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<td>X</td>
<td>Y</td>
<td>L</td>
</tr>
<tr>
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<td>738</td>
</tr>
<tr>
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<tr>
<td>14:45</td>
<td>290</td>
<td>0.307</td>
<td>0.350</td>
<td>320</td>
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</table>

190
Figure 336
Figure 337

192
Table 69 lists the maximum luminance reading acquired for each of the three M1A1 facets measured and the times for which these maximums occur. These values are comparable to those obtained in other studies (Table 50).

As was found in the 20 June, 1991 study, with the M1A1 oriented along a north-south line, large scale shading occurs for all vertical facets (skirt area) also oriented along a north-south line when the sun crosses the meridian (13:30 EDST). The contrast variation produced by this shading, between Area #12 (turret) and Area #15 (skirt), ranges from -0.03 at 8:00 to 3.59 at 13:30 (Table 57 and Table 59). This contrast variation increases the visibility of the vehicle and produces a visual signature.

The axis of polarization which produced a minimum luminance reading had an orientation of approximately 80° from the horizontal. In other words, the transmission axis of the polarizer was nearly vertical for minimum readings. This was found to be true for all three M1A1 facets studied and for all times during the day except during the early morning hours (8:00 - 9:00) when the sun was in the eastern sky (Figure 315). Since the region of the sky near the sun produces little polarized light (Figure 307), the sunlight reflected from a north-south oriented vehicle during the times 8:00 to 10:00 EDST is mostly unpolarized light. This accounts for the difficulty in determining minimum and maximum polarization angles during this time of the day.

The axis of polarization which produced a maximum luminance reading had an orientation of approximately -10° from the horizontal. In other words, the transmission axis of the polarizer was nearly horizontal for maximum readings. This was found to be true for all three M1A1 facets studied and for all times during the day except during the early morning hours (8:00 - 9:00) when the sun was in the eastern sky (Figure 316).

Table 60, Table 61 and Figure 320 give the calculated degree of polarization obtained for the three M1A1 surface areas studied. The degree of polarization is given by

$$\frac{L_{\text{MAX}} - L_{\text{MIN}}}{L_{\text{MAX}} + L_{\text{MIN}}}$$

where $L_{\text{MAX}}$ and $L_{\text{MIN}}$ are the maximum and minimum luminance readings obtained while rotating a linear polarizer in front of the luminance meter.
For turret Area #12, the degree of polarization increased from 0.01 to 0.21 during the time interval from 8:00 to 14:00.

For turret Area #13, the degree of polarization increased from 0.01 to 0.12 during the time interval from 8:00 to 12:30. It then decreased from 0.12 to 0.09 during the time interval from 12:30 to 14:00.

For skirt Area #15, the degree of polarization increased from 0.01 to 0.11 during the time interval from 8:00 to 12:30. It then decreased from 0.11 to 0.05 during the one hour time interval from 12:30 to 13:30; rising again after the sun crossed the meridian (13:30 EDST) to a value of .08 at 14:45.

The sky polarization photographs of Figure 307 illustrate why the amount of linear polarized light reflected from a north-south oriented M1A1 should increases after 8:00. The eastern hemispherical sky is the only sky region which can affect western polarization readings from a north-south oriented M1A1. Therefore, since the amount of polarized light from this sky region increases from sunset to solar noon (Figure 307), the degree of polarized light reflected from the M1A1 also increases during this same period.

To discover when and where the greatest degree of polarized light can be detected from a vehicle, a circuit was constructed to operate a small d.c. motor at 32 RPM. A linear polarized was positioned on the motor shaft. The entire unit was then positioned in front of a camcorder as shown in Figure 338.
As the transmission axis of the linear polarizer rotated in front of the camcorder lens, polarized light entering the camcorder was observed to "flicker" in unison with the phase angle between the polarized incident light and the rotating analyzer.

A video tape was created using the arrangement described above. The video includes 360° views of an M1A1, M60, skylight and objects along the horizon. There is one dramatic feature of this video that stands out above all others. An outstanding amount of "flicker" (reflected polarized light) can be detected from surfaces which receive no light directly from the sun. Shadowed areas were observed to blink on and off like flashing neon signs. Rounded surfaces, like the M60 turret, fence posts, car hoods and windows, produced a considerable amount of "flicker" when illuminated by direct sun light. Flat surfaces, like the skirt area of the M1A1, showed very little "flicker" when illuminated by direct sun light. But these same flat surfaces flashed on and off as soon as sky light became the only source of illumination.

Initial attempts at finding a curve fit for luminance readings acquired from different M1A1 facets are not completely satisfactory. The closest curve fit achieved to date is shown in Figure 332. This graph shows luminance plotted as a function of Cos i (i = angle of incidence). The curves for the three facets are nearly straight lines and coincident for the time interval 12:30 to 14:00. The horizontal tapering at the upper part of the curves for Area #13 and Area #15 correspond to the time interval 8:00 to 9:30 for both curves. The horizontal tapering of the upper part of the Area #15 curve corresponds to the time interval 8:00 to 12:00. Deviations from a linear relation between luminance and Cos i appear to occur during the earlier times of the day.

Two factors have yet to be explored: (1) diurnal changes in the sun's power output, (2) the bidirectional reflectance distribution function for CARC-painted surfaces. These two factors will be explored at a later date.

SUMMARY OF CHROMATICITY STUDY

1. The CIE coordinates of the three different facets measured on the M1A1 shift slightly toward the white light coordinate as the sun moves westward from 8:00 to 14:00 (Table 19). Figure 126 shows the CIE coordinate placement of Area #12, Area #13, Area 15 and grass at 8:00 and 14:00.

2. There is virtually no change in the CIE coordinates for grass from 8:00 to 14:00 (Table 20 and Figure 126).

3. The CIE coordinates measured for the three different tree areas have virtually the same behavior. The value of both the X and Y coordinates continuously decrease from 8:00 to 14:00 (Table 20). The trees have a greater saturation of green than the M1A1 and they show a greater shift toward the white light coordinate from 8:00 to 14:00 (Figure 127).
LUMINANCE OF NEW AND OLD CARC PAINTED SURFACES

The paint plant painted a small steel plate in the same fashion as an M1A1. The steel plate was first sandblasted and then chemically cleaned. The same epoxy primer and green CARC paint was applied to the steel plate as would be used for an M1A1.

The CARC plate was then alternately placed adjacent to Area #12 and Area #15 as shown in Figure 339 and Figure 340. The CARC plate was positioned so that it would have the same slope and azimuth as Area #12 and Area #15.

Diurnal measurements of the luminance from Area #12, Area #15 and the CARC plate positioned adjacent to these areas is given in Table 70. The results of this study are shown graphically in Figure 341, Figure 342 and Figure 343.

Table 70. Luminance of M1A1 Areas (#12 & #15) and CARC Painted Steel Plate

<table>
<thead>
<tr>
<th>TIME</th>
<th>L #12</th>
<th>L #12'</th>
<th>L #15</th>
<th>L #15'</th>
<th>L12/L12'</th>
<th>L15/L15'</th>
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<td>3020</td>
<td>2399</td>
<td>2858</td>
<td>2257</td>
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<td>1.27</td>
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<td>1.25</td>
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<td>2842</td>
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<td>1.21</td>
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<td>2934</td>
<td>2630</td>
<td>2158</td>
<td>1.22</td>
<td>1.24</td>
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<td>2939</td>
<td>2466</td>
<td>1961</td>
<td>1.21</td>
<td>1.26</td>
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<td>2555</td>
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<td>1699</td>
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<td>1668</td>
<td>1394</td>
<td>1.23</td>
<td>1.20</td>
</tr>
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<td>2467</td>
<td>1144</td>
<td>1005</td>
<td>1.26</td>
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<td>515</td>
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<td>503</td>
<td>396</td>
<td>1.31</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Notes: Date: 31 July, 1991
Sky Conditions: Clear Skies
Range - 36 Feet
Readings from Minolta LS-100

L #12 refers to the luminance reading acquired from Area #12 on the M1A1.
L #12' refers to the luminance reading acquired from the CARC painted steel plate when it was positioned adjacent to Area #12 on the M1A1.

L #15 refers to the luminance reading acquired from Area #15 on the M1A1.
L #15' refers to the luminance reading acquired from the CARC painted steel plate when it was positioned adjacent to Area #15 on the M1A1.
Figure 339
Position of CARC-Painted Steel Plate (#12') Near Area #12

Figure 340
Position of CARC-Painted Steel Plate (#15') Near Area #15

197
LUMINANCE OF AREA #12
M1A1 AND CARC-PAINTED STEEL PLATE

TIME OF DAY (31 JULY 91)

- M1A1 #12       + CARC PLATE

Figure 341
198
LUMINANCE OF AREA #15
M1A1 AND CARC-PAINTED STEEL PLATE

TIME OF DAY (31 JULY 91)

M1A1 #15 --- CARC PLATE

Figure 342

199
LUMINANCE RATIOS
M1A1 / CARC-PAINTED STEEL PLATE

TIME OF DAY (31 JULY 91)

Figure 343

200
Luminance of Area #12
MIAI and CARC Painted Steel Plate

Luminance of Area #15
MIAI and CARC Painted Steel Plate

Luminance Ratios
MIAI/CARC Painted Steel Plate

Figure 344

201
ANALYSIS AND SUMMARY OF NEW/OLD CARC SURFACE STUDY

The diurnal luminance graphs (Figure 341 and Figure 342) for the weathered M1A1 CARC-painted surfaces and the newly painted CARC surface look very similar. However, the luminance of the weathered surface was always greater than the newly painted CARC surface. The graph of the luminance ratio of the weathered CARC painted surface to the newly painted CARC surface (Figure 343) shows a nearly straight horizontal line for each of two different facets metered on the M1A1. The luminance ratios, \( L_{17}/L_{12} \) and \( L_{15}/L_{15} \), (weathered/new) is approximately 1.25. In other words, the weathered CARC painted surface is 25 percent brighter than a newly painted CARC surface.

The dip in the graph for Area #15 at 13:30 is due to shading. In hind sight, the position selected adjacent to Area #15 for the CARC plate was a poor choice. The plate rested on a ledge recessed two inches from the plane of Area #15. This position became shaded by turret areas before adjacent Area #15.
GONIOPHOTOMETRIC STUDIES OF A CARC-PAINTED SURFACE

AZIMUTHAL STUDY

PURPOSE

The purpose of this study was to acquire information on the light-distributing properties of a CARC (Chemical Agent Resistant Coating) painted sample illuminated by sunlight; in particular, to determine how luminance readings are affected by changes in azimuthal viewing angle when the altitude of the viewing angle is constant.

PROCEDURE

1. A five foot radius circle was drawn on a horizontal concrete parking lot.
2. A north-south line, determined by a compass, was drawn through the center of the circle.
3. The circumference of the circle was divided into eighteen equal arc lengths.
4. A CARC painted surface was positioned horizontally at the center of the circle.
5. Two metal rods were positioned vertically 12 inches apart in a block of wood.
6. The rods were positioned on one of the azimuth marks so that the shadows cast by the two rods were coincident.

<table>
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<tr>
<th>Azimuth (degree)</th>
<th>Luminance (cd/m²)</th>
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</thead>
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<tr>
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</tr>
<tr>
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<td>3130</td>
</tr>
<tr>
<td>60</td>
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<td>3005</td>
</tr>
<tr>
<td>160</td>
<td>2970</td>
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<td>2968</td>
</tr>
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<td>2999</td>
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<td>340</td>
<td>3975</td>
</tr>
<tr>
<td>360</td>
<td>3703</td>
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</table>

Figure 345:
Experimental Setup For Azimuth Study.
GONIOPHOTOMETRIC RECORD
CARC-PAINTED STEEL PLATE
ILLUMINATION FROM SUN

CARC PLATE SLOPE = 0°; METER SLOPE = 30°

12:00 EDST, 13 AUGUST 1991; 42.5° N, 83° W
SOUTH = 0°, WEST = 90°, NORTH = 180°, EAST = 270°

Figure 346.
7. The LS-100 Minolta Luminance Meter was positioned, with the aid of an angle level, on a tripod at a 30° angle with the horizontal.

8. The luminance meter was positioned so that the two rods appeared as one when sighting through the meter view finder.

9. The positioning of the rods and luminance meter was repeated for each of the eighteen azimuth marks along the perimeter of the circle.

Metering was toward the south when the azimuth was 0°. Azimuth was measured clockwise from the south point.

The time to acquire the data shown in Table 71 was 21 minutes.

The sun's altitude and azimuth on 13 August, 1991 at 12:00 EDT was +55.6° and 315.3° respectfully. The sun's altitude and azimuth on 13 August, 1991 at 12:30 EDT was +59.1° and 327.2° respectfully.

Skies were clear during data acquisition.

SUMMARY

The gloss of a surface is the degree it approaches a mirror surface. The two extreme cases of glossiness occur for Lambertian and specular surfaces. By definition, a Lambertian surface is a perfect reflecting diffuser. The luminance of a Lambertian surface is constant and has no dependence on angle of view. Incident light is distributed equally in every direction. It is the ideal surface of zero gloss. A purely specular surface produces a nonzero luminance value only at the angle of mirror reflection.

Table 71 and Figure 346 illustrate that the CARC painted sample exhibits approximately Lambertian properties for azimuth angles from 60° to 240°. Luminance readings varied by only 108 cd/m² (3.6%) for this range of azimuth angles. This range corresponds to the hemisphere opposite the sun and at right angles to the plane of incidence.

The sample showed intermediate light-distributing properties between Lambertian and specular for azimuth angles from 240° to 60°. The difference between the maximum luminance reading and the minimum luminance reading acquired was 1039 cd/m² (30.1%). As would be expected from a semi-gloss surface, the largest luminance reading acquired (3975 cd/m²) corresponded approximately to an azimuth angle equal to the sun's azimuth.

Figure 346 also illustrates azimuthal symmetry in the sample's light-distributing properties. A line parallel to the incident plane, approximately the 160°-340° line in Figure 346, is the approximate axis of symmetry.
GONIOPHOTOMETRIC READINGS IN THE PLANE OF INCIDENCE

PURPOSE

The purpose of this study was to acquire information on the light distributing properties of a CARC (Chemical Agent Resistant Coating) painted sample illuminated by sunlight; in particular, to determine how luminance readings are affected by changes in the surface altitude of the viewing angle for readings in the plane of incidence.

PROCEDURE

1. A magnet was attached to a camera tripod mount, which, in turn, was attached to a goniometric stand, as shown in Figure 347 below.
2. A CARC-painted steel plate was attached to the magnet, as shown in Figure 348 below.
3. An angle level (Figure 348) was used to set the slope of the CARC-painted sample.
4. A metal rod was attached to a magnet so that the rod was normal to the sample when the magnet was placed on the sample (Figure 348).
5. Two metal rods were positioned vertically, 12 inches apart, in a block of wood (Figure 348).
6. The rods were positioned so that the shadows cast by the two rods were coincident.
7. The CARC-painted sample was rotated until the shadows cast by the two vertical rods were coincident with the shadow cast by the rod normal to the sample's surface (Figure 4).

Figure 347.
Goniometric Support

Figure 348.
Alignment to the Plane of Incidence
8. The LS-100 Minolta Luminance Meter was positioned, with the aid of an angle level, on a tripod at a 20° angle with the horizontal. Figure 349 shows all the equipment used to collect data for this study.

9. The luminance meter was positioned so that the two vertical rods and the rod normal to the sample’s surface appeared as one when sighting through the meter’s view finder.

10. The sample was rotated by 5° increments, in the plane of incidence, for as many angles as allowed by the altitude of the sun and the 20° slope of the luminance meter. This procedure was followed every 30 minutes from 03:00 to 12:30.

The time to acquire data for each 30-minute interval varied between 5 and 15 minutes. The duration depended on the number of measurements available. Frequent adjustments were made to the position of the vertical rods as the sun changed its position relative to the sample. Skies were clear during data acquisition.

