UNIVERSITY OF CALIFORNIA, SAN DIEGO
SCRIPPS INSTITUTION OF OCEANOGRAPHY
VISIBILITY LABORATORY
SAN DIEGO, CALIFORNIA 92152

ATMOSPHERIC OPTICAL MEASUREMENTS IN CENTRAL COLORADO IN CONNECTION WITH LONG RANGE OBLIQUE PHOTOGRAPHY

ALMERIAN R. BOILEAU

SIO Ref. 67-26
August 1967

AFCRL, U.S. Air Force, Bedford, Massachusetts
AFAL, U.S. Air Force, Wright-Patterson AFB, Dayton, Ohio
Air Force Tasks P-7621 and P-66220
Naval Ship Systems Command, Washington, D. C.
Contract NObsr-95251, Task II
Project Serial No. SF0180201, Task 538

Approved:

Seibert Q. Duntley, Director
Visibility Laboratory

Approved for Distribution:

William A. Nierenberg, Director
Scripps Institution of Oceanography

Contents

Illustrations

ATMOSPHERIC OPTICAL MEASUREMENTS IN CENTRAL COLORADO IN CONNECTION WITH LONG RANGE OBLIQUE PHOTOGRAPHY*

Almerian R. Boileau

INTRODUCTION

The Visibility Laboratory of the University of California, San Diego Campus, is engaged in an ongoing research program relating to image transmission through the atmosphere. This work has been carried on under U.S. Navy Ship Systems Command Contract No. NObrs-95251, Task II, and this report is the final report under that task. The work is continuing, however, under Air Force Contract No. F19628-67-C-0181. Included in this report, as Appendix B, is a list of Visibility Laboratory reports and journal articles that are applicable to this work.

As a part of this program, atmospheric optical and meteorological data were recorded in central Colorado, Flight No. 660911, simultaneously with experiments in Long Range Oblique Reconnaissance Photography (LOROP) conducted by Honeywell Systems and Research Division, Minneapolis-Honeywell Corporation for the Air Force Avionics Laboratory at Wright-Patterson Air Force Base, Ohio.

The primary purpose of the flight was to obtain data for calculating atmospheric beam transmittance, contrast transmittance, and path luminance along a path of sight from Pikes Peak to Castle Rock, Colorado in support of LOROP. An additional purpose was to obtain data for calculating beam transmittances for vertical paths of sight from several selected altitudes to the ground, the altitudes being those used for photographic photometry.

SUMMARY OF RESULTS

The luminous transmittances and path luminance from Pikes Peak to Castle Rock, Colorado, were†:

Beam Transmittance – $T_{33.03\ n.m.}(14\,000, 92° 17\ , 14°) = 0.238$

Universal Contrast Transmittance – $\tau_{33.03\ n.m.}(14\,000, 92° 17\ , 14°) = 0.161$

Path Luminance – $B^*_{33.03\ n.m.}(14\,000, 95°, 14°) = 204$ Candles ft^{-2}

*This report is a result of research supported by Air Force Cambridge Research Laboratories, Air Force Avionics Laboratory, and Naval Ship Systems Command.

† Here the path length (subscript) is given in nautical miles and altitude (parenthetical quantity) is in feet. See J. Opt. Soc. Am. 47, 6, 499-500 for discussion of notation and App. Opt. 3, 5, May 1964, for discussion of transmittances.

The beam transmittances for the vertical paths of sight for the total atmosphere and the several altitudes were:

Altitude (Feet)	$T_r(z, 180°, 0°)$
∞	0.686
30 000	0.752
25 000	0.756
20 000	0.762
15 000	0.791
10 000	0.839
7 200	0.950

The target reflectances were:

Target	$_tR(0, 0°, 0°)$
White target	0.822
Gray target	0.315
Black target	0.030

FLIGHT PLAN

The two main components of the Honeywell LOROP installation were a camera located on Pikes Peak, pointing in a northerly direction, in the direction of Castle Rock, and a target array spread on the sloping southern side of a mesa (referred to as "target mesa") located several miles south of the town of Castle Rock. The altitude of the camera was approximately 14 000 feet. The altitude of the target array was approximately 6000 feet. The zenith angle of the line of sight was 92° 17 , or 2° 17 below the horizontal.

For the primary purpose of the flight it was planned to record data along the path of sight from a starting point near the camera to an end point just above the target array.

For the second part of the flight it was planned to go to altitude over the target mesa and photograph a panel of three 25-foot-square targets, one black, one white, and one gray, spread horizontally on the mesa. This panel was to be photographed from various altitudes (as listed in *Introduction and Summary*) with a modified K22 Aerial Camera mounted in the aircraft, pointing vertically downward. (Camera fitted with nine identical lenses but with nine different optical filters making nine spectrally different, simultaneous exposures.) At the completion of the photographic phase the aircraft was to be taken back to altitude and atmospheric optical data necessary for the calculation of the vertical path of sight transmittances was to be recorded during a continuous, level-attitude, constant-heading descent. Meteorological data were to be recorded throughout the flight.

During the period of this flight, atmospheric optical data were to be recorded also in a mobile ground station situated on the target mesa close to the three-target panel.

PROCEDURE

The aircraft, Air Force C-130 No. 022, took off from Peterson Field (Colorado Springs), at 0855*, 11 September 1966, and proceeded to the vicinity of Pikes Peak. At the time of take-off the dry air temperature was 14.2°C, the atmospheric pressure was 811 mb, and the sky was free of clouds. The wet bulb thermometer at take-off showed a temperature of 9.4°C, from which the relative humidity was calculated to be 56 percent. The relative humidity at take-off as recorded by AMQ-17 aerograph was 48.4 percent.

At 0919, a continuous, level-attitude descent was initiated near the camera station on Pikes Peak at an altitude of 14 000 feet. The descent ended at 0929, at 6600 feet, over the target mesa. This aircraft track is shown in Fig. 1. The pilot of the aircraft, trying to keep his flight

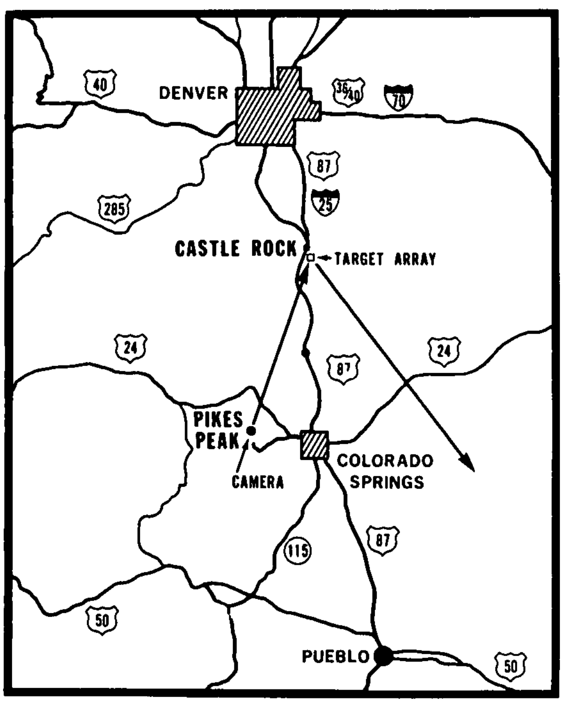


Fig. 1. Aircraft track for Flight 660911. The first descent was started at 0919 from 14 000 feet near Pikes Peak and ended at 0929 at 6600 feet over the target array. The second descent was from 1155 at 32 000 feet over the target mesa ending at 1216 at 5500 feet east of Colorado Springs. All times are mountain daylight-saving time (MDT).

path close to the slant path of sight from the camera to the target array, failed to keep the aircraft on a constant heading, or at a level attitude. As shown in Fig. 2, the aircraft heading at the start of the descent was 19° Mag., and at the end of the descent was 345° Mag. The deviation of the aircraft from a level attitude can be inferred from a plot of the altitude of the aircraft vs. time, Fig. 3.

Following the completion of the slant path of sight descent at 0929 the aircraft was flown to an altitude of 30 000 feet over the target mesa for the start of the photographic phase of the flight plan. Seven photographic runs were made, the first at 1010, at an altitude of 30 000 feet,

*Mountain daylight-saving time.

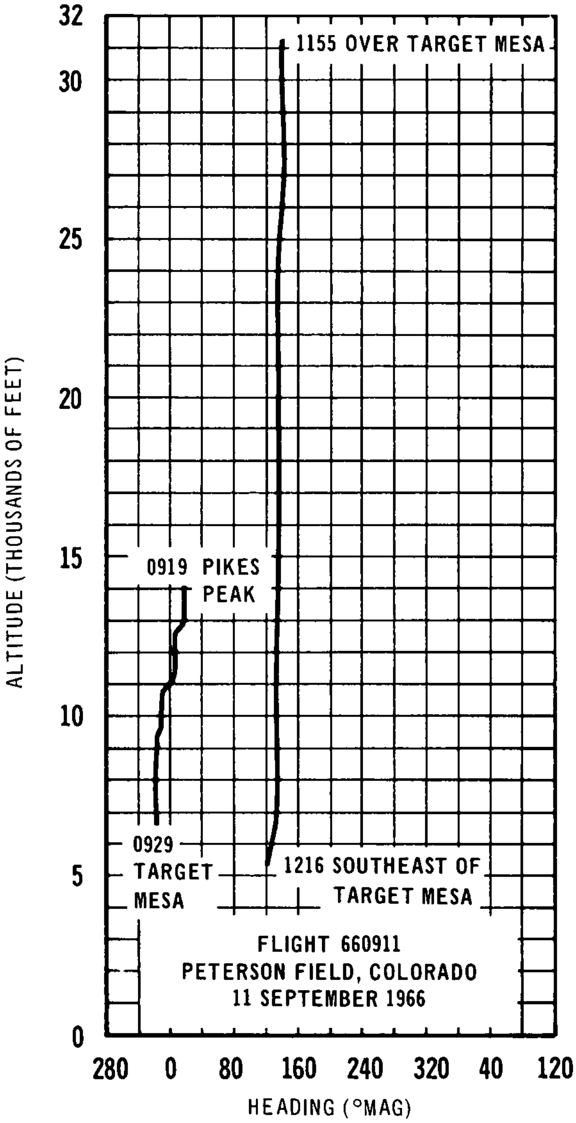


Fig. 2. Magnetic heading of aircraft during descents. During the first descent, from 0919 to 0929, the requirement to keep aircraft pointing toward target array necessitated different magnetic headings to compensate for wind drift at various altitudes. During the second descent the requirement was to maintain the selected heading.