Table 72 gives the sun’s altitude and azimuth on 12 August, 1991 for the times data was collected. The data tables; Table 72, Table 73,...Table 79; were constructed by filtering out data pertaining to the same CARC slope for each of the time intervals data was acquired. Positive CARC slopes refer to tilts toward the sun. Negative CARC slopes refer to tilts away from the sun (Figure 350).

The calculation of the angle of incidence of the sun’s rays on the CARC painted surface is shown in Figure 352, \[ \angle i = 90° - (\text{Sun’s Altitude} + \text{CARC Slope}). \]

Figure 349.
Goniometric Equipment for Readings in the Plane of Incidence

207
Table 72. Luminance Readings When Metering Parallel to the Incident Plane, Slope of CARC-Painted Sample = 0°. Luminance Meter Slope = 20°.

<table>
<thead>
<tr>
<th>Sun's Azimuth</th>
<th>Sun's Latitude (°)</th>
<th>Luminance (cd/m²)</th>
<th>EDST</th>
<th>&lt;i</th>
<th>Cos i (cd/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30 267.4 19.7 70.3</td>
<td>0.337 7837</td>
<td>65.3 0.569 7195</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>09:00 272.4 25.2 64.8</td>
<td>0.426 6932</td>
<td>75.3 0.254 5015</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>09:30 277.8 30.7 59.3</td>
<td>0.511 6830</td>
<td>69.8 0.346 5353</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>0.590 5855</td>
<td>58.8 0.518 5926</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10:30 289.9 41.5 48.5</td>
<td>0.662 5134</td>
<td>53.5 0.594 4994</td>
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<td>0.726 5012</td>
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<td>12:00 315.3 55.5 34.5</td>
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<td>0.857 4341</td>
<td>36.0 0.809 4099</td>
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</table>

<i - the angle of incidence of the sun's rays on the CARC painted sample.

Table 73. Luminance Readings When Metering Parallel to the Incident Plane, Slopes of CARC-Painted Sample = 5° and 10°. Luminance Meter Slope = 20°.

<table>
<thead>
<tr>
<th>CARC Slope = 5°</th>
<th>Luminance</th>
<th>CARC Slope = 10°</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDST</td>
<td>&lt;i</td>
<td>Cos i</td>
<td>Luminance (cd/m²)</td>
</tr>
<tr>
<td>08:30 65.3 0.569 7195</td>
<td>60.3 0.496 7291</td>
<td>65.3 0.569 7195</td>
<td>60.3 0.496 7291</td>
</tr>
<tr>
<td>09:00 59.8 0.504 6575</td>
<td>54.8 0.577 6989</td>
<td>59.8 0.504 6575</td>
<td>54.8 0.577 6989</td>
</tr>
<tr>
<td>09:30 54.3 0.584 6432</td>
<td>49.3 0.653 6503</td>
<td>54.3 0.584 6432</td>
<td>49.3 0.653 6503</td>
</tr>
<tr>
<td>10:00 48.8 0.653 5955</td>
<td>43.8 0.721 6238</td>
<td>48.8 0.653 5955</td>
<td>43.8 0.721 6238</td>
</tr>
<tr>
<td>10:30 43.5 0.725 5357</td>
<td>38.5 0.782 5668</td>
<td>43.5 0.725 5357</td>
<td>38.5 0.782 5668</td>
</tr>
<tr>
<td>11:00 38.5 0.783 5080</td>
<td>33.5 0.834 5328</td>
<td>38.5 0.783 5080</td>
<td>33.5 0.834 5328</td>
</tr>
<tr>
<td>11:30 33.7 0.832 5061</td>
<td>28.7 0.877 5291</td>
<td>33.7 0.832 5061</td>
<td>28.7 0.877 5291</td>
</tr>
<tr>
<td>12:00 29.5 0.870 4688</td>
<td>24.5 0.910 4894</td>
<td>29.5 0.870 4688</td>
<td>24.5 0.910 4894</td>
</tr>
<tr>
<td>12:30 26.0 0.898 4528</td>
<td>21.0 0.933 4690</td>
<td>26.0 0.898 4528</td>
<td>21.0 0.933 4690</td>
</tr>
</tbody>
</table>

Table 74. Luminance Readings When Metering Parallel to the Incident Plane, Slopes of CARC-Painted Sample = 15° and -5°. Luminance Meter Slope = 20°.

<table>
<thead>
<tr>
<th>CARC Slope = 15°</th>
<th>Luminance</th>
<th>CARC Slope = -5°</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDST</td>
<td>&lt;i</td>
<td>Cos i</td>
<td>Luminance (cd/m²)</td>
</tr>
<tr>
<td>08:30 55.3 0.569 7195</td>
<td>75.3 0.254 5015</td>
<td>55.3 0.569 7195</td>
<td>75.3 0.254 5015</td>
</tr>
<tr>
<td>09:00 49.8 0.646 6943</td>
<td>69.8 0.346 5353</td>
<td>49.8 0.646 6943</td>
<td>69.8 0.346 5353</td>
</tr>
<tr>
<td>09:30 44.3 0.716 6690</td>
<td>64.3 0.434 4730</td>
<td>44.3 0.716 6690</td>
<td>64.3 0.434 4730</td>
</tr>
<tr>
<td>10:00 38.8 0.779 6345</td>
<td>58.8 0.518 5926</td>
<td>38.8 0.779 6345</td>
<td>58.8 0.518 5926</td>
</tr>
<tr>
<td>10:30 33.5 0.834 5782</td>
<td>53.5 0.594 4994</td>
<td>33.5 0.834 5782</td>
<td>53.5 0.594 4994</td>
</tr>
<tr>
<td>11:00 28.5 0.879 5561</td>
<td>48.5 0.663 4723</td>
<td>28.5 0.879 5561</td>
<td>48.5 0.663 4723</td>
</tr>
<tr>
<td>11:30 23.7 0.915 5177</td>
<td>43.7 0.723 4644</td>
<td>23.7 0.915 5177</td>
<td>43.7 0.723 4644</td>
</tr>
<tr>
<td>12:00 19.5 0.943 4997</td>
<td>39.5 0.771 4264</td>
<td>19.5 0.943 4997</td>
<td>39.5 0.771 4264</td>
</tr>
<tr>
<td>12:30 16.0 0.961 4674</td>
<td>36.0 0.809 4099</td>
<td>16.0 0.961 4674</td>
<td>36.0 0.809 4099</td>
</tr>
</tbody>
</table>
Table 75. Luminance Readings When Metering Parallel to the Incident Plane.

<table>
<thead>
<tr>
<th>Time</th>
<th>CARC Slope = -10°</th>
<th>Luminance</th>
<th>CARC Slope = -15°</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EDST &lt;i</td>
<td>Cos i</td>
<td>(cd/m²)</td>
<td>EDST</td>
</tr>
<tr>
<td>08:30</td>
<td>80.3</td>
<td>0.169</td>
<td>3010</td>
<td>85.3</td>
</tr>
<tr>
<td>09:00</td>
<td>74.8</td>
<td>0.263</td>
<td>3865</td>
<td>79.8</td>
</tr>
<tr>
<td>09:30</td>
<td>69.3</td>
<td>0.385</td>
<td>4507</td>
<td>74.3</td>
</tr>
<tr>
<td>10:00</td>
<td>63.8</td>
<td>0.441</td>
<td>5340</td>
<td>68.8</td>
</tr>
<tr>
<td>10:30</td>
<td>58.5</td>
<td>0.522</td>
<td>6095</td>
<td>63.5</td>
</tr>
<tr>
<td>11:00</td>
<td>53.5</td>
<td>0.595</td>
<td>6899</td>
<td>58.5</td>
</tr>
<tr>
<td>11:30</td>
<td>48.7</td>
<td>0.660</td>
<td>7688</td>
<td>53.7</td>
</tr>
<tr>
<td>12:00</td>
<td>44.5</td>
<td>0.713</td>
<td>4023</td>
<td>49.5</td>
</tr>
<tr>
<td>12:30</td>
<td>41.0</td>
<td>0.754</td>
<td>3860</td>
<td>46.0</td>
</tr>
</tbody>
</table>

Table 76. Luminance Readings When Metering Parallel to the Incident Plane.

<table>
<thead>
<tr>
<th>Time</th>
<th>CARC Slope = -20°</th>
<th>Luminance</th>
<th>CARC Slope = -25°</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EDST &lt;i</td>
<td>Cos i</td>
<td>(cd/m²)</td>
<td>EDST</td>
</tr>
<tr>
<td>08:30</td>
<td>90.0</td>
<td>0.000</td>
<td>661</td>
<td>NA</td>
</tr>
<tr>
<td>09:00</td>
<td>84.8</td>
<td>0.091</td>
<td>1464</td>
<td>89.8</td>
</tr>
<tr>
<td>09:30</td>
<td>79.3</td>
<td>0.186</td>
<td>2309</td>
<td>84.3</td>
</tr>
<tr>
<td>10:00</td>
<td>73.8</td>
<td>0.279</td>
<td>2995</td>
<td>78.8</td>
</tr>
<tr>
<td>10:30</td>
<td>68.5</td>
<td>0.366</td>
<td>2960</td>
<td>73.5</td>
</tr>
<tr>
<td>11:00</td>
<td>63.5</td>
<td>0.447</td>
<td>2968</td>
<td>68.5</td>
</tr>
<tr>
<td>11:30</td>
<td>58.7</td>
<td>0.519</td>
<td>3431</td>
<td>63.7</td>
</tr>
<tr>
<td>12:00</td>
<td>54.5</td>
<td>0.581</td>
<td>3502</td>
<td>59.5</td>
</tr>
<tr>
<td>12:30</td>
<td>51.0</td>
<td>0.629</td>
<td>3320</td>
<td>56.0</td>
</tr>
</tbody>
</table>

Table 77. Luminance Readings When Metering Parallel to the Incident Plane.

<table>
<thead>
<tr>
<th>Time</th>
<th>CARC Slope = -30°</th>
<th>Luminance</th>
<th>CARC Slope = -35°</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EDST &lt;i</td>
<td>Cos i</td>
<td>(cd/m²)</td>
<td>EDST</td>
</tr>
<tr>
<td>08:30</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>09:00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>09:30</td>
<td>89.3</td>
<td>0.013</td>
<td>827</td>
<td>NA</td>
</tr>
<tr>
<td>10:00</td>
<td>83.8</td>
<td>0.108</td>
<td>1403</td>
<td>NA</td>
</tr>
<tr>
<td>10:30</td>
<td>78.5</td>
<td>0.199</td>
<td>1640</td>
<td>83.5</td>
</tr>
<tr>
<td>11:00</td>
<td>73.5</td>
<td>0.285</td>
<td>1964</td>
<td>78.5</td>
</tr>
<tr>
<td>11:30</td>
<td>68.7</td>
<td>0.363</td>
<td>2277</td>
<td>73.7</td>
</tr>
<tr>
<td>12:00</td>
<td>64.5</td>
<td>0.430</td>
<td>2319</td>
<td>69.5</td>
</tr>
<tr>
<td>12:30</td>
<td>61.0</td>
<td>0.484</td>
<td>2277</td>
<td>66.0</td>
</tr>
</tbody>
</table>
Table 8. Luminance Readings When Metering Parallel to the Incident Plane.

<table>
<thead>
<tr>
<th>Time</th>
<th>EDST</th>
<th>Slope</th>
<th>Cos i</th>
<th>Luminance</th>
<th>Slope</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>09:00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>09:30</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10:00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10:30</td>
<td>88.5</td>
<td>0.026</td>
<td>419</td>
<td>88.5</td>
<td>0.027</td>
<td>633</td>
</tr>
<tr>
<td>11:00</td>
<td>83.5</td>
<td>0.114</td>
<td>1100</td>
<td>83.7</td>
<td>0.109</td>
<td>986</td>
</tr>
<tr>
<td>11:30</td>
<td>78.7</td>
<td>0.195</td>
<td>1329</td>
<td>79.5</td>
<td>0.182</td>
<td>1228</td>
</tr>
<tr>
<td>12:00</td>
<td>74.5</td>
<td>0.267</td>
<td>1626</td>
<td>76.0</td>
<td>0.241</td>
<td>1429</td>
</tr>
<tr>
<td>12:30</td>
<td>71.0</td>
<td>0.325</td>
<td>1709</td>
<td>76.0</td>
<td>0.241</td>
<td>1429</td>
</tr>
</tbody>
</table>

Table 79. Luminance Readings When Metering Parallel to the Incident Plane.

<table>
<thead>
<tr>
<th>Time</th>
<th>EDST</th>
<th>Slope</th>
<th>Cos i</th>
<th>Luminance</th>
<th>Slope</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>09:00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>09:30</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10:00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10:30</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>11:00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>11:30</td>
<td>88.7</td>
<td>0.022</td>
<td>606</td>
<td>89.5</td>
<td>0.009</td>
<td>443</td>
</tr>
<tr>
<td>12:00</td>
<td>84.5</td>
<td>0.096</td>
<td>807</td>
<td>86.0</td>
<td>0.069</td>
<td>672</td>
</tr>
<tr>
<td>12:30</td>
<td>81.0</td>
<td>0.156</td>
<td>1054</td>
<td>86.0</td>
<td>0.069</td>
<td>672</td>
</tr>
</tbody>
</table>

Because of small sun altitudes in the early morning hours and a meter slope of 20°, a number of luminance readings were not available.

The range of positive slopes was restricted to values between 5° and 15° because of the 20° meter slope.

The range of negative slopes was restricted by the sun’s altitude.

Figure 350.
Positive and Negative CARC Slopes

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Table 80. Luminance Readings When Metering Parallel to the Incident Plane. Data Arranged According to Metering Angle $\theta$. Luminance Meter Slope = 20°.

<table>
<thead>
<tr>
<th>EDST</th>
<th>i</th>
<th>Luminance</th>
<th>COS i</th>
<th>$\theta$</th>
<th>EDST</th>
<th>i</th>
<th>Luminance</th>
<th>COS i</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00</td>
<td>89.5</td>
<td>443</td>
<td>0.009</td>
<td>75</td>
<td>08:30</td>
<td>90.0</td>
<td>661</td>
<td>0.000</td>
<td>40</td>
</tr>
<tr>
<td>12:30</td>
<td>86.0</td>
<td>679</td>
<td>0.069</td>
<td>75</td>
<td>09:00</td>
<td>84.8</td>
<td>1464</td>
<td>0.091</td>
<td>40</td>
</tr>
<tr>
<td>11:30</td>
<td>88.7</td>
<td>606</td>
<td>0.022</td>
<td>70</td>
<td>09:30</td>
<td>79.3</td>
<td>2309</td>
<td>0.186</td>
<td>40</td>
</tr>
<tr>
<td>12:00</td>
<td>84.5</td>
<td>807</td>
<td>0.096</td>
<td>70</td>
<td>10:00</td>
<td>73.8</td>
<td>2995</td>
<td>0.279</td>
<td>40</td>
</tr>
<tr>
<td>12:30</td>
<td>81.0</td>
<td>1054</td>
<td>0.156</td>
<td>70</td>
<td>10:30</td>
<td>68.5</td>
<td>2960</td>
<td>0.366</td>
<td>40</td>
</tr>
<tr>
<td>11:00</td>
<td>88.5</td>
<td>633</td>
<td>0.027</td>
<td>65</td>
<td>11:00</td>
<td>63.5</td>
<td>2962</td>
<td>0.447</td>
<td>40</td>
</tr>
<tr>
<td>11:30</td>
<td>83.7</td>
<td>986</td>
<td>0.109</td>
<td>65</td>
<td>11:30</td>
<td>58.7</td>
<td>3431</td>
<td>0.519</td>
<td>40</td>
</tr>
<tr>
<td>12:00</td>
<td>79.5</td>
<td>1228</td>
<td>0.182</td>
<td>65</td>
<td>12:00</td>
<td>54.5</td>
<td>3502</td>
<td>0.561</td>
<td>40</td>
</tr>
<tr>
<td>12:30</td>
<td>76.0</td>
<td>1429</td>
<td>0.241</td>
<td>65</td>
<td>12:30</td>
<td>51.0</td>
<td>3320</td>
<td>0.629</td>
<td>40</td>
</tr>
<tr>
<td>10:30</td>
<td>88.5</td>
<td>419</td>
<td>0.026</td>
<td>60</td>
<td>08:30</td>
<td>85.3</td>
<td>1693</td>
<td>0.082</td>
<td>35</td>
</tr>
<tr>
<td>11:00</td>
<td>83.5</td>
<td>1100</td>
<td>0.114</td>
<td>60</td>
<td>09:00</td>
<td>79.8</td>
<td>2563</td>
<td>0.178</td>
<td>35</td>
</tr>
<tr>
<td>11:30</td>
<td>78.7</td>
<td>1329</td>
<td>0.195</td>
<td>60</td>
<td>09:30</td>
<td>74.3</td>
<td>3177</td>
<td>0.271</td>
<td>35</td>
</tr>
<tr>
<td>12:00</td>
<td>74.5</td>
<td>1626</td>
<td>0.267</td>
<td>60</td>
<td>10:00</td>
<td>68.8</td>
<td>3967</td>
<td>0.361</td>
<td>35</td>
</tr>
<tr>
<td>12:30</td>
<td>71.0</td>
<td>1709</td>
<td>0.325</td>
<td>60</td>
<td>10:30</td>
<td>63.5</td>
<td>4047</td>
<td>0.446</td>
<td>35</td>
</tr>
<tr>
<td>10:00</td>
<td>88.8</td>
<td>728</td>
<td>0.020</td>
<td>55</td>
<td>11:00</td>
<td>58.5</td>
<td>4116</td>
<td>0.523</td>
<td>35</td>
</tr>
<tr>
<td>10:30</td>
<td>83.5</td>
<td>1118</td>
<td>0.113</td>
<td>55</td>
<td>11:30</td>
<td>53.7</td>
<td>4787</td>
<td>0.592</td>
<td>35</td>
</tr>
<tr>
<td>11:00</td>
<td>78.5</td>
<td>1505</td>
<td>0.200</td>
<td>55</td>
<td>12:00</td>
<td>49.5</td>
<td>3863</td>
<td>0.649</td>
<td>35</td>
</tr>
<tr>
<td>11:30</td>
<td>73.7</td>
<td>1705</td>
<td>0.280</td>
<td>55</td>
<td>12:30</td>
<td>46.0</td>
<td>3582</td>
<td>0.694</td>
<td>35</td>
</tr>
<tr>
<td>12:00</td>
<td>69.5</td>
<td>1924</td>
<td>0.350</td>
<td>55</td>
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$s =$ slope of CARC sample  
$\theta =$ Angle between Meter and Sample  
$\theta =$ 20° - s