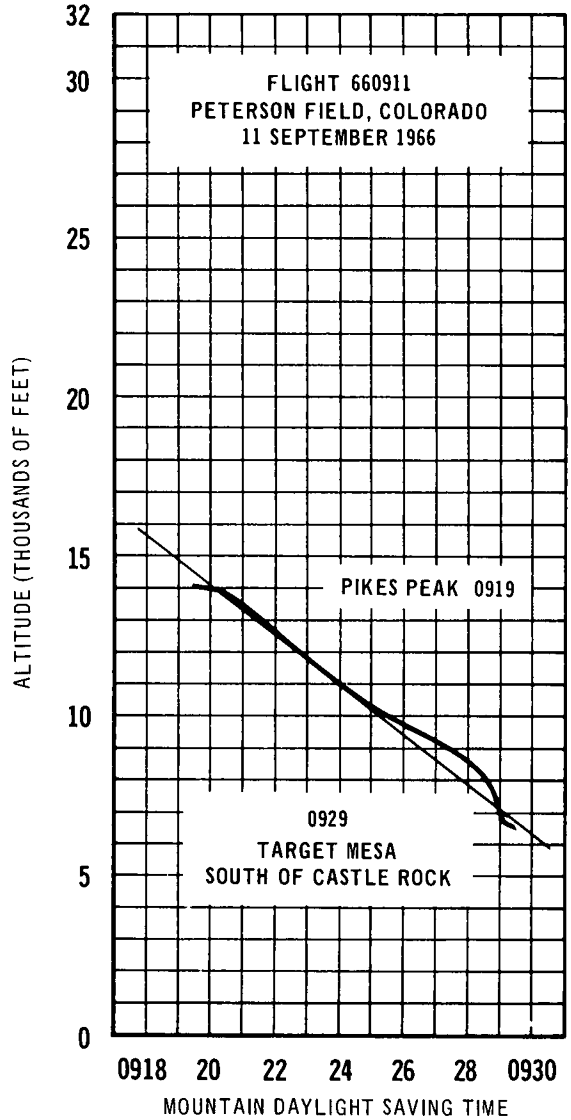


Fig. 3. Aircraft attitude during first descent. The requirement during this descent was to keep aircraft on camera path of sight from Pikes Peak to target array, a very difficult task when the target array was not discernible to the pilot until the last part of the descent.

the last at 1108, at an altitude of 7200 feet. Immediately after the photographic runs, the aircraft was flown to an altitude of 32 000 feet, over the target mesa, and at 1155 the pilot started a level attitude, constant rate descent from the target mesa in a southeasterly direction, on a heading of 150° Mag. This track is also shown in Fig. 1. The pilot kept the level attitude and a nearly constant rate of descent but did not keep the aircraft heading constant, ending the descent at 1216, at an altitude of 5500 feet, on a heading of 127° Mag. Again, the aircraft heading is shown in Fig. 2 During this descent, clouds were observed along the flight path.

The temperature profiles for both descents are shown in Fig. 4. The profiles for relative humidity, recorded on AMQ-17 aerograph, are shown in Fig. 5.

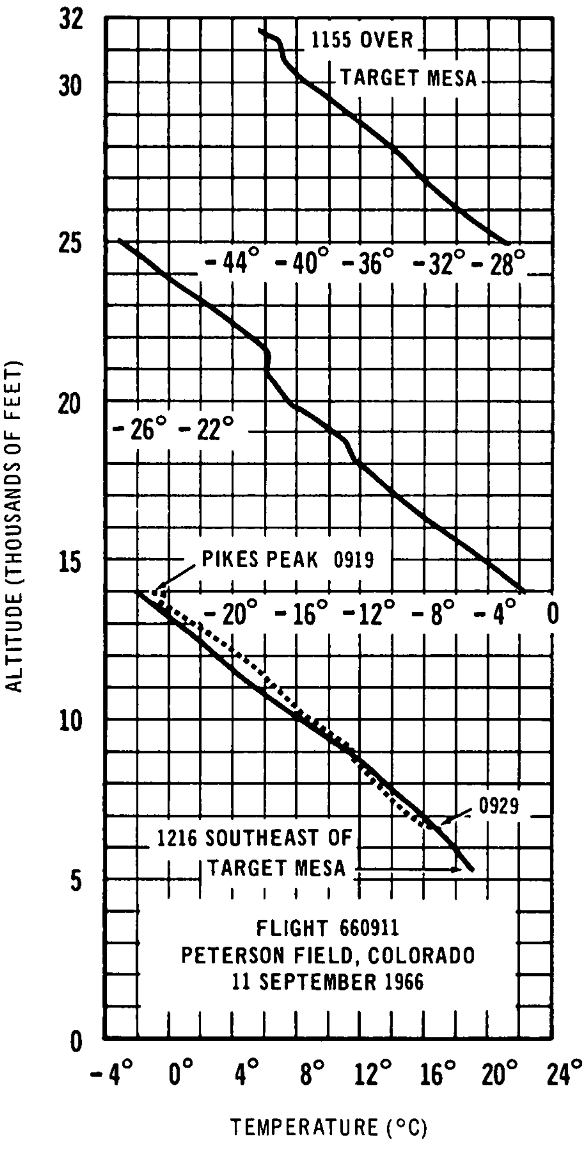


Fig. 4. Temperature profiles. The temperature profile for the first descent is shown in the broken line; the second descent is the solid line.

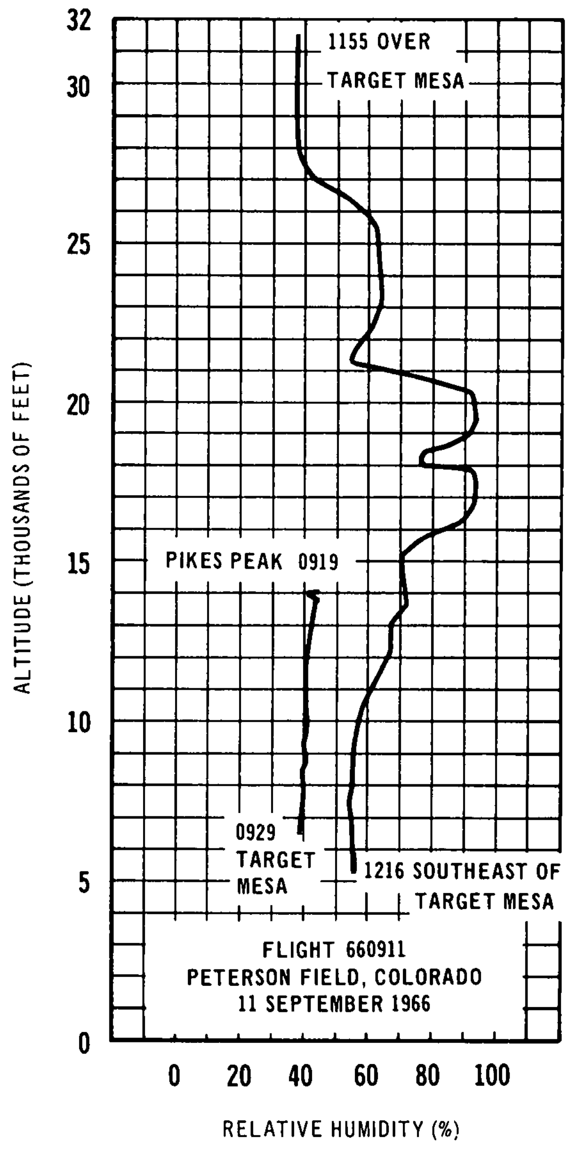


Fig. 5. Relative humidity profiles. The relative humidity during the first descent was about 40%. During the second descent, between altitudes of 21 000 feet, the altitude of the temperature inversion (see Fig. 4), and 13 500 feet, the relative humidity was 70% or more. Relative humidity of 70% is a "critical" value above which water droplets change greatly in size with small changes of relative humidity. Hence this is a value above which moisture tends to condense on exposed optical elements, a condition experienced during flight 660911.

DATA

The following optical and meteorological quantities were recorded:

Aircraft Data

QUANTITY	SYMBOL	UNITS
Downwelling illuminance	$E(z, -)$	Lumen ft^{-2}
Upwelling illuminance	$E(z, +)$	Lumen ft^{-2}
Horizontal luminance path function	$B_*(z, 90°, \phi)$	Candle ft^{-2} $n.m.^{-1}$
Equilibrium luminance	$B_q(z, 90°, \phi)$	Candle ft^{-2}
Background luminance	${}_bB_r(z, 95°, \phi)$	Candle ft^{-2}
Ambient pressure	p	mb
Ambient temperature	t	°C
Relative humidity	R.H.	%

Ground Station Data

QUANTITY	SYMBOL	UNITS
Downwelling illuminance	$E(6000, -)$	Lumen ft^{-2}
Equilibrium luminance	$B_q(6000, 90°, 0°)$	Candle ft^{-2}
Zenith luminance	$B_\infty^*(6000, 0°, 0°)$	Candle ft^{-2}
Luminance of sun's disc	${}_sB_\infty(6000, \theta_s, \phi_s)$	Candle ft^{-2}
Sky luminance 90° from sun	$B_\infty^*(6000, \theta', \phi')$	Candle ft^{-2}
Target luminances	${}_tB_0(6000, 180°, 0°)$	Candle ft^{-2}