Figure 351. Calculation of Meter Angle $\theta$
Table 81. Luminance Readings Parallel to the Incident Plane Continued.
Data Arranged According to Metering Angle $\theta$. Luminance Meter Slope = 20$^\circ$.

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<th>COS $\theta$</th>
<th>$\theta$</th>
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<td>4690</td>
<td>0.898</td>
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</table>

\[ s = \text{CARC slope}, \quad A = \text{sun's altitude} \]
\[ i = 90^\circ - (A + s) \]

Figure 352.
Calculation of the Angle of Incidence

\[ \text{Area B} = \frac{\text{Area A}}{\cos i} \]

Figure 353.
Area B = Area A / Cos i
SUN'S RAYS ON CARC-PAINTED SURFACE
METERING AT 20 DEGREES FROM HORIZONTAL
AND TOWARD SUN

Figure 354.
GONIOPHOTOMETRIC RECORD
Sun's Rays Incident on CARC Paint
Measuring in the Plane of Incidence

LUMINANCE ($10^4 \text{ cd/m}^2$)

Figure 367

GONIOPHOTOMETRIC RECORD
Sun's Rays Incident on CARC Paint
Measuring in the Plane of Incidence

LUMINANCE ($10^4 \text{ cd/m}^2$)

Figure 368

GONIOPHOTOMETRIC RECORD
Sun's Rays Incident on CARC Paint
Measuring in the Plane of Incidence

LUMINANCE ($10^4 \text{ cd/m}^2$)

Figure 369

GONIOPHOTOMETRIC RECORD
Sun's Rays Incident on CARC Paint
Measuring in the Plane of Incidence

LUMINANCE ($10^4 \text{ cd/m}^2$)

Figure 370

217
SUMMARY

The luminance readings for reflected sunlight from a Lambertian surface for the same metering angle from the surface would all be identical. However, the luminance readings should be different for different metering angles. For a Lambertian surface, luminance should be directly proportional to the cosine of the angle of incidence. Figure 353 illustrates how the light energy from the sun per unit area decreases with an increase in the angle of incidence. The energy per unit area is directly proportional to the cosine of the angle of incidence. This is the same principle which produces the seasons. Figure 354 is a plot of all the luminance readings acquired as a function of Cos i. Since this graph does not plot as a straight line, the surface of the CARC sample is not perfectly Lambertian.

Table 80 and Table 81 show the data from Table 72, Table 73, ...Table 79, arranged according to metering angle θ. Figure 351 shows how these metering angles were calculated. The graphs of Figure 355, Figure 356, Figure 357 and Figure 358 consist of sets of points which correspond to the same metering angle. For luminance readings in the plane of incidence, these four graphs suggest a surface microstructure which produces an increase in luminance for angles of incidence from 90° to 60° but a decrease in luminance for angles of incidence from 60° to 0°. These results are a bit peculiar since the light energy per unit area should increase with a decrease in the angle of incidence (Figure 353). Also, luminance readings are higher for smaller metering angles; metering closer to the surface.

The graphs of Figure 359, Figure 360,...Figure 370 show luminance as a function of metering angle from the CARC-painted surface for similar angles of incidence (within a few degrees). The circular plots correspond to goniophotometric records of a Lambertian surface. The line extending outward from the origin past the Lambertian record indicates the approximate angle of incidence for which the data applies. The graphs of Figure 364, Figure 365,...Figure 370 dramatically show that higher luminance readings are acquired for smaller metering angles; metering closer to the surface; rather than in the direction of mirror reflection when metering is in the plane of incidence.

There was no control over the source of illumination, the sun. The sun continuously changed its azimuth and altitude and time was required to move the meter so that it was always close to being in the plane of incidence. Little time was available to also change the 20° meter slope. Therefore, many gaps occur in the data. In particular, it would be helpful to have goniophotometric data for angles of incidence from 60° to 90° with corresponding meter angles from 5° to 15° and angles of incidence from 0° to 60° with corresponding metering angles from 40° to 90°.
GONIOPHOTOMETRIC READINGS PERPENDICULAR TO THE PLANE OF INCIDENTE

PURPOSE

The purpose of this study was to acquire information on the light distributing properties of a CARC- (Chemical Agent Resistant Coating) painted sample illuminated by sunlight; in particular, to determine how luminance readings are affected by changes in the surface altitude of the viewing angle for readings perpendicular to the plane of incidence.

PROCEDURE

1. A magnet was attached to a camera tripod mount, which, in turn, was attached to a goniometric stand (Figure 347).
2. A CARC-painted steel plate was attached to the magnet (Figure 348).
3. An angle level (Figure 348) was used to set the slope of the CARC-painted sample.
4. A metal rod was attached to a magnet so that the rod was normal to the sample when the magnet was placed on the sample (Figure 348).
5. Two metal rods were positioned vertically, 12 inches apart, in a block of wood (Figure 348).
6. The rods were positioned so that the shadows cast by the two rods were coincident.
7. The CARC painted sample was rotated until the shadows cast by the two vertical rods were coincident with the shadow cast by the rod normal to the sample’s surface (Figure 348).
8. A long, straight metal tube was placed on the ground parallel to the two rods used to establish the plane of incidence.
9. The wood block holding the two rods was repositioned perpendicular to the metal tube (perpendicular to the sun’s rays).
10. The LS-100 Minolta Luminance Meter was positioned, with the aid of an angle level, on a tripod at a 20° angle with the horizontal. Figure 349 shows all the equipment used to collect data for this study.
11. The luminance meter was positioned so that the two vertical rods appeared as one when sighting through the meter’s view finder.
12. The sample was rotated by 5° increments, in the plane of incidence, for as many angles as allowed by the altitude of the sun and the 20° slope of the luminance meter. This procedure was followed every 30 minutes from 08:00 to 12:30.

The time to acquire data for each 30 minute interval varied between five minutes and 15 minutes. The duration depended on the number of measurements available. Frequent adjustments were made to the position of the vertical rods as the sun changed its position relative to the sample.

Skies were clear during data acquisition.

Table 72 gives the sun’s altitude and azimuth on 12 August, 1991 for the times data was collected. The data tables, Table 82, Table 83 and Table 84, were constructed by filtering out data pertaining to the same CARC slope for each of the time intervals data was acquired.
Positive CARC slopes refer to tilts toward the sun. Negative CARC slopes refer to tilts away from the sun (Figure 350). The calculation of the angle of incidence of the sun’s rays on the CARC-painted surface is shown in Figure 352, \( < \theta = 90^\circ \) - (Sun's Altitude + CARC Slope).

Table 82. Luminance Readings When Metering Perpendicular to the Incident Plane.
CARC Surface Slopes: \( \phi = 0^\circ, 5^\circ, 10^\circ, 15^\circ, 20^\circ \) and \( 25^\circ \).
Luminance Meter Slope = 20°.

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<th>Latitude: 42.5°</th>
</tr>
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<table>
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<th>( \phi = 5^\circ )</th>
<th>Luminance</th>
<th>( \phi = 10^\circ )</th>
<th>Luminance</th>
<th>( \phi = 15^\circ )</th>
<th>Luminance</th>
<th>( \phi = 20^\circ )</th>
<th>Luminance</th>
<th>( \phi = 25^\circ )</th>
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<td>Cos ( \theta )</td>
<td>(cd/m(^2))</td>
<td>Cos ( \theta )</td>
<td>(cd/m(^2))</td>
<td>Cos ( \theta )</td>
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Table 83. Luminance Readings When Metering Perpendicular to the Incident Plane.
CARC Surface Slopes: $\phi = 30^\circ$, 35°, 0°, -5°, -10°, and -15°.
Luminance Meter Slope = 20°.

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<td>Luminance (cd/m²)</td>
<td>$\cos \theta$</td>
<td>Luminance (cd/m²)</td>
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<td>53.5 (0.354)</td>
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<td>44.5 (0.713)</td>
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<tr>
<td>09:00</td>
<td>74.8 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
<tr>
<td>09:30</td>
<td>69.3 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
<tr>
<td>10:00</td>
<td>74.8 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
<tr>
<td>10:30</td>
<td>69.3 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
<tr>
<td>11:00</td>
<td>74.8 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
<tr>
<td>11:30</td>
<td>69.3 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
<tr>
<td>12:00</td>
<td>69.3 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
<tr>
<td>12:30</td>
<td>69.3 (0.263)</td>
<td>63.8 (0.341)</td>
<td>53.5 (0.354)</td>
<td>48.7 (0.660)</td>
<td>44.5 (0.713)</td>
</tr>
</tbody>
</table>

Note: An explanation of $\phi$ is given in Figure 350.
Table 84. Luminance Readings When Metering Perpendicular to the Incident Plane.
CARC Surface Slopes: $\phi = -20^\circ$, -25°, -30°, -35°, -40°, -45°, -50 and -55°.
Luminance Meter Slope = 20°.

<table>
<thead>
<tr>
<th>$\phi = -20^\circ$</th>
<th>Luminance</th>
<th>$\phi = -25^\circ$</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDST</td>
<td>Cos $i$</td>
<td>(cd/m²)</td>
<td>Cos $i$</td>
</tr>
<tr>
<td>09:00</td>
<td>84.8</td>
<td>0.091</td>
<td>89.8</td>
</tr>
<tr>
<td>09:30</td>
<td>79.3</td>
<td>0.186</td>
<td>84.5</td>
</tr>
<tr>
<td>10:00</td>
<td>80.8</td>
<td>0.279</td>
<td>78.8</td>
</tr>
<tr>
<td>10:30</td>
<td>86.5</td>
<td>0.366</td>
<td>73.5</td>
</tr>
<tr>
<td>11:00</td>
<td>63.5</td>
<td>0.447</td>
<td>68.5</td>
</tr>
<tr>
<td>11:30</td>
<td>52.7</td>
<td>0.519</td>
<td>63.7</td>
</tr>
<tr>
<td>12:00</td>
<td>54.5</td>
<td>0.581</td>
<td>59.5</td>
</tr>
<tr>
<td>12:30</td>
<td>51.0</td>
<td>0.529</td>
<td>56.0</td>
</tr>
</tbody>
</table>
CALCULATION OF METER ANGLE $\theta$

As the CARC sample was rotated through angle $\phi$, the angle $\theta$ (meter angle) between the meter direction and the CARC surface varied. Figure 371 illustrates the geometry of the situation. The derivation of the meter angle $\theta$ follows:

$\phi$ is the angle the CARC sample is rotated about the x-axis. 

$M$ is a unit vector representing a reflected ray of sun light toward the luminance meter.

$$M = \cos 20^\circ \mathbf{i} + \sin 20^\circ \mathbf{k}$$

$N$ is a vector normal to the CARC sample and through the tip of the unit vector $M$. 

$R$ is a position vector to point $B$.

The coordinates of the points $A$ and $C$ are $A(\cos 20^\circ, 0, \sin 20^\circ)$ and $C(\cos 20^\circ, 0, 0)$. 

Since $AC = \sin 20^\circ$ and $CB = \sin 20^\circ \sin \phi$, the coordinates of point $B$ are $B(\cos 20^\circ, \sin 20^\circ \sin \phi \cos \phi, \sin 20^\circ \sin^2 \phi)$. Therefore,

$$R = \cos 20^\circ \mathbf{i} + \sin 20^\circ \sin \phi \cos \phi \mathbf{j} + \sin 20^\circ \sin^2 \phi \mathbf{k}$$

Since $R \cdot M = |R| |M| \cos \theta = \cos^2 20^\circ + \sin^2 20^\circ \sin^2 \phi$,

$$\cos \theta = (\cos^2 20^\circ + \sin^2 20^\circ \sin^2 \phi)^{1/2}$$

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20.0</td>
</tr>
<tr>
<td>5</td>
<td>19.9</td>
</tr>
<tr>
<td>10</td>
<td>19.7</td>
</tr>
<tr>
<td>15</td>
<td>19.3</td>
</tr>
<tr>
<td>20</td>
<td>18.8</td>
</tr>
<tr>
<td>25</td>
<td>18.1</td>
</tr>
<tr>
<td>30</td>
<td>17.2</td>
</tr>
<tr>
<td>35</td>
<td>16.3</td>
</tr>
<tr>
<td>40</td>
<td>15.2</td>
</tr>
<tr>
<td>45</td>
<td>14.0</td>
</tr>
<tr>
<td>50</td>
<td>12.7</td>
</tr>
<tr>
<td>55</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Table 85.

Figure 371. 
Geometry for Calculating Meter Angle $\theta$
SUN'S RAYS ON CARC-PAINTED SURFACE
METERING AT 20 DEGREES FROM HORIZONTAL
AND PERPENDICULAR TO SUN'S AZIMUTH

Figure 372.

224
SUN'S RAYS ON CARC PAINTED SURFACE
METEoric AT 30 DEGREES FROM HORIZONTAL
AND PERPENDICULAR TO SUN'S AZIMUTH

SUN'S RAYS ON CARC PAINTED SURFACE
METEoric AT 30 DEGREES FROM HORIZONTAL
AND PERPENDICULAR TO SUN'S AZIMUTH

Figure 373.

Figure 374.

SUN'S RAYS ON CARC PAINTED SURFACE
METEoric AT 30 DEGREES FROM HORIZONTAL
AND PERPENDICULAR TO SUN'S AZIMUTH

SUN'S RAYS ON CARC PAINTED SURFACE
METEoric AT 30 DEGREES FROM HORIZONTAL
AND PERPENDICULAR TO SUN'S AZIMUTH

Figure 375.