The following quantities were derived from the above measured quantities:

QUANTITY	SYMBOL	UNITS
Terrain reflectance[1]	$R(z, 0°, 0°) = \dfrac{E(z, +)}{E(z, -)}$	Dimensionless
Target reflectances	${}_tR_0(6000, 0°, 0°) = \dfrac{\pi\, {}_tB_0(6000, 180°, 0°)}{E(6000, -)}$	Dimensionless
Attenuation length	$L(z) = \dfrac{B_q(z, 90°, \phi)}{B_*(z, 90°, \phi)}$	Nautical miles

1. Terrain plus intervening atmosphere.

QUANTITY	SYMBOL	UNITS
Beam transmittance	$T_r(z, \theta, \phi) = e^{-\sec\theta \int_0^z \frac{1}{L(0)} e^{-\frac{z}{30\,000}} dz}$	Dimensionless
	or	
	$T_r(z, \theta, \phi) = e^{-\sec\theta \, \Sigma \frac{\Delta z}{L(z)}}$	Dimensionless
Total atmospheric transmittance [1]	$T_\infty(6000, \theta_s, \phi_s) = \frac{{}_sB_\infty(6000, \theta_s, \phi_s)}{{}_sB_0(\infty, \theta_s, \phi_s)}$	Dimensionless
Total atmospheric transmittance	$T_\infty(6000, 0°, 0°) = \left[T_\infty(6000, \theta_s, \phi_s)\right]^{\cos\theta_s}$	Dimensionless
Contrast transmittance	$\tau_r(z, \theta, \phi) = \frac{T_r(z, \theta, \phi)\, {}_bB_0(z, \theta, \phi)}{{}_bB_r(z, \theta, \phi)}$	Dimensionless
Path luminance	$B_r^*(z, \theta, \phi) = {}_bB_r(z, \theta, \phi) - {}_bB_0(z, \theta, \phi)\, T_r(z, \theta, \phi)$	Candle ft^{-2}

GRAPHS

Illuminance and Reflectance

Downwelling and upwelling illuminance, E(z, −) and E(z, +), respectively, are shown in Fig. 6. Both the downwelling and upwelling illuminance profiles for the first descent, from 0919 to 0929, are "noisy". The noisiness of the downwelling profile is believed to be caused by one of the aircraft's radio antenna intermittently casting a shadow across the illuminometer. The noisiness of the upwelling illuminance profile is believed to be due to the terrain features. And, of course, the reflectance profile for the first descent, Fig. 7, is also noisy.

The illuminances for the second descent, from 1155 to 1216, are much smoother plots than the first descent plots, and the reflectance profile for that descent is also much smoother than that for the first descent.

The reflectance during the first descent varies from about seven percent to fourteen percent. The reflectance during the second descent varies about ten percent to twenty percent.

---

1. The exact equation is:

$$T_\infty(6000, \theta_s, \phi_s) = \frac{{}_sB_\infty(6000, \theta_s, \phi_s)}{{}_sB_0(\infty, \theta_s, \phi_s)} - \frac{B_\infty^*(6000, \theta_s, \phi_s)}{{}_sB_0(\infty, \theta_s, \phi_s)}$$

where $B_\infty^*(6000, \theta_s, \phi_s)$ is the luminance of the aureole of the sun very close to the sun. This quantity is, to a very close approximation, the path luminance along the path of sight to the sun, and is usually less than one percent of the luminance of the sun.

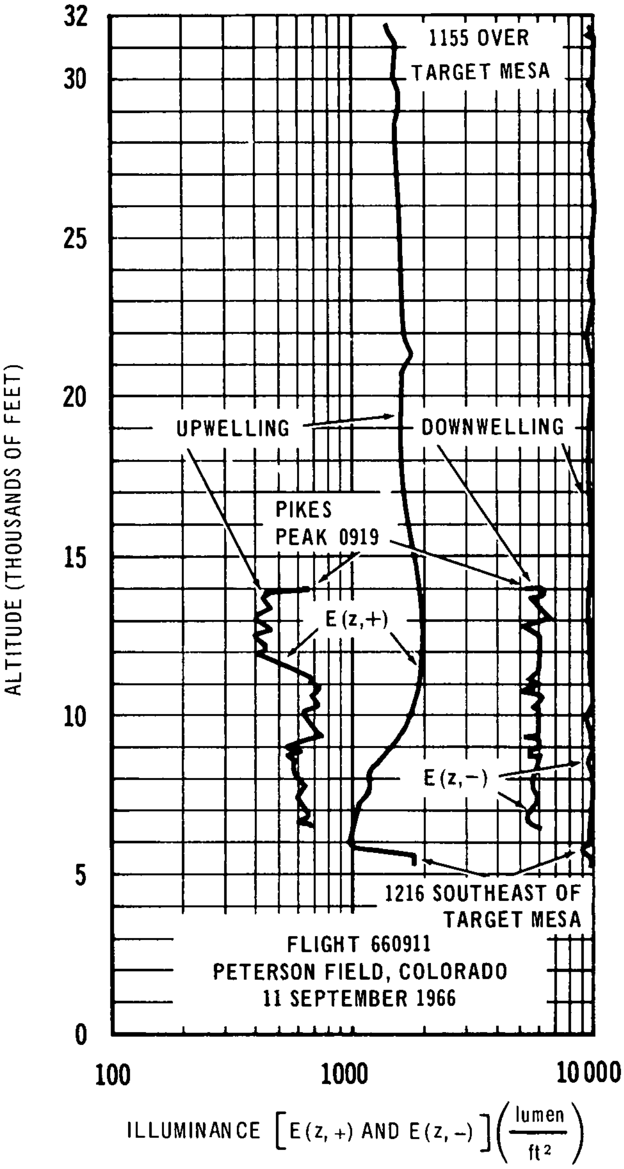


Fig. 6. Downwelling and upwelling illuminances. The irregularities in the profile of the downwelling illuminance during the first descent are believed to be due to a shadow of an antenna falling intermittently across the illuminometer. The irregularities in the profile of the upwelling illuminance during that descent are believed to be due to the terrain features and shadows caused by a low sun. The approximate zenith angles of the sun during the two descents were 58° and 37°.

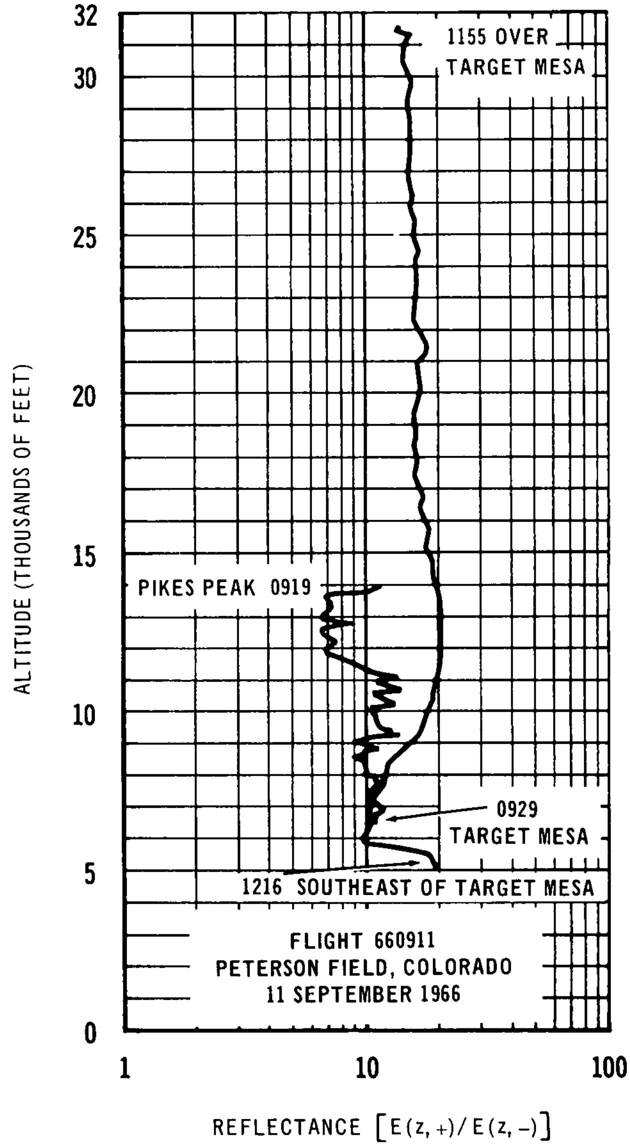
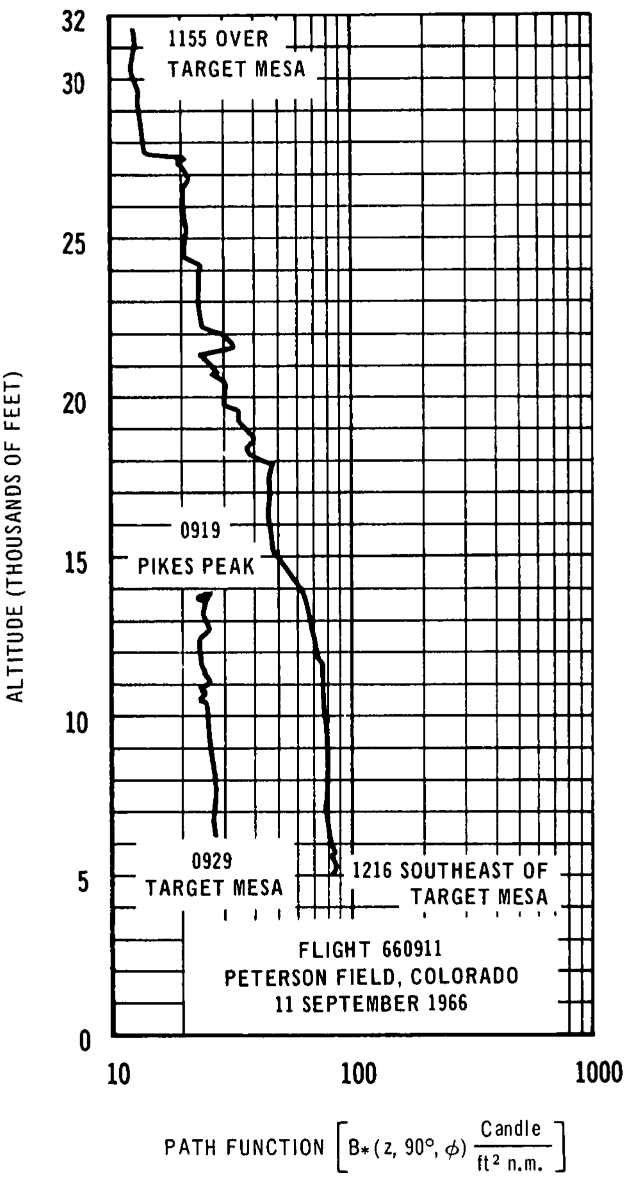