Figure 376.
SUMMARY

Figure 372 is a plot of all the luminance readings acquired as a function of Cos i when metering was perpendicular to the plane of incidence. The graphs of Figure 373, Figure 374, Figure 377 consist of sets of points from Figure 372 which correspond to the same CARC surface slope $\phi$. Each set of points for each CARC surface slope plots nearly as a straight line. This suggests a Lambertian type surface when metering perpendicular to the plane of incidence.

As the CARC sample was rotated, the angle between the sample and the metering direction changed (Figure 371). As $\phi$ increased, $\theta$ decreased (Table 85). In general, slightly larger luminance readings were acquired for larger CARC surface slopes (for $\phi = 0^\circ$ to $\phi = -55^\circ$). This corresponds to smaller metering angles $\theta$ (Table 85). Similar results, but more dramatic, were obtained when metering in the plane of incidence. Luminance readings are higher than what would be predicted for a Lambertian surface when metering closer to the surface of the CARC sample.

In the previous study, where metering was in the plane of incidence, a decrease in luminance was observed for decreasing angles of incidence from $60^\circ$ to $0^\circ$ for the same metering angle. This observation is the opposite of what would be expected, since a decrease in the angle of incidence produces more energy per area. This peculiar behavior was not observed when metering perpendicular to the incident plane.
LUMINANCE FROM A CARC PAINTED SAMPLE USING XENON LIGHT

PURPOSE

The purpose of this study was to acquire information on the light-distributing properties of a CARC-(Chemical Agent Resistant Coating) painted sample illuminated by an artificial Xenon light source; in particular, to determine how luminance readings are affected by changes in the angle of incidence. Additionally, this study determines how luminance readings are affected by changes in the meter-sample angle.

PROCEDURES

1. A Xenon light source was mounted at one end of a wood board.
2. A three inch diameter lens was clamped at the other end of the board so that light leaving the lens was collimated.
3. The wood board was mounted on a tripod and adjusted, with the aid of an angle level, to produce a 40° slope (Figure 378 and Figure 379, \( \gamma = 40^\circ \)).
4. A contact print of an 8" diameter protractor was made on an 8" X 10" sheet of photographic paper.
5. The protractor print was positioned on a horizontal, granite, holographic table (Figure 379).
6. Two vertical rods were placed on the protractor print; one at the 0° mark and the other at the 180° mark.
7. The protractor print was rotated so that collimated light from the Xenon source produced coincident shadows of the two vertical rods. The protractor print was taped to the table in this position.
8. One of the two vertical rods was positioned on the 40° mark and the other was positioned on the 220° mark.

Figure 378

Figure 379
9. The LS-100 luminance meter, secured to a tripod, was positioned so that the two rods appeared as one rod while sighting through the meter’s view finder.

10. A CARC-painted steel plate was positioned vertically on the protractor print along various lines through the center of the protractor while luminance readings were acquired.

Table 86. Luminance Readings from a CARC-painted Sample using a Xenon Light Source. Linear polarizer in front of source. Polarization axis horizontal. O.D. = 0.50 Xenon light source slope = 40°. Xenon Azimuth = 0°. α = 40°.

<table>
<thead>
<tr>
<th>θ</th>
<th>i</th>
<th>Cos θ</th>
<th>cd/m²</th>
<th>cd/m²</th>
<th>cd/m²</th>
<th>cd/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>82.4</td>
<td>0.133</td>
<td>0.956</td>
<td>0.906</td>
<td>0.951</td>
<td>0.995</td>
</tr>
<tr>
<td>20</td>
<td>74.8</td>
<td>0.262</td>
<td>1.654</td>
<td>1.626</td>
<td>1.716</td>
<td>1.750</td>
</tr>
<tr>
<td>30</td>
<td>67.5</td>
<td>0.383</td>
<td>2.252</td>
<td>2.225</td>
<td>2.331</td>
<td>2.374</td>
</tr>
<tr>
<td>40</td>
<td>60.5</td>
<td>0.492</td>
<td>2.792</td>
<td>2.778</td>
<td>2.865</td>
<td>2.905</td>
</tr>
<tr>
<td>50</td>
<td>54.1</td>
<td>0.587</td>
<td>3.466</td>
<td>3.276</td>
<td>3.330</td>
<td>3.380</td>
</tr>
<tr>
<td>60</td>
<td>48.4</td>
<td>0.663</td>
<td>3.892</td>
<td>3.684</td>
<td>3.744</td>
<td>3.792</td>
</tr>
<tr>
<td>70</td>
<td>44.0</td>
<td>0.720</td>
<td>4.259</td>
<td>4.006</td>
<td>4.079</td>
<td>4.183</td>
</tr>
<tr>
<td>80</td>
<td>41.0</td>
<td>0.754</td>
<td>4.409</td>
<td>4.163</td>
<td>4.252</td>
<td>4.377</td>
</tr>
<tr>
<td>90</td>
<td>40.0</td>
<td>0.766</td>
<td>4.463</td>
<td>4.438</td>
<td>4.434</td>
<td>4.522</td>
</tr>
</tbody>
</table>

Table 87. Luminance Readings from a CARC-painted Sample using a Xenon Light Source. Unpolarized light. Xenon light source slope = 0°. Xe Azimuth = 0°. δ = 0°.

<table>
<thead>
<tr>
<th>θ</th>
<th>i</th>
<th>Cos θ</th>
<th>α = 40°</th>
<th>α = 60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>80.0</td>
<td>0.174</td>
<td>4.110</td>
<td>4.028</td>
</tr>
<tr>
<td>20</td>
<td>70.0</td>
<td>0.342</td>
<td>7.345</td>
<td>7.455</td>
</tr>
<tr>
<td>30</td>
<td>60.0</td>
<td>0.500</td>
<td>9.985</td>
<td>10.640</td>
</tr>
<tr>
<td>40</td>
<td>50.0</td>
<td>0.643</td>
<td>12.320</td>
<td>13.740</td>
</tr>
<tr>
<td>50</td>
<td>40.0</td>
<td>0.766</td>
<td>14.720</td>
<td>16.730</td>
</tr>
<tr>
<td>60</td>
<td>30.0</td>
<td>0.866</td>
<td>17.020</td>
<td>19.650</td>
</tr>
<tr>
<td>70</td>
<td>20.0</td>
<td>0.940</td>
<td>19.930</td>
<td>19.770</td>
</tr>
<tr>
<td>80</td>
<td>10.0</td>
<td>0.985</td>
<td>19.820</td>
<td>20.050</td>
</tr>
<tr>
<td>90</td>
<td>0.0</td>
<td>1.000</td>
<td>19.650</td>
<td>20.430</td>
</tr>
</tbody>
</table>
DERIVATION OF ANGLE OF INCIDENCE \( i \)

Let \( N \) represent a unit vector normal to the sample:

\[
N = \sin \psi \, \mathbf{i} + \cos \psi \, \mathbf{j}.
\]

Let \( I \) represent a unit vector in the direction of an incident Xenon light ray:

\[
I = \cos 40^\circ \, \mathbf{i} + \sin 40^\circ \, \mathbf{j}.
\]

\[ N \cdot I = \cos i = \cos 40^\circ \sin \psi, \]

where angle \( i \) is the angle of incidence.

\[
\cos i = \cos 40^\circ \sin \psi
\]

DERIVATION OF METER SAMPLE ANGLE \( \beta \)

Let \( R \) represent a unit position vector in the plane of the sample and with the same slope as the meter (Figure 380 and Figure 381):

\[
R = -\cos \delta \cos \psi \, \mathbf{i} + \cos \delta \sin \psi \, \mathbf{j} + \sin \delta \, \mathbf{k}
\]

Let \( L \) represent a unit position vector in the direction of the luminance readings:

\[
L = \cos \delta \cos \alpha \, \mathbf{i} + \cos \delta \sin \alpha \, \mathbf{j} + \sin \delta \, \mathbf{k}
\]

\[
R \cdot L = \cos \beta = -\cos^2 \delta \cos \psi \cos \alpha + \cos^2 \delta \sin \psi \sin \alpha + \sin^2 \delta
\]

\[
\cos \beta = -\cos^2 \delta \cos (180 - [\psi + \alpha]) + \sin^2 \delta
\]
Table 58. Angles (β) Between Meter and Sample

<table>
<thead>
<tr>
<th>α</th>
<th>β</th>
<th>β</th>
<th>β</th>
<th>β</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>130</td>
<td>126.4</td>
<td>116.8</td>
<td>103.4</td>
<td>110</td>
</tr>
<tr>
<td>20</td>
<td>120</td>
<td>117.1</td>
<td>108.9</td>
<td>97.2</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>110</td>
<td>107.6</td>
<td>100.7</td>
<td>90.4</td>
<td>90</td>
</tr>
<tr>
<td>40</td>
<td>100</td>
<td>97.9</td>
<td>92.1</td>
<td>83.1</td>
<td>80</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>88.3</td>
<td>83.3</td>
<td>75.5</td>
<td>70</td>
</tr>
<tr>
<td>60</td>
<td>80</td>
<td>78.5</td>
<td>74.3</td>
<td>67.7</td>
<td>60</td>
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<tr>
<td>70</td>
<td>70</td>
<td>68.8</td>
<td>65.2</td>
<td>59.6</td>
<td>50</td>
</tr>
<tr>
<td>80</td>
<td>60</td>
<td>59.0</td>
<td>56.0</td>
<td>51.3</td>
<td>40</td>
</tr>
<tr>
<td>90</td>
<td>50</td>
<td>49.2</td>
<td>46.8</td>
<td>42.9</td>
<td>30</td>
</tr>
</tbody>
</table>

SUMMARY

The importance of this study arises from the fact that sky conditions do not influence the final results. Data was acquired in a darkroom setting with a Xenon light source as the only source of illumination. Light reflected from the apparatus and the room's walls were the only other source of radiation. Also, the range of luminance readings acquired in this study (1 cd/m² - 24 cd/m²), using a Xenon light source, were considerably smaller than those acquired in other studies (400 cd/m² - 7000 cd/m²) using the sun as a source of light.

There were two parts to this study. In the first, measurements were made outside the plane of incidence. In the second, measurements were made in the plane of incidence.

Table 86 and the graph of Figure 383 summarize the results obtained when metering was outside the plane of incidence (sample in a vertical plane; Xe source slope = 40°, azimuth = 0°; meter slopes of 0°, 10°, 20° and 30° with azimuth = 40°). The graph of Figure 383 shows a near-perfect direct proportion between luminance and the cosine of the angle of incidence for the CARC-painted sample. This graph does not suggest any luminance dependence on the meter-sample angle β. Even though the range of β is from 40° to 130° (Table 88), there is no observable deviation in the direct proportion between the luminance and Cos i. The sets of points for each of the four meter slopes, 0°, 10°, 20° and 30°, are nearly all coincident.
These results support the following conclusions when metering outside the plane of incidence:

1. The light-distributing properties of the CARC-painted sample produces luminance readings which would be obtained from a Lambertian type surface when metering is outside the plane of incidence.

2. Light energy per unit area is directly proportional to the cosine of the angle of incidence for a collimated light beam incident on the CARC-painted sample, just as it would be for a perfect diffuse reflector (Lambertian surface).

In the second part of this study, luminance measurements were made in the plane of incidence. Changes in the angle of incidence were made by rotating the sample in a horizontal plane while keeping the direction of the Xenon light source and the direction of the luminance meter constant. Figure 382 shows the geometry used for these measurements.

Table 87 and the graph of Figure 384 summarize the results obtained when metering was in the plane of incidence (sample in a vertical plane; Xenon source slope = 0°, azimuth = 0°; LS-100 meter slope = 0°, azimuth = 40° and 60°). The two plots of Figure 384 (meter azimuth = 40° and 60°) are straight lines except for measurements acquired near the mirror reflection angle ($\psi = 60°$, see Table 83). The CARC-painted sample has light-distributing properties similar to a Lambertian surface when luminance measurements are away from the direction of mirror reflection. However, it has light-distributing properties similar to a semi-gloss surface when luminance measurements are near the direction of mirror reflection. If the CARC-painted sample was a perfect diffuser, the two plots of Figure 384 would be straight lines and the plots would also be coincident.
GONIOPHOTOMETRIC STUDY
CARC-PAINTED SAMPLE
POLARIZED Xe LIGHT SOURCE

Figure 383.

232
GONIOPHOTOMETRIC STUDY
CARC-PAINTED SAMPLE
UNPOLARIZED Xe LIGHT SOURCE

CARC sample in vertical plane.
Xe slope = 0°, azimuth = 0°.
LS-100 meter slope = 0°.

\[ \cos i \]

Meter Azimuth = 40
+----+ Meter Azimuth = 60

Figure 384.
POLARIZATION AXIS OF REFLECTED WHITE LIGHT FROM A CARC-PAINTED SAMPLE

PURPOSE

The purpose of this study was to acquire information on the polarization properties of a CARC-(Chemical Agent Resistant Coating) painted sample illuminated by a collimated Xenon light source; in particular, to determine how the degree of polarization and the polarization angle are affected by changes in azimuthal viewing angle when the altitude of the viewing angle is constant.

PROCEDURES

1. A Xenon light source was mounted at one end of a wood board.
2. A three inch diameter lens was clamped at the other end of the board so that light leaving the lens was collimated.
3. A linear polarizer attached to an adjustable ring, to change the polarization angle \( \theta \), was positioned in front of the collimating lens.
4. The wood board was mounted on a tripod and adjusted, with the aid of an angle level, to produce a 40° slope (Figure 385 and Figure 386, \( \gamma = 40^\circ \)).
5. A contact print of an eight inch diameter protractor was made on an 8" X 10" sheet of photographic paper.
6. The protractor print was positioned on a horizontal, granite, holographic table (Figure 379).
7. Two vertical rods were placed on the protractor print; one at the 0° mark and the other at the 180° mark.
8. The protractor print was rotated so that collimated light from the Xenon source produced coincident shadows of the two vertical rods. The protractor print was taped to the table in this position.

\[ \text{Figure 385} \quad \text{Figure 386} \]
9. A 3/4" X 2" X 3' wooden board was placed across the protractor print at 20° intervals and pieces of tape were positioned on the table at opposite ends of the board.

10. A six inch tube with a polarization axis finder at one end was mounted on a 35 mm camera. A 4" X 1" mirror was taped to the top of the tube as shown in Figure 388 and Figure 389.

11. The azimuth angle \( \alpha \) (Figure 385) of the camera's line of sight was obtained through the use of the mirror (Figure 388 and Figure 389). The block of wood was positioned at the desired azimuth. The camera was then positioned so that the image of the edge of the wood and the wood edge were coincident, as shown in Figure 389.

12. The azimuth angle \( \alpha \) was varied from 180° to 20°.

13. The transmission axis of the linear polarizer was horizontal when \( \theta = 0^\circ \) (Figure 387). The linear polarizer was rotated clockwise, when looking toward the Xenon light source, in 10° increments from 0° to 90° for each azimuth angle \( \alpha \).

Figure 387.