Fig. 7. Reflectance profiles, ratios of upwelling and downwelling illuminances. This quantity is the reflectance of the terrain plus the intervening atmosphere.

Path Function

Figure 8 presents the Horizontal Path Function profile for both descents. The horizontal path function profile for the first descent shows that there was an absence of haze layers between 14 000 feet and 6600 feet at the time indicated. The profile for the second descent shows the presence of several haze layers.



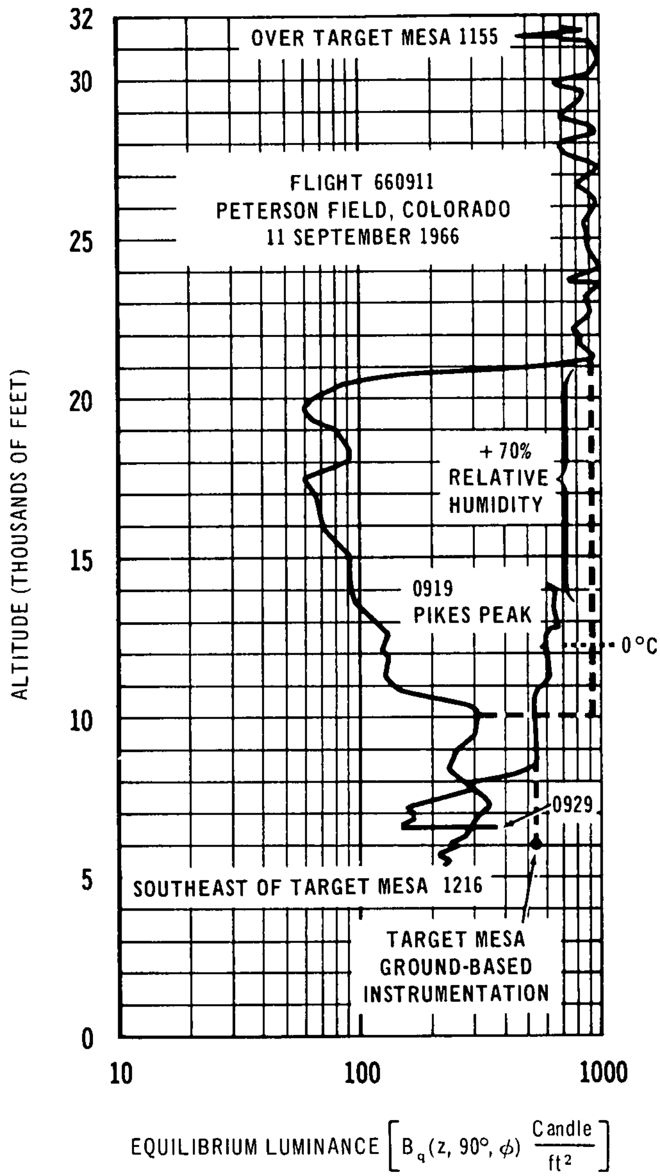


Fig. 8. Horizontal path function profiles. The atmosphere between 14 000 feet and 6600 feet was virtually free of measurable haze layers during the first descent. During the second descent clearly defined haze layers were present at 27 700 feet, 24 400 feet, 21 800 feet, and 18 100 feet. The shape of the profile between 15 400 feet and about 12 700 feet indicates an increasingly heavy but not clearly defined haze layer.

Fig. 9. Equilibrium luminance measured and derived profiles. Condensation of moisture on optical elements of the equilibrium luminance telephotometer at about 21 000 feet caused instrument to indicate incorrect luminance values down to about 10 000 feet. The broken line section of the profile between those altitudes was derived from other data. See Appendix A for derivation.