Figure 388

Figure 389

Figure 390, Figure 391,... Figure 394 show the results of this study. See Appendix B for an interpretation of the wedge shaped patterns.
CARC-Painted Sample Viewed Through a Polarization Axis Finder Using Xenon Light Source. Xe Slope = 40°, Camera Slope = 40° and CARC-Painted Sample in a Horizontal Plane.

\[ \alpha = 180^\circ \]

\[ \alpha = 160^\circ \]

Figure 390.
CARC-Painted Sample Viewed Through a Polarization Axis Finder Using Xenon Light Source. Xe Slope = 40°, Camera Slope = 40° and CARC-Fainted Sample in a Horizontal Plane.

\[ \alpha = 140° \]

\[ \theta = 0° \quad \theta = 10° \quad \theta = 20° \quad \theta = 30° \quad \theta = 40° \]

\[ \theta = 50° \quad \theta = 60° \quad \theta = 70° \quad \theta = 80° \quad \theta = 90° \]

\[ \alpha = 120° \]

\[ \theta = 0° \quad \theta = 10° \quad \theta = 20° \quad \theta = 30° \quad \theta = 40° \]

\[ \theta = 50° \quad \theta = 60° \quad \theta = 70° \quad \theta = 80° \quad \theta = 90° \]

Figure 391.
CARC-Painted Sample Viewed Through a Polarization Axis Finder Using Xenon Light Source. Xe Slope = 40°, Camera Slope = 40° and CARC-Painted Sample in a Horizontal Plane.

\[ \alpha = 100^\circ \]

\[ \theta = 0^\circ, \ 10^\circ, \ 20^\circ, \ 30^\circ, \ 40^\circ \]

\[ \theta = 50^\circ, \ 60^\circ, \ 70^\circ, \ 80^\circ, \ 90^\circ \]

\[ \alpha = 80^\circ \]

\[ \theta = 0^\circ, \ 10^\circ, \ 20^\circ, \ 30^\circ, \ 40^\circ \]

\[ \theta = 50^\circ, \ 60^\circ, \ 70^\circ, \ 80^\circ, \ 90^\circ \]

Figure 392.
CARC-Painted Sample Viewed Through a Polarization Axis Finder Using Xenon Light Source. Xe Slope = 40°, Camera Slope = 40° and CARC-Painted Sample in a Horizontal Plane.

\[ \alpha = 60° \]

\[ \theta = 0° \quad \theta = 10° \quad \theta = 20° \quad \theta = 30° \quad \theta = 40° \]

\[ \theta = 50° \quad \theta = 60° \quad \theta = 70° \quad \theta = 80° \quad \theta = 90° \]

\[ \alpha = 40° \]

\[ \theta = 0° \quad \theta = 10° \quad \theta = 20° \quad \theta = 30° \quad \theta = 40° \]

\[ \theta = 50° \quad \theta = 60° \quad \theta = 70° \quad \theta = 80° \quad \theta = 90° \]

Figure 393.
CARC-Painted Sample Viewed Through a Polarization Axis Finder Using Xenon Light Source. Xe Slope = 40°, Camera Slope = 40° and CARC-Painted Sample in a Horizontal Plane.

\[ \alpha = 20° \]

\[ \begin{align*}
\theta &= 0° & \theta &= 10° & \theta &= 20° & \theta &= 30° & \theta &= 40° \\
\theta &= 50° & \theta &= 60° & \theta &= 70° & \theta &= 80° & \theta &= 90°
\end{align*} \]

Figure 394.

Table 89. Orientation of Polarization Axis for Reflected Xe Light from CARC-Painted Surface. Degree of Polarization is near zero for \( \alpha = 140° \) and \( \theta = 40° \).

\[
\begin{array}{cccccccccc}
\alpha & \theta & 0 & 10 & 20 & 30 & 40 & 50 & 60 & 70 & 80 & 90 \\
180 & & & & & & & & & & & \\
160 & & & & & & & & & & & \\
140 & & & & & & & & & & & \\
120 & & & & & & & & & & & \\
100 & & & & & & & & & & & \\
80 & & & & & & & & & & & \\
60 & & & & & & & & & & & \\
40 & & & & & & & & & & & \\
20 & & & & & & & & & & &
\end{array}
\]
FRESNEL MODEL

Fresnel's laws of reflection, derived from the elastic solid theory, are as follows:

\[
\frac{P_s}{E_s} = -\frac{\sin(\phi - \phi')}{\sin(\phi + \phi')} \quad \frac{R_p}{E_p} = \frac{\tan(\phi - \phi')}{\tan(\phi + \phi')} \quad (1)
\]

\[
\frac{E'_s}{E_s} = \frac{2\sin\phi' \cos\phi}{\sin(\phi + \phi')} \quad \frac{E'_p}{E_p} = \frac{2\sin\phi' \cos\phi}{\sin(\phi + \phi') \cos(\phi - \phi')} \quad (2)
\]

E, R and E' refer to the amplitudes of the electric vectors in the incident, reflected and refracted light respectively.

The subscripts s and p denote two planes of vibration: p vibrations are parallel to the plane of incidence and s vibrations are perpendicular to the plane of incidence.

The angles \(\phi\) and \(\phi'\) are the angles of incidence and refraction respectively.

---

Table 90. Degrees of polarization axis from horizontal, \(\psi\), for reflected Xe light from CARC painted surface. Angles are positive when orientations are clockwise from horizontal and negative for orientations counterclockwise from horizontal.

<table>
<thead>
<tr>
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<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
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<td>-9</td>
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<td>79</td>
<td>81</td>
<td>82</td>
<td>82</td>
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<td>-60</td>
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<td>60</td>
<td>40</td>
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<td>13</td>
<td>4</td>
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<td>-13</td>
<td>-24</td>
<td>-26</td>
<td>-45</td>
<td>-59</td>
<td>-87</td>
</tr>
</tbody>
</table>
The ratio of the two equations of (1) produces an equation which predicts the nature of the reflected light when plane polarized light is incident on the surface of a dielectric at any angle. Equation (3) below gives the variation of the plane of vibration of the reflected light with the angle of incidence.

\[
\frac{R_P}{R_s} = -\frac{\frac{R_P}{E_s}}{\frac{E}{E}} \cos (\phi + \phi') \cos (\phi - \phi')
\]  

(3)

The ratio \(\frac{R_P}{R_s}\) is the tangent of the angle \(\psi\), the angle between \(R\) and \(R_s\) (Figure 11).

The ratio \(\frac{E_P}{E_s}\) is the tangent of the angle \(\theta\), the angle between \(E\) and \(E_s\) (Figure 11).

Although this study is only concerned with reflected light, it is necessary to assume an index of refraction \(n\) for the CARC-painted sample in order to determine the angle of refraction \(\phi'\) in equation (3). The angle of refraction is determined from Snell's Law: \(\sin \phi = n \sin \phi'\). Since no index of refraction was available, indices between 1.1 and 1.7 were tried. The best match between theory and experimental results was obtained using an index of 1.2.

In general, equation (3) is only valid for reflected polarized light in the plane of incidence. The plane of incidence is normally taken to be the plane containing the incident and reflected rays of light and the normal to the surface. The only data collected for this condition (azimuth angle \(\alpha = 180^\circ\), Figure 385) is shown in Figure 399. The graph of Figure 399 shows very good agreement between experimental data and predicted results using equation (3) with \(n = 1.2\).
The CARC-painted surface is not a mirror reflector but reflects light out of the plane of incidence. As a first step at explaining the nature of the reflected light out of the plane of incidence, the following ideas were incorporated into equation (3):

1. The plane passing through the incident ray and the reflected ray was taken to be the new plane of incidence.

2. The angle of incidence was assumed to be one half the angle between the incident ray and the reflected ray.

3. \( E_p \) was replaced with its projection onto a unit vector (vector D, Figure 398) perpendicular to \( I \) and in the new incident plane. \( E_s \) was replaced with its projection onto a unit vector (vector \(-C\), Figure 393) perpendicular to the incident ray \( I \) and also to the new incident plane.

4. The angle between \( R \) and \( R_S \) (\( \psi \)), obtained from equation (3), was decreased (clockwise rotation) by the angle \( \epsilon \), the angle between the plane containing \( I \) and \( r \) and the plane containing \( r \) and the normal to the CARC-painted surface (N). Vertical lines in the photographs were in the plane containing \( r \) and \( N \).

Let \( I \) equal a unit vector opposite in direction to an incident ray of light (Figure 396).

\[
I = \cos 40 \, i + \sin 40 \, k
\]

Let \( r \) equal a unit vector in the direction of the reflected ray of light (Figure 396).

\[
r = -\cos 40 \cos \beta \, i + \cos 40 \sin \beta \, j + \sin 40 \, k
\]

From Figure 395 and Figure 397:

\[
E = -\sin 40 \sin \theta \, i + \cos \theta \, j + \cos 40 \sin \theta \, k
\]
From Figure 397:  \( E_3 = \cos \theta \mathbf{j} \) and \( E_p = -\sin 40 \sin \theta \mathbf{i} + \cos 40 \sin \theta \mathbf{k} \)

\[
-C = \frac{\mathbf{x} \times \mathbf{y}}{|\mathbf{x} \times \mathbf{y}|} = \frac{\sin 40 \sin \beta \mathbf{\hat{i}} + \sin 40 (1 + \cos \beta) \mathbf{\hat{j}} - \cos 40 \sin \beta \mathbf{\hat{k}}}{\sqrt{\sin^2 \beta + \sin^2 40 (1 + \cos \beta)^2}}
\]

Unit vector \( \mathbf{D} = x \mathbf{i} + y \mathbf{j} + z \mathbf{k} \) satisfies the following conditions:

1. \( x^2 + y^2 + z^2 = 1 \)
2. \( \mathbf{D} \cdot \mathbf{I} = 0 \)
3. \( \mathbf{D} \cdot \mathbf{C} = 0 \)

\[
\mathbf{D} = \frac{-\sin^2 40 (1 + \cos \beta) \mathbf{\hat{i}} + \sin \beta \mathbf{\hat{j}} + \sin 40 \cos 40 (1 + \cos \beta) \mathbf{\hat{k}}}{\sqrt{\sin^2 \beta + \sin^2 40 (1 + \cos \beta)^2}}
\]

\( E_s' \) is the projection of \( \mathbf{E} \) onto \( -\mathbf{C} \).  \( E_p' \) is the projection of \( \mathbf{E} \) onto \( \mathbf{D} \).

\[
E_s' = \mathbf{E} \cdot (-\mathbf{C}) = \frac{\sin 40 \cos \beta (1 + \cos \beta) - \sin \beta \sin \theta}{\sqrt{\sin^2 \beta + \sin^2 40 (1 + \cos \beta)^2}}
\]

\[
E_p' = \mathbf{E} \cdot \mathbf{D} = \frac{\sin 40 \sin \theta (1 + \cos \beta) + \sin \beta \cos \theta}{\sqrt{\sin^2 \beta + \sin^2 40 (1 + \cos \beta)^2}}
\]

The angle \( \epsilon \) between the plane containing \( \mathbf{r} \) and \( \mathbf{I} \) and the plane containing \( \mathbf{r} \) and \( \mathbf{N} \) (\( \mathbf{N} = \mathbf{k} \)) is found by determining the angle between their normals.

The unit vector \( \mathbf{N}' \), normal to the plane containing \( \mathbf{r} \) and \( \mathbf{N} \), is

\[
\mathbf{N}' = \frac{\mathbf{N} \times \mathbf{r}}{|\mathbf{N} \times \mathbf{r}|} = -\sin \beta \mathbf{\hat{i}} - \cos \beta \mathbf{\hat{j}}
\]

Since \( \mathbf{C} \) is a unit vector normal to the plane containing \( \mathbf{I} \) and \( \mathbf{r} \),

\[
\mathbf{C} \cdot \mathbf{N}' = \frac{\sin 40 (1 + \cos \beta)}{\sqrt{\sin^2 \beta + \sin^2 40 (1 + \cos \beta)^2}} = \cos \epsilon
\]

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Table 91. Calculations. C+/C- = Cos (φ + φ')/Cos (φ - φ'). ψ' = ψ - ε.
Exp. = Experimental values for ψ. Diff. = ψ' - Exp.

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<th>C+/C- = -0.01</th>
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<th>Ep'</th>
<th>Ep'/Es'</th>
<th>θ'</th>
<th>Rp/Rs</th>
<th>ψ</th>
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<th>Diff.</th>
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<th>Ep'</th>
<th>Ep'/Es'</th>
<th>θ'</th>
<th>Rp/Rs</th>
<th>ψ</th>
<th>ψ'</th>
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<th>Diff.</th>
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<td>( \psi )</td>
<td>( \psi' )</td>
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<td>Diff.</td>
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<td>( \text{Ep}' )</td>
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<td>( \psi )</td>
<td>( \psi' )</td>
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Fresnel Model

Azimuth Angle = 180

\[ \ominus n = 1.2 \quad \ominus n = 1.7 \quad \ast \exp. \]

Figure 399. \( \psi' \) vs \( \theta \) for \( \alpha = 180 \).
Figure 400. $\psi'$ vs $\theta$ for $\alpha = 160$. 

$n = 1.2 \quad n = 1.7 \quad \times \text{Exp.}$
Fresnel Model

Azimuth Angle = 140

$\psi' \text{ vs } \theta \text{ for } \alpha = 140.$
Fresnel Model

Azimuth Angle = 120

\[ n = 1.2 \quad \Theta n = 1.7 \quad \star \text{Exp.} \]

Figure 402. \( \psi' \) vs \( \theta \) for \( \alpha = 120 \).
Fresnel Model

Azimuth Angle = 100

\[ \psi' \text{ vs } \theta \text{ for } \alpha = 100. \]

\[ \ominus n = 1.2 \quad \odot n = 1.7 \quad \forall \text{ Exp.} \]

Figure 403. \( \psi' \) vs \( \theta \) for \( \alpha = 100 \).
Fresnel Model

Azimuth Angle = 80

\[ \psi' \text{ vs } \theta \text{ for } \alpha = 80. \]
Fresnel Model

Azimuth Angle = 60

\[ n = 1.2 \quad \Rightarrow n = 1.7 \quad \Rightarrow \text{Exp.} \]

Figure 405. \( \psi' \) vs \( \theta \) for \( \alpha = 60 \).

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Fresnel Model

Azimuth Angle = 40

\[ \psi' \text{ vs } \theta \text{ for } \alpha = 40. \]

Figure 406. \( \psi' \text{ vs } \theta \text{ for } \alpha = 40. \)
Figure 407. $\psi'$ vs $\theta$ for $\alpha = 20$. 

Fresnel Model

Azimuth Angle = 20

$n = 1.2 \quad n = 1.7 \quad \times \text{Exp.}$
Figure 408.
Experimental polarization axes of reflected light from CARC sample. Shaded areas indicate conditions where predicted polarization axes deviate by more than 20° from experimental values.

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Figure 409.
Angular difference between predicted and experimental polarization axes of reflected light from CARC sample using the Fresnel model.
The graphs of Figure 399, Figure 400, ...Figure 407 and the charts of Figure 408 and Figure 409 indicate that the modified laws of reflection of Fresnel closely fit over 75 percent of the collected data. The greatest deviations occur within 60° of the plane containing the incident ray, the reflected ray and the normal to the surface and for θ > 40°.

RELATIVE INTENSITIES

The components $R_s$ and $R_p$ of the amplitude $R$ of the electric vector for reflected light is obtained from equation (3)

$$R_s = -\frac{\sin(\phi - \phi')}{\sin(\phi + \phi')} E_s$$
$$R_p = \frac{\tan(\phi - \phi')}{\tan(\phi + \phi')} E_p$$

where $R_s$ is the component perpendicular to the plane of incidence, $R_p$ is the component parallel to the plane of incidence and $R = \sqrt{R_p^2 + R_s^2}$

By definition, $R' = \frac{R}{R_{\text{MAX}}}$

$R'^2$ represents the relative intensities of the reflected light.

Table 92 shows the calculations of $R'^2$ for an index of refraction $n = 1.2$. Table 93 shows the calculations of $R'^2$ for an index of refraction $n = 1.7$. The graphs of Figure 410, Figure 411, ... Figure 413 show the results graphically.

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Table 92. Calculations of Relative Intensities for Reflected Light from CARC Sample for $n = 1.2$

$$\begin{array}{|c|c|c|c|c|c|}
\hline
\theta & R_p & R_S & R & R' & R'^2 \\
\hline
0 & 0.00000 & 0.17931 & 0.17931 & 1.0000 & 1.00 \\
10 & 0.00018 & 0.17659 & 0.17659 & 0.98481 & 0.97 \\
20 & 0.00036 & 0.16850 & 0.16850 & 0.93969 & 0.88 \\
30 & 0.00052 & 0.15529 & 0.15529 & 0.86603 & 0.75 \\
40 & 0.00067 & 0.13736 & 0.13736 & 0.76605 & 0.59 \\
50 & 0.00080 & 0.11526 & 0.11526 & 0.64280 & 0.41 \\
60 & 0.00091 & 0.08966 & 0.08966 & 0.50003 & 0.25 \\
70 & 0.00099 & 0.06133 & 0.06134 & 0.34206 & 0.12 \\
80 & 0.00103 & 0.03114 & 0.03115 & 0.17374 & 0.03 \\
90 & 0.00105 & 0.00000 & 0.00105 & 0.00585 & 0.00 \\
\hline
\end{array}$$

$$\begin{array}{|c|c|c|c|c|c|}
\hline
\theta & R_p & R_S & R & R' & R'^2 \\
\hline
0 & 0.00169 & 0.16793 & 0.16793 & 0.93654 & 0.88 \\
10 & 0.00274 & 0.15737 & 0.15740 & 0.87779 & 0.77 \\
20 & 0.00370 & 0.14204 & 0.14209 & 0.79242 & 0.63 \\
30 & 0.00455 & 0.12240 & 0.12248 & 0.68305 & 0.47 \\
40 & 0.00526 & 0.09903 & 0.09917 & 0.55304 & 0.31 \\
50 & 0.00582 & 0.07265 & 0.07289 & 0.40647 & 0.17 \\
60 & 0.00619 & 0.04407 & 0.04450 & 0.24818 & 0.06 \\
70 & 0.00638 & 0.01415 & 0.01552 & 0.08655 & 0.01 \\
80 & 0.00637 & -0.01620 & 0.01741 & 0.09711 & 0.01 \\
90 & 0.00617 & -0.04610 & 0.04648 & 0.25919 & 0.07 \\
\hline
\end{array}$$
\[ \alpha = 140 \]

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Reflection From CARC-Painted Surface

Fresnel Polarization Model (n = 1.2)

Figure 410.
Relative Reflection Intensities

\[ \equiv \alpha = 180 \quad \leftrightarrow \alpha = 160 \quad \Rightarrow \alpha = 140 \quad \ast \alpha = 120 \quad \times \alpha = 100 \]
Reflection From CARC-Painted Surface

Fresnel Polarization Model \( n = 1.2 \)

\[
\begin{array}{c}
\begin{array}{cccccccc}
\text{Incident Polarization Angle} & 0 & 10 & 20 & 30 & 40 & 50 & 60 & 70 & 80 & 90 \\
\hline
\text{Relative Reflection Intensities} & & & & & & & & & & \\
\end{array}
\end{array}
\]

\( \alpha = 80 \), \( \alpha = 60 \), \( \alpha = 40 \), \( \pm \alpha = 20 \)

Figure 411.
Relative Reflection Intensities

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Reflection From CARC-Painted Surface

Fresnel Polarization Model (n = 1.7)

![Graph showing relative reflection intensities versus incident polarization angle.](image)

\[ \theta = 180 \quad \alpha = 160 \quad \alpha = 140 \quad \alpha = 120 \quad \alpha = 100 \]

Figure 412.
Relative Reflection Intensities

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Reflection From CARC-Painted Surface

Fresnel Polarization Model (n = 1.7)

Figure 413.
Relative Reflection Intensities

\[ \text{Relative Reflection Intensities} \]

Incident Polarization Angle

\( \alpha = 80 \), \( \alpha = 60 \), \( \alpha = 40 \), \( \alpha = 20 \)

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SUMMARY

Polarization Axis

By using a modified definition of the plane of incidence, it has been demonstrated that the
Fresnel equations for reflection are useful in predicting the angle of polarization for linear
polarized light reflected from a CARC-painted sample. The results are shown in Figure 408
and Figure 409. The theory used fits over 75 percent of the collected data. Most of the
development from theory occurs for azimuth angles between \( \alpha = 160^\circ \) and \( \alpha = 100^\circ \) and for
incident polarization angles \( \theta \) greater than 50\(^\circ\). This is an interesting development since this
range agrees closely to the azimuth angles found in a previous study, "Goniophotometric
The azimuth angles for which the modified Fresnel equations work best correspond to
viewing angles for which the CARC surface acts as a diffuse reflector (Figure 346).

The photographs of Figure 390 for \( \alpha = 180^\circ \) (i = 50\(^\circ\)) and the graph of Figure 399 suggest
an index of refraction close to \( n = 1.2 \) for the CARC-paint layer. The selected light source
slope and camera slope of 40\(^\circ\) produced an angle of incidence of 50\(^\circ\) for \( \alpha = 180^\circ \). This
is, coincidentally, close to the Brewster angle since the condition for the Brewster angle is
given by \( \tan \alpha = n \) and \( \tan 50^\circ = 1.19 \). Unpolarized light incident on a dielectric at the
Brewster angle produces reflected light that is plane-polarized parallel to the surface of the
dielectric. The photographs of Figure 390 for \( \alpha = 180^\circ \) (i = 50\(^\circ\)) and Table 89 illustrate
that the reflected light was nearly plane-polarized parallel to the CARC-painted surface for
all incident polarization angles \( \theta = 0^\circ \) to \( \theta = 90^\circ \). Also, light vibrating in the plane of
incidence (\( \theta = 90^\circ \)) is not reflected at the Brewster angle. The photographs of Figure 390
for \( \alpha = 180^\circ \) show very low intensities for the reflected light when the incident polarization
angle was close to 90\(^\circ\).

Intensity

Since all the data collected for this study was in the form of photographs, intensity
measurements are at best semi-quantitative. However, various trends can be identified in the
collection of photographs which can be compared to theoretical predictions.

The trends in relative intensities shown in Figure 410 and Figure 411 for an index of
refraction \( n = 1.2 \) more closely match the intensities shown in the polarization axis finder
photographs than do the trends shown in Figure 412 and Figure 413 for \( n = 1.7 \).
Figure 399 also supports the idea that the CARC paint layer has an index of refraction
closer to 1.2 than to 1.7.
The plots of relative intensity from Figure 411 correspond to the photographs of Figure 392, Figure 393 and Figure 394. This graph and corresponding photographs are for azimuth angles $\alpha = 20^\circ$ to $\alpha = 100^\circ$. There is close agreement between theory and experimental data for this range of azimuth angles. The predicted values appear to be lower than the photographs indicate. However, theory predicts that the relative intensities are nearly constant for all incident polarization angles $\theta$ and this is the trend indicated in the photographs for this range of azimuth angles. Once again, theory and experimental data are in close agreement for viewing azimuth angles for which the CARC surface acts as a diffuse reflector.

The modified Fresnel equations, for azimuth angles $\alpha = 120^\circ$ to $\alpha = 180^\circ$, predict a continuous decrease in relative intensity which, after reaching zero, is accompanied by an increase in relative intensity. All the corresponding photographs show this same trend. However, the incident polarization angles for which the zero intensity values are reached differ by approximately $20^\circ$.

Limitations

Since this study was primarily phenomenological in nature, restrictions were imposed regarding space, available equipment and time. The slope of the light source and camera were limited to $40^\circ$. This limited the range of angles of incident and reflectances as shown in Table 94.

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<tr>
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<td>15.19</td>
<td>12.61</td>
<td>0.00729</td>
<td>0.00930</td>
<td>8.87</td>
<td>0.06163</td>
</tr>
<tr>
<td>20.00</td>
<td>7.64</td>
<td>6.36</td>
<td>0.00802</td>
<td>0.00851</td>
<td>4.49</td>
<td>0.06581</td>
</tr>
</tbody>
</table>

Table 94. Range of Angles of Incidence $i$, Angles of Refraction $r$ and Reflectances $r_p$ and $r_s$. 

279
The diameter of the aperture of the polarization axis finder was two inches. The tube it was connected to was approximately 12 inches long. This geometry allows for an approximately $10^\circ$ solid angle of reflected light to be incident on the film plane.

The centers of the wedges in the photographs were determined to within two degrees. This introduces an approximately two degree error in determining the polarization axis of the reflected light.
CONCLUSIONS

LUMINANCE

The largest luminance readings for sunlight reflected from three ground combat vehicles, the M60 tank, the M1 Abrahams tank and the Marine Corps amphibious Light Armored Vehicle (LAV25), were obtained from the turret areas of the vehicles. The highest luminance reading from these vehicles (16,600 cd/m²) was obtained from the top of the turret of the M60 and is due to specular reflection. Specular reflection is enhanced by (1) smooth surfaces, (2) elevated positions, (3) beveled or rounded shapes, and (4) gloss and semi-gloss painted surfaces. Luminance readings for the M60 decreased, in general, for areas closer to the ground because specular reflections for these regions are frequently below the ground plane.

Specular reflection is reduced or eliminated by overcast sky conditions. Dense, overcast skies tend to make the luminance ratios more constant. Openings in cloud cover contribute to variance in luminance. Cumulus clouds near the direction of the sun were observed to increase the luminance readings of ground vehicles. These clouds reflected more light onto a target area than would be produced by light coming directly from the sun alone.

The M1 has three distinguishing luminance areas: the turret, the skirt and the track and suspension areas. These areas remain distinguishing features despite orientation, time of day or sky condition. The average luminance obtained from the skirt area is approximately 70 percent of the average luminance obtained from the turret areas. The average luminance obtained from the track and suspension areas is approximately 30 percent of the average luminance obtained from the turret areas. The largest luminance reading obtained from a M1 turret area was 4,618 cd/m²; acquired at 10:00 on 1 August 1990 during clear skies. The M1 turret areas also showed the greatest variance in luminance (as great as 50 percent of the average turret value) compared to other areas (maximum variance for skirt: 18 percent of the average; maximum variance for track and suspension: 16 percent of the average). Although large variances in luminance occur for individual points on the turret, the average luminance of the turret changed less than the other areas. During clear skies, the average luminance of the turret decreased at the approximate rate of 600 cd/m²/hr from 11:00 to 15:00. The average luminance of the skirt (11:00 to 14:00) and track and suspension areas (10:00 to 12:00) decreased at approximately 1,000 cd/m²/hr.

The largest luminance reading acquired from the LAV25 (3,300 cd/m²) was obtained from a turret area. In terms of luminance, the LAV25 is a bisectional vehicle. The wheel areas are separated from the upper beveled regions of the vehicle by a horizontal joint running the entire length of the vehicle. When the vehicle is positioned on the ground, the wheel areas make up nearly 50 percent of the vehicle's side surface area. Significant diurnal shading occurs in this area. In the early morning hours, with the vehicle positioned along a north-south line and metering to the west, the luminance of the road wheels and the areas...
immediately above them are nearly the same. However, diurnal shading in the wheel areas produces variation in the luminance ratio of these two areas. During clear skies, the ratio of the average luminance of the wheel areas to the average luminance of the areas above them decreased at the approximate rate of 0.15 per hour.

During clear skies, there are extended periods of time for which the average luminance of the M1, the LAV25, grass and trees can be expressed by linear equations. Table 95 gives a summary of the equations for the approximate average luminance for these targets and backgrounds. Average luminance $L$ is expressed in $\text{cd/m}^2$ and time $t$ is in hours. These equations are valid for times 10:00 to 15:00 with $t = 0$ at 10:00.

The best curve fit, during clear skies, for diurnal luminance readings of sunlight reflected from plane surface facets was obtained when luminance was plotted as a function of the cosine of the angle of incidence. This is the same principle which produces the seasons. Light energy from the sun per unit area decreases with an increase in the angle of incidence. The curves are nearly straight lines for the time interval 12:30 to 14:00. Deviations from a linear relationship between luminance and the cosine of the angle of incidence occurred before 12:30. These deviations are a result of the diurnal changes in the sun’s power output. However, luminance was found to be directly proportional to the cosine of the angle of incidence when luminance readings were acquired from a CARC-(Chemical Agent Resistant Coating) painted flat surface using a collimated white light source in a dark room.

There is a significant difference between the luminance readings from a newly CARC painted surface and those from a weathered CARC-painted surface. A weathered CARC-painted surface was found to be approximately 25 percent brighter than a newly CARC-painted surface. This result was obtained during clear skies using three different M1 facets during the time interval 8:00 to 15:00.

The gloss of a surface is the degree it approaches a mirror surface. The two extreme cases of glossiness occur for Lambertian and specular surfaces. By definition, a Lambertian surface is a perfect reflecting diffuser. The luminance of a Lambertian surface is constant and has no dependence on angle of view. Incident light is distributed equally in every direction. It is the ideal surface of zero gloss. A purely specular surface produces a non-zero luminance value only at the angle of mirror reflection.

The newly CARC-painted surface was found to exhibit approximately Lambertian properties for azimuth angles from 60° to 240°. Luminance readings varied by only 108 $\text{cd/m}^2$ (3.6 percent) for this range of azimuth angles. This range corresponds to the hemisphere opposite the sun and at right angles to the plane of incidence.
The sample showed intermediate light-distributing properties between Lambertian and specular for azimuth angles from 60° to 240°. The difference between the maximum luminance reading and the minimum luminance reading acquired was 1039 cd/m² (30.1 percent). As would be expected from a semi-gloss surface, the largest luminance reading acquired (3975 cd/m²) corresponded approximately to an azimuth angle equal to the sun’s azimuth.

Goniophotometric records obtained for the CARC-painted sample show that higher luminance readings are acquired for smaller metering angles; metering closer to the surface; rather than in the direction of mirror reflection when metering is in the plane of incidence. This is in agreement with Fresnel’s laws of reflection for polarized light reflected from a dielectric parallel to the plane of incidence. Also, the records show a decrease in luminance for angles of incidence between 0° and 60° but an increase in luminance for angles of incidence between 60° and 90° when metering was in the plane of incidence. This is also in agreement with Fresnel’s laws for polarized reflected light parallel to the plane of incidence.

**CONTRAST**

Contrast is one of many factors which influences the ability to detect targets. All successful models that predict the probability of detecting targets will contain a contrast term. Contrast values for the M60 varied considerably, both the contrast for a given area and the average contrast for the entire vehicle. Using grass as a background, the largest contrast value for a single area and the largest variation in contrast (+0.84 to +3.80) was obtained from the top of the M60 turret. When considering the contrast of the M60 as a whole, using a grass background, the range of contrast extends from -0.95 to +3.80. The range of contrast, using trees as background, extends from -0.24 to +2.50.

During clear skies, the average M1 contrast using tree and grass backgrounds can be expressed as linear equations for extended periods of time; examples are given in Table 96. The equations of Table 96 are valid for the times 10:00 to 15:00. The correlation coefficients for these equations are greater than 0.98. Contrast is represented by C; the time t is in hours with t = 0 at 10:00. The data from which these equations were derived was acquired for a M1 orientation along a north-south line and metering toward the west. There is a small change in the rate at which average contrast decreases when the range increases. This is due to more recessed areas being included in the measurement area at greater ranges.
Table 96. Average M1 Contrast Using Tree and Grass Backgrounds on 1 August, 1990.

<table>
<thead>
<tr>
<th>Range</th>
<th>Contrast/Trees</th>
<th>Contrast/Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>( C = 2.06 - 0.49 t )</td>
<td>( C = 0.38 - 0.20 t )</td>
</tr>
<tr>
<td>100 feet</td>
<td>( C = 1.53 - 0.38 t )</td>
<td>( C = 0.02 - 0.14 t )</td>
</tr>
<tr>
<td>200 feet</td>
<td>( C = 1.34 - 0.35 t )</td>
<td>( C = -0.11 - 0.12 t )</td>
</tr>
<tr>
<td>300 feet</td>
<td>( C = 1.21 - 0.33 t )</td>
<td>( C = -0.03 - 0.12 t )</td>
</tr>
</tbody>
</table>

An important consequence of the shading of selected areas on a vehicle is contrast variation between different areas of the vehicle. This contrast variation increases the visibility of the vehicle and produces a visual signature. Also, high contrast areas increase vehicle detectability and can become prominent cue features for threat observers. Significant contrast occurs between M1 turret areas and the M1 skirt areas due to diurnal shading of the skirt area. The luminance of the turret areas was observed to be as much as five times greater than the luminance of skirt areas (14:00, 1 August, 1990).

During clear skies, the average LAV25 contrast using tree and grass backgrounds can be expressed as linear equations for extended periods of time; examples are given in Table 97. The equations of Table 97 are valid for the times 9:30 to 14:30. The correlation coefficients for these equations range from 0.87 to 0.99. Contrast is represented by \( C \); the time \( t \) is in hours with \( t = 0 \) at the beginning of the time interval. The data from which these equations were derived was acquired for a LAV25 orientation along a north-south line and metering toward the west. The negative contrast values obtained using a grass background indicate that the luminance of the grass was greater than the average luminance of the LAV25. The change in the description of contrast after 12:30 is due to shading of the LAV25 wheels.

Table 97. Average LAV25 Contrast Using Tree and Grass Backgrounds on 1 August, 1990.

<table>
<thead>
<tr>
<th>Range</th>
<th>Time Interval</th>
<th>Contrast/Trees</th>
<th>Contrast/Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 feet</td>
<td>9:30 - 12:30</td>
<td>( C = 0.55 )</td>
<td>( C = -0.31 )</td>
</tr>
<tr>
<td>36 feet</td>
<td>12:30 - 14:30</td>
<td>( C = 0.57 - 0.31 t )</td>
<td>( C = -0.31 - 0.16 t )</td>
</tr>
<tr>
<td>100 feet</td>
<td>9:30 - 14:30</td>
<td>( C = 0.33 - 0.11 t )</td>
<td>( C = -0.41 - 0.06 t )</td>
</tr>
<tr>
<td>200 feet</td>
<td>9:30 - 14:30</td>
<td>( C = 0.25 - 0.09 t )</td>
<td>( C = -0.56 - 0.03 t )</td>
</tr>
<tr>
<td>300 feet</td>
<td>9:30 - 14:30</td>
<td>( C = 0.27 - 0.10 t )</td>
<td>( C = -0.47 - 0.04 t )</td>
</tr>
</tbody>
</table>
When two nonparallel surfaces of a vehicle meet, a rounded edge is formed. This edge may be formed by a single metal plate, a weld joint or a bend. Under the right conditions, an edge may appear as a white line. These white lines are produced by specular reflection. Because of the roundness of the edge, there are many different angles of incidence for an edge surface for any given sun position. Hence, the white outline can be observed from many different directions, especially for edges near the top of the vehicle. Different colors of paint have little effect on the degree of glare. White lines were observed on edges painted with three different colors; one of the colors being flat black. Since the entire illuminated edge appeared white, the white line is associated with light that has not interacted with the paint pigments; there is little absorption by the pigment materials.

An important consequence of the edge effect is to increase the contrast between the edge and surrounding surfaces. This increase in contrast increases the visibility of the vehicle. A linear polarizer is effective in reducing glare because the specularly reflected light from the edges is linearly polarized to a considerable extent. The degree of glare extinction depends on the angle between the transmission axis of the polarizer and the plane of polarization of the reflected light. Controlling edge contrast is important for limiting recognition and identification of threat observers.

POLARIZATION

Sunlight reflected from three different M1 facets was found to be partially polarized. The degree of polarization depends on the time of day, sky conditions, and facet orientations. However, the reflected light was nearly horizontally polarized for all three M1 facets studied and for all times during the day except during early morning hours (8:00 to 10:00) when the sun was in the eastern sky. Since the region of the sky near the sun produces little polarized light, sunlight reflected from a north-south oriented vehicle during the times 8:00 to 10:00 (Eastern Daylight Standard Time) is mostly unpolarized light. This accounts for the small degree of polarization during this time of the day.

For the turret area with a slope of 60° and an azimuth of 270°, the degree of polarization increased continuously from 0.01 to 0.21 during the time interval from 8:00 to 14:00. For the turret area with a slope of 60° and an azimuth of 204°, the degree of polarization increased from 0.01 to 0.12 during the time interval from 8:00 to 12:30. It then decreased from 0.12 to 0.09 during the time interval from 12:30 to 14:00. For the skirt area, the degree of polarization increased from 0.01 to 0.11 during the time interval from 8:00 to 12:30. It then decreased from 0.11 to 0.05 during the one hour time interval from 12:30 to 13:30; rising again after the sun crossed the meridian (13:30 EDST) to a value of .08 at 14:45.
Sky polarization photographs were obtained by placing a polarization axis finder in front of the lens of a 35 mm camera. These photographs illustrate why the amount of linear polarized light reflected from a north-south oriented M1 should increase after 8:00. The eastern hemispherical sky is the only sky region which can affect western polarization readings from a north-south oriented M1. Therefore, since the amount of polarized light from this sky region increases from sunset to solar noon, the degree of polarized light reflected from the M1 also increases during this same period.

A video tape was created from a camcorder with a rotating linear polarizer in front of the camcorder lens. As the transmission axis of the linear polarizer rotated in front of the camcorder lens, polarized light entering the camcorder was observed to "flicker" in unison with the phase angle between the polarized incident light and the rotating analyzer. The video includes 360° views of an M1, M60, skylight and objects along the horizon.

There is one dramatic feature of this video that stands out above all others. An outstanding amount of "flicker" (reflected polarized light) can be detected from surfaces which receive no light directly from the sun. Shadowed areas were observed to blink on and off like flashing neon signs. Rounded surfaces, like the M60 turret, fence posts, car hoods and windows, produced a considerable amount of "flicker" when illuminated by direct sunlight. Flat surfaces, like the skirt area of the M1, showed very little "flicker" when illuminated by direct sunlight. But these same flat surfaces flashed on and off as soon as sky light became the only source of illumination. This "flicker" phenomenon, as it relates to polarized light reflected from ground combat vehicles, has capabilities of being used as a detection device. Ground combat vehicles, shielded from direct sunlight, might be detected because of polarized sky light reflected from their surfaces.

By using a modified definition of the plane of incidence, it has been demonstrated that the Fresnel equations for reflection are useful in predicting the angle of polarization for linear polarized light reflected from a CARC-painted sample. The theory used fits over 75 percent of collected in-house data relating to collimated, plane polarized, xenon light reflected from a CARC painted sample. Most of the deviation from theory occurs for azimuth angles between 60° and 100° and for incident polarization angles greater than 50°. The azimuth angles for which the modified Fresnel equations work best correspond to viewing angles for which the CARC surface acts as a diffuse reflector.

Unpolarized light incident on a dielectric at the Brewster angle \( \phi \) (\( \tan \phi \) = index of refraction) produces reflected light that is plane-polarized parallel to the surface of the dielectric. Experimental results indicate that the reflected xenon light was nearly plane-polarized parallel to the CARC-painted surface for all incident polarization angles 0° to 80° when the angle of incidence was 50°. These results suggest an index of refraction close to 1.2 for the CARC paint layer. Analysis also shows very low intensities for the reflected light when the incident polarization angle was close to 90°.
The modified Fresnel equations, for azimuth angles 120° to 180°, predict a continuous decrease in relative intensity which, after reaching zero, is accompanied by an increase in relative intensity. All photographic data for the in-house study show this same trend. However, the incident polarization angles for which the zero intensity values are reached differ by approximately 20°.

CHROMATICITY

The three coordinates for the CIE Chromaticity Diagram were measured for three different M1 facets, three different tree areas and a grass area. Measurements were made from 8:00 to 14:45. Clear skies prevailed until 12:00; light overcast and cloudy conditions existed after 12:00. The CIE coordinates of the three different M1 facets shifted slightly toward the white light coordinate as the sun moved westward from 8:00 to 14:00. There was virtually no change in the CIE coordinates for grass from 8:00 to 14:00. There was little difference in the behavior of the CIE coordinates for the three different tree areas measured. The value of both the X and Y tree coordinates continuously decreased from 8:00 to 14:00. The tree areas had a greater saturation of green than the M1 and they showed a greater shift toward the white light coordinate from 8:00 to 14:00.
RECOMMENDATIONS

Preliminary investigations have identified sky illumination as the principle source of polarized reflected light from ground combat vehicles. Since this source of illumination produces a unique visual signature of ground vehicles, it is desirable to obtain a mathematical description of this source of illumination. Ideally, the model should be able to predict the polarization axis and the relative intensity of polarized light for any point in the sky at any time of the day for which sky illumination is the principle source of polarized light. Hopefully, this model can be integrated with a second model which predicts the degree of polarization and the polarization axis of reflected light from the surfaces of ground vehicles. This second model should produce acceptable results for any surface orientation. Presently, only a framework has been established from which these models can be derived.

One of the limitations of the diurnal luminance and contrast studies relates to an inability to spot measure the entire surface area of a ground vehicle in a reasonable amount of time. New technological advances in digital cameras could remedy this limitation. With the click of a button, the entire exposed surface area of a vehicle can be digitally recorded for computer analysis. Since these digital cameras have color capabilities, vehicle signatures could be studied in terms of diurnal color changes.
APPENDIX A

OPTICAL DENSITY AND TRANSMITTANCE

Optical Density is defined as the logarithm to the base ten of the ratio of the power of the incident beam to that of the exiting beam.

\[ D = \log_{10} \frac{I_0}{I_T} = -\log_{10} T \]

Where:

- \( D \) = Optical Density, \( I_0 \) = Incident power and \( I_T \) = Transmitted power

The transmittance, \( T \), is \( \frac{I_T}{I_0} \) and is given by

\[ T = 10^{-D} \]

Suppose that a luminance reading from the Minolta LS-100 luminance meter is \( L \). If a polarizer of optical density 0.5 (transmittance = 0.316) is placed in front of the Minolta LS-100 luminance meter, the luminance reading should never be greater than 0.316 \( L \). However, data collected using polarized light with a polarizer of optical density 0.5 placed in front of the LS-100 produced luminance readings greater than 0.316 \( L \). Luminance readings as high as 0.6 \( L \) were obtained.

Figure 414, Figure 415 and Figure 416 describe a simple experiment to obtain the luminance from a source of unpolarized light. The optical density of the neutral density filter and the polarizer \( P_1 \) were measured using a densitometer; both were found to be 0.50. The results are given in Table 98. The transmittance through the neutral density filter and the polarizer are both close to the predicted value of 0.316.

Figure 418, Figure 419 and Figure 420 describe a simple experiment to obtain the luminance from a source of polarized light. The linear polarizer \( P_0 \) polarizes the light from the frosted glass plate. Linear polarizer \( P_1 \) serves as an analyzer. Table 99 gives a summary of the results.

When polarized light was transmitted through a neutral density filter positioned in front of the LS-100, the transmittance through the neutral density filter was found to be close to the predicted value of 0.316.
The results obtained from the arrangement shown in Figure 420, however, illustrate that there are clearly angles between the transmission axes of the polarizers that produce transmittance greater than 0.316. When the angle between the transmission axes of the polarizers is varied from 0° to 180°, the transmittance increases from 0.00 to 0.59 and then decrease to 0.00. Figure 421 and Figure 422 show the results graphically. From the Law of Malus, the transmittance should be directly proportional to \( \cos^2 \theta \).

Although the collected data for the crossed polarizers agrees with the Law of Malus, \( L_1 = 857 \cos^2 \theta \), the expected values for the luminance, considering that the transmittance of the polarizer is 0.316, should fit the equation \( L_1 = 0.316 \cos^2 \theta \). The ratio of the experimental luminance readings to the expected luminance readings is a constant, 1.87, for light passing through crossed polarizers and incident on the Minolta LS-100.

Obviously, the optical density of 0.5 (transmittance 0.316), measured with the densitometer, is only appropriate for unpolarized light.

Figure 414
Macbeth TD 502 Densitometer
Table 98. Luminance (L) and luminance ratios using polarized and unpolarized light with the Minolta LS-100 luminance meter.

<table>
<thead>
<tr>
<th>L_0</th>
<th>L_P</th>
<th>L_1</th>
</tr>
</thead>
<tbody>
<tr>
<td>5833</td>
<td>1921</td>
<td>1730</td>
</tr>
</tbody>
</table>

\[
\frac{L_P}{L_0} = 0.330 \\
\frac{L_1}{L_0} = 0.297
\]

Note: All luminance (L) values are in cd/m².

Figure A-1

Figure 415

Figure 416

Figure 417

Experimental setup for measuring luminance of polarized light with the Minolta LS-100
Table 99. Luminance (L) and luminance ratios using polarized light with the Minolta LS-100 luminance meter.

<table>
<thead>
<tr>
<th>$\theta_1$</th>
<th>$\theta - \theta_1 - \theta_0$</th>
<th>$L_1$</th>
<th>$L_1/L_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-90</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td>10</td>
<td>-80</td>
<td>18</td>
<td>0.012</td>
</tr>
<tr>
<td>20</td>
<td>-70</td>
<td>82</td>
<td>0.057</td>
</tr>
<tr>
<td>30</td>
<td>-60</td>
<td>185</td>
<td>0.128</td>
</tr>
<tr>
<td>40</td>
<td>-50</td>
<td>318</td>
<td>0.220</td>
</tr>
<tr>
<td>50</td>
<td>-40</td>
<td>464</td>
<td>0.321</td>
</tr>
<tr>
<td>60</td>
<td>-30</td>
<td>610</td>
<td>0.422</td>
</tr>
<tr>
<td>70</td>
<td>-20</td>
<td>730</td>
<td>0.504</td>
</tr>
<tr>
<td>80</td>
<td>-10</td>
<td>813</td>
<td>0.561</td>
</tr>
<tr>
<td>90</td>
<td>0</td>
<td>857</td>
<td>0.592</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
<td>848</td>
<td>0.586</td>
</tr>
<tr>
<td>110</td>
<td>20</td>
<td>779</td>
<td>0.538</td>
</tr>
<tr>
<td>120</td>
<td>30</td>
<td>673</td>
<td>0.463</td>
</tr>
<tr>
<td>130</td>
<td>40</td>
<td>535</td>
<td>0.370</td>
</tr>
<tr>
<td>140</td>
<td>50</td>
<td>378</td>
<td>0.261</td>
</tr>
<tr>
<td>150</td>
<td>60</td>
<td>247</td>
<td>0.170</td>
</tr>
<tr>
<td>160</td>
<td>70</td>
<td>125</td>
<td>0.086</td>
</tr>
<tr>
<td>170</td>
<td>80</td>
<td>36</td>
<td>0.023</td>
</tr>
<tr>
<td>180</td>
<td>90</td>
<td>3</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Note: All luminance (L) values are in cd/m².
LUMINANCE USING CROSSED POLARIZERS
METERING FROM MINOLTA LS-100

![Graph showing luminance vs. angle between axis of polarizers.](image)

- Experimental: $0.316 L_0 \cos^2 \theta$
- $857 \cos^2 \theta$

Figure 421

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LUMINANCE RATIOS
USING CROSSED POLARIZERS
METERING FROM MINOLTA LS-100

Figure 422

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APPENDIX B

POLARIZATION AXIS FINDER

This device finds the polarization axis of linear polarized light and visually indicates the intensity of polarization. The circular lens element is polarized concentrically about the center. Each tiny area is a linear polarizer, with the direction of the transmission axis perpendicular to the radius. This arrangement causes a blackout (two dark opposing wedges) of polarized light in direct alignment with the axis of polarity of the incident light. The polarization axis is along a line through the center of the two dark opposing wedges. The darker and broader these wedges appear, the greater the intensity of the polarization of the incident light.

Figure 423
The axis finder is a polarizer with circular concentric transmission axes.

Figure 424
Axis finder used to locate the transmission axis of a linear polarizer.

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Figure 425
The Astronomical Triangle ZRP.

Vertices: North Pole P, Zenith Z and Heavenly Body R.

Sides: $PZ = 90 - \text{Latitude (} \phi \text{)}$
$ZR = z = 90 - \text{Altitude (} h \text{)}$
$PR = 90 - \text{Declination (} \delta \text{)}$

Angles: $< P = \text{hour angle (} \omega \text{)}$
$< Z = 180 - \text{Azimuth (} A \text{)}$

$\Sigma$ is the intersection of the meridian and the equator.
N is north. S is south. W is west.
Figure 426
Astronomical Triangle, with heavenly body R west of meridian.

Figure 427
Astronomical Triangle, with heavenly body R east of meridian.
FORMULAS FOR SPHERICAL TRIANGLES

Law of Sines:
\[
\frac{\sin a}{\sin A} = \frac{\sin b}{\sin B} = \frac{\sin c}{\sin C}
\]
(1)

Law of Cosines:
\[
\cos a = \cos b \cos c + \sin b \sin c \cos A
\]
(2)
\[
\cos b = \cos a \cos c + \sin a \sin c \cos B
\]
(3)
\[
\cos c = \cos a \cos b + \sin a \sin b \cos C
\]
(4)
\[
\cos A = -\cos B \cos C + \sin B \sin C \cos a
\]
(5)
\[
\cos B = -\cos A \cos C + \sin A \sin C \cos b
\]
(6)
\[
\cos C = -\cos A \cos B + \sin A \sin B \cos c
\]
(7)

Relation between Two Angles and Three Sides:
\[
\sin a \cos B = \sin c \cos b - \cos c \sin b \cos A
\]
(8)

Half-Angle Formulas:
\[
\tan \frac{A}{2} = \frac{p}{\sin(s - a)} \quad \tan \frac{B}{2} = \frac{p}{\sin(s - b)}
\]
(9)
\[
\tan \frac{C}{2} = \frac{p}{\sin(s - c)} \quad \text{where} \quad s = \frac{a + b + c}{2}
\]

and
\[
p = \sqrt{\frac{\sin(s - a) \sin(s - b) \sin(s - c)}{\sin s}}
\]
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FORMULAS FOR THE ASTRONOMICAL TRIANGLE

From (1)
\[ \sin \omega \cos \delta = \sin z \sin A \]  
\[ \text{(10)} \]

From (2)
\[ \cos z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega \]  
\[ \text{(11)} \]

From (3)
\[ \sin \delta = \sin \phi \cos z - \cos \phi \sin z \cos A \]  
\[ \text{(12)} \]

From (8)
\[ \sin z \cos A = \sin \phi \cos \delta \cos \omega - \cos \phi \sin \delta \]  
\[ \text{(13)} \]

From (9)
\[ \tan \frac{\omega}{2} = \pm \sqrt{\frac{\sin \left[ z - (\phi - \delta) \right] \sin \left[ z + (\phi - \delta) \right]}{\cos \left[ z - (\phi + \delta) \right] \cos \left[ z + (\phi + \delta) \right]}} \]  
\[ \text{(14)} \]

From (8)
\[ \cos \delta \cos \omega = \cos \phi \cos z + \sin \phi \sin z \cos A \]  
\[ \text{(15)} \]
APPENDIX D
ANGLE BETWEEN SUN'S RAYS AND PLANE

If \( \mathbf{r} \) is a unit vector,

\[
Z = \cos \beta \tag{16}
\]

\[
X = W \sin \alpha \tag{17}
\]

\[
Y = W \cos \alpha \tag{18}
\]

\[
W = \sin \beta \tag{19}
\]

\[
X = \sin \beta \sin \alpha \tag{20}
\]

\[
Y = \sin \beta \cos \alpha \tag{21}
\]

![Figure 429](image)

\[
\mathbf{r} = X \mathbf{i} + Y \mathbf{j} + Z \mathbf{k} \tag{22}
\]

\[
\mathbf{r} = \sin \beta \sin \alpha \mathbf{i} + \sin \beta \cos \alpha \mathbf{j} + \cos \beta \mathbf{k} \tag{23}
\]

If \( \mathbf{r} \) is a unit vector opposite in direction to an incident sun ray, then

\[
\beta = \text{zenith distance of sun (z) and } \alpha = \text{azimuth of sun (A)}.
\]

\[
\mathbf{r} = \sin z \sin A \mathbf{i} + \sin z \cos A \mathbf{j} + \cos z \mathbf{k} \tag{24}
\]

The azimuth of the sun is measured westward from south and is zero when the sun is on the meridian.

Let \( \mathbf{n} \) be a unit vector in the direction of a normal to a plane surface. Then

\[
\mathbf{n} = \sin s \sin \gamma \mathbf{i} + \sin s \cos \gamma \mathbf{j} + \cos s \mathbf{k} \tag{25}
\]

where \( s \) is the slope of the plane and \( \gamma \) is the azimuth of the plane.
The azimuth of the plane is measured westward from south and is zero when the normal to the plane points south.

The vector dot product can be used to find the angle between \( r \) and \( n \):

\[
r \cdot n = |r| |n| \cos i \quad (26)
\]

where \( i \) is the angle between \( r \) and \( n \).

Angle \( i \) is the angle of incidence the sun's rays make with the normal to the surface.

Since \( r \) and \( n \) are unit vectors

\[
\cos i = \frac{r \cdot n}{|r| |n|} = r \cdot n \quad (27)
\]

\[
\cos i = \sin z \sin A \sin s \sin \gamma + \sin z \cos A \sin s \cos \gamma + \cos z \cos s \quad (28)
\]

Using the expression for \( \sin z \sin A \) from (10), the expression for \( \cos z \) from (11) and the expression for \( \sin z \cos A \) from (13), equation (28) can be rewritten as:

\[
\cos i = \sin \omega \cos \delta \sin s \sin \gamma + \sin \phi \cos \delta \cos \omega \sin s \cos \gamma - \cos \phi \sin \delta \sin s \cos \gamma + \sin \phi \sin \delta \cos s + \cos \phi \cos \delta \cos \omega \cos s \quad (29)
\]
APPENDIX E
EQUATIONS FOR REFLECTED SUN RAY

The following is a derivation of the equation for the direction of a reflected sun ray from any plane surface.

Let \( z \) = zenith angle of sun

Let \( A \) = azimuth of sun

Let \( \mathbf{I} \) be a unit vector opposite in direction to an incident sun ray.

From (24):
\[
\mathbf{I} = \sin z \, \sin A \, \mathbf{i} + \sin z \, \cos A \, \mathbf{j} + \cos z \, \mathbf{k} \quad (30)
\]

Let \( s \) = slope of plane surface

Let \( \gamma \) = azimuth of plane surface (south = 0)

Let \( \mathbf{N} \) be a unit vector normal to a plane surface \( P \).

From (25):
\[
\mathbf{N} = \sin s \, \sin \gamma \, \mathbf{i} + \sin s \, \cos \gamma \, \mathbf{j} + \cos s \, \mathbf{k} \quad (31)
\]

Let \( \mathbf{R} \) be a unit vector in the direction of the reflected sun ray from \( P \).
\[
\mathbf{R} = X \, \mathbf{i} + Y \, \mathbf{j} + Z \, \mathbf{k} \quad (32)
\]

Since vector \( \mathbf{R} \) is a unit vector, \( X \), \( Y \) and \( Z \) are the direction cosines of vector \( \mathbf{R} \).
Find X, Y, Z.

Let \( i \) = angle of incidence.

From the laws of reflection:

A. \( I, N \) and \( R \) are coplanar

\[
R \cdot (I \times N) = 0
\]  
(33)

B. The angle of incidence equals the angle of reflection

\[
N \cdot R = \cos i
\]  
(34)

\[
I \cdot R = \cos 2i
\]  
(35)

Let

\[
I_1 = \sin z \sin A
\]  
(36)

\[
I_2 = \sin z \cos A
\]  
(37)

\[
I_3 = \cos z
\]  
(38)

\[
N_1 = \sin s \sin \gamma
\]  
(39)

\[
N_2 = \sin s \cos \gamma
\]  
(40)

\[
N_3 = \cos s
\]  
(41)

Also, from (28)

\[
\cos i = I_1 N_1 + I_2 N_2 + I_3 N_3
\]  
(42)

\[
\cos 2i = 2(I_1 N_1 + I_2 N_2 + I_3 N_3)^2 - 1
\]  
(43)

Equations (30) and (31) become

\[
I = I_1 i + I_2 j + I_3 k
\]  
(44)

\[
N = N_1 i + N_2 j + N_3 k
\]  
(45)
Equation (33) can be written as

\[ R \cdot (I \times N) = \begin{vmatrix} X & Y & Z \\ I_1 & I_2 & I_3 \\ N_1 & N_2 & N_3 \end{vmatrix} = 0 \quad (45) \]

Expanding the determinant in (45)

\[ (I_2 N_3 - I_3 N_2) X + (I_3 N_1 - I_1 N_3) Y + (I_1 N_2 - I_2 N_1) Z = 0 \quad (47) \]

From (34)

\[ N_1 X + N_2 Y + N_3 Z = \cos i \quad (48) \]

From (35)

\[ I_1 X + I_2 Y + I_3 Z = \cos 2i \quad (49) \]

Using the following matrices,

\[
M = \begin{pmatrix}
(I_2 N_3 - I_3 N_2) & (I_3 N_1 - I_1 N_3) & (I_1 N_2 - I_2 N_1) \\
N_1 & N_2 & N_3 \\
I_1 & I_2 & I_3
\end{pmatrix}
\]

\[ Q = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad \text{and} \quad K = \begin{pmatrix} 0 \\ \cos i \\ \cos 2i \end{pmatrix} \]

equations (47), (48) and (49) become

\[ MQ = K \quad (50) \]
Solving for $Q$

$$Q = K M^{-1}$$

(51)

By definition

$$M^{-1} = \frac{\text{adj} M}{\det M}$$

(52)

Combining (51) and (52)

$$Q = \frac{K \text{adj} M}{\det M}$$

(53)

The adjoint matrix of $M$ (adj $M$) is found by replacing each element of $M$ by its cofactor and then transposing. The signed minor $(-1)^{i+j} m_{ij}$ is called the cofactor of the element $a_{ij}$.

Replacing each element of $M$ by its cofactor

$$\text{adj} M = \text{transpose of}$$

$$\left[\begin{array}{ccc}
(I_3N_2 - I_2N_3) & (I_1N_3 - I_3N_1) & (I_2N_1 - I_1N_2) \\
(I_3N_3 - I_3N_1 + I_1N_2 - I_2N_1) & (I_2N_3 - I_1N_2 - I_1N_2 + I_1N_2) & (I_2N_2 - I_2N_2 + I_1N_1 - I_1N_1) \\
(I_3N_1 - I_1N_3 - I_1N_2 + I_2N_1) & (I_3N_2 - I_2N_3 + I_1N_2 - I_2N_1) & (I_2N_1 - I_1N_2 + I_1N_1 - I_1N_1)
\end{array}\right]$$

(54)

$$\text{adj} M =$$

$$\left[\begin{array}{ccc}
(I_3N_2 - I_2N_3) & (I_1I_2N_3 - I_1I_3N_1 + I_1I_2N_2 - I_1I_2N_1) & (I_2I_1N_3 - I_2I_1N_2 - I_2I_1N_1 + I_2I_1N_1) \\
(I_3N_3 - I_3N_1 + I_1N_2 - I_2N_1) & (I_2N_3 - I_1N_2 - I_1N_2 + I_1N_2) & (I_2N_2 - I_2N_2 + I_1N_1 - I_1N_1) \\
(I_3N_1 - I_1N_3 - I_1N_2 + I_2N_1) & (I_3N_2 - I_2N_3 + I_1N_2 - I_2N_1) & (I_2N_1 - I_1N_2 + I_1N_1 - I_1N_1)
\end{array}\right]$$

(55)

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K adj M =

\[
\begin{pmatrix}
(I_1 I_3 N_3 - I_3^2 N_1 + I_1 I_2 N_2 - I_2^2 N_1) \cos i + (I_1 N_1 N_3 - I_1 N_2^2 - I_2 N_1 N_2) \cos 2i \\
(I_2 I_3 N_3 - I_3^2 N_2 - I_2^2 N_2 + I_1 I_3 N_2) \cos i + (I_1 N_2 N_3 - I_1 N_2^2 + I_2 N_1 N_2 - I_2 N_2^2) \cos 2i \\
(I_2 I_3 N_2 - I_3^2 N_3 + I_1 I_2 N_1 - I_2^2 N_2) \cos i + (I_2 N_2 N_3 - I_2 N_2^2 - I_3 N_1 N_2 + I_2 N_2 N_2) \cos 2i \\
\end{pmatrix}
\]

(56)

The determinant of M (\(\text{det } M\)) =

\[
- (I_2 N_3 - I_3 N_2)^2 - (I_1 N_3 - I_3 N_1)^2 - (I_1 N_2 - I_2 N_1)^2
\]

(57)

\[
X = \frac{(I_2 N_3 - I_1 N_3 - I_2 N_3 - I_3 N_3) \cos i + (I_1 N_1 N_3 - I_1 N_2^2 - I_2 N_1 N_1 + I_3 N_2^2) \cos 2i}{(I_1 N_2 - I_2 N_1)^2 + (I_2 N_3 - I_3 N_2)^2 + (I_1 N_3 - I_3 N_1)^2}
\]

(58)

\[
Y = \frac{(I_2 N_3 - I_1 N_3 - I_2 N_3 - I_3 N_3) \cos i + (I_2 N_1 N_3 - I_1 N_2^2 - I_2 N_1 N_2 + I_3 N_2^2) \cos 2i}{(I_1 N_2 - I_2 N_1)^2 + (I_2 N_3 - I_3 N_2)^2 + (I_1 N_3 - I_3 N_1)^2}
\]

(59)

\[
Z = \frac{(I_2 N_3 - I_1 N_3 - I_2 N_3 - I_3 N_3) \cos i + (I_2 N_1 N_3 - I_1 N_2^2 - I_2 N_1 N_2 + I_3 N_2^2) \cos 2i}{(I_1 N_2 - I_2 N_1)^2 + (I_2 N_3 - I_3 N_2)^2 + (I_1 N_3 - I_3 N_1)^2}
\]

(60)
CASE 1: HORIZONTAL SURFACE ($S = \gamma = 0$):

If the slope ($s$) and azimuth ($\gamma$) of the surface are both zero (surface is horizontal), then from (39), (40) and (41): $N_1 = N_2 = 0$ and $N_3 = 1$.

The direction cosines of $R$ ($X$, $Y$, and $Z$) from (59), (60) and (61) become

\[ X = \frac{I_1 (\cos 2\gamma - I_3 \cos \gamma)}{I_1^2 + I_2^2} = \frac{\sin A (\cos 2\gamma - \cos \gamma \cos \gamma)}{\sin \gamma} \quad (62) \]

\[ Y = \frac{I_2 (\cos 2\gamma - I_3 \cos \gamma)}{I_1^2 + I_2^2} = \frac{\cos A (\cos 2\gamma - \cos \gamma \cos \gamma)}{\sin \gamma} \quad (63) \]

\[ Z = \cos \gamma \quad (64) \]

Equation (28) with $s = \gamma = 0$ becomes

$\cos \gamma = \cos \beta \quad (65)$

Substituting (65) and the identity

$\cos 2\gamma = 2 \cos^2 \gamma - 1$ into (62), (63) and (64), and using

$\sin^2 \gamma + \cos^2 \gamma = 1$, (32) becomes

$R = -\sin \gamma \sin A \gamma - \sin \gamma \cos A \beta + \cos \gamma \kappa \quad (66)$

From (30), a unit vector in the direction of an incident sun ray is

$-I = -\sin \gamma \sin A \gamma - \sin \gamma \cos A \beta - \cos \gamma \kappa \quad (67)$

Note: The direction cosines for the $X$ and $Y$ axis of (66) and (67) are equal but the direction cosines for the $Z$ axis are supplementary.
CASE 2: VERTICAL SURFACE FACING SOUTH ($S = 90^\circ, \gamma = 0$):

If the slope ($s$) of the reflecting surface is $90^\circ$ and the azimuth ($\gamma$) of the surface is zero (surface is vertical and facing south), then from (36), (37)...(43):

$I_1 = \sin z \sin A$
$I_2 = \sin z \cos A$, $I_3 = \cos z$
$N_1 = 0$, $N_2 = 1$, $N_3 = 0$,
$\cos i = \sin z \cos A$
$\cos 2i = 2 \sin^2 z \cos^2 z - 1$

The direction cosines of $R$ ($X, Y, \text{and} Z$) from (59), (60) and (61) become

$X = 0$ \hspace{1cm} (68)

$Y = \frac{\cos^2 z \sin z}{\cos^2 z} = \sin z$ \hspace{1cm} (69)

$Z = -\sin^2 z \cos z + \cos z (2 \sin^2 z - 1) = -\cos z$ \hspace{1cm} (70)

Equation (32) becomes

$R = \sin z j - \cos z k$ \hspace{1cm} (71)

From (30), a unit vector in the direction of an incident sun ray is

$-I = -\sin z j - \cos z k$ \hspace{1cm} (72)
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