Equilibrium Luminance

The profiles of the equilibrium luminance for both descents are presented in Fig. 9. The radical change of equilibrium luminance during the first descent, at 8500 feet, was the result of either the equilibrium luminance telephotometer looking at the target mesa during the time the pilot put the aircraft in a nose-down attitude, as indicated in Fig. 3, or condensation of moisture on the telephotometer optics. The relative humidity profile, Fig. 5, shows 40 percent relative humidity at that time, so the probability of moisture having condensed on the optics is not considered likely. The general similarity between the equilibrium luminance profile, from 8500 feet down to 6600 feet, and the background luminance profile for the same altitudes (see Fig. 11), causes one to think that the radical change of equilibrium luminance was due to the pilot having put the aircraft in a nose-down attitude. Inasmuch as the equilibrium luminance as measured by the ground-based photometer during the time of this descent was 529 candles ft^{-2}, a value very close to the values between 10 000 and 8500 feet as measured by the aircraft photometer (540 candles ft^{-2}) an interpolation as shown in Fig. 9 was used to replace the questionable data of the first descent.

The equilibrium luminance profile for the second descent shows a radical change at 21 000 feet which, in view of the seventy percent relative humidity at that altitude (see Fig. 5), must be interpreted as being caused by the condensation of moisture. This profile from 10 000 feet to 5300 feet appears to be good data, but using these data for calculating attenuation length L (z) introduces doubt as to their validity.

Attenuation Length

Figure 10 presents the attenuation length for both descents. This is calculated from the equilibrium luminance values and the horizontal path function values by the equation

$$L(z) = B_q(z, 90°, \phi)/B_*(z, 90°, \phi).$$

The data for the first descent appear to be good data, and are believed to be correct. The data for the second descent below 21 400 feet are open to question, but are considered to be the best available.*

Background Luminance

Figure 11 presents the background luminance data ${}_bB_r(z, 95°, \phi)$ for both descents. The first descent, along the path of sight from Pikes Peak to the target mesa, was at an angle of 2° 17′ below the horizontal. The telephotometer with a 5° field was set at a 5° angle below the horizontal so that the upper limit of the acceptance cone was 2½° below the horizontal. This insured that if the aircraft was maintained at a level attitude the field of the telephotometer was always filled with terrain radiance and not sky radiance. It also caused the telephotometer to see the terrain from 2½° below the horizontal to 7½° below the horizontal, just below the target array at 2°17 below the horizontal. From Fig. 2 we know that the pilot did *not* maintain the aircraft in a level attitude, but we do not know how far he deviated from the horizontal attitude.

---

*See Appendix A for the development of the derived data, the data indicated by the broken line.

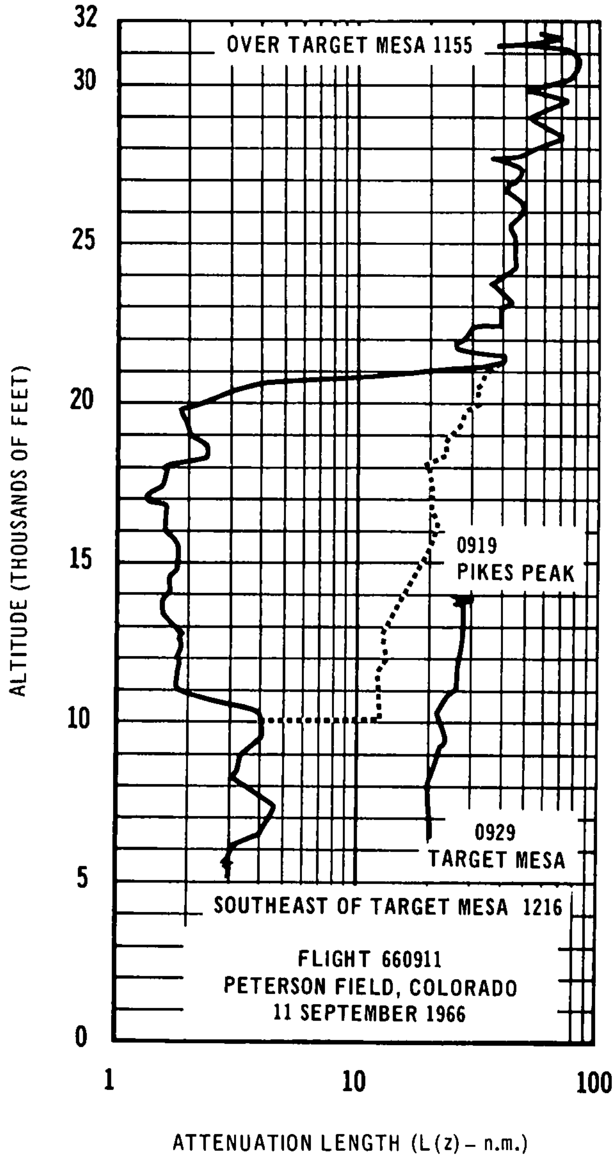


Fig. 10. Attenuation length profiles calculated from equilibrium luminance and horizontal path function data. The broken line section of the profile of the second descent resulted from using the derived part of the equilibrium luminance profile (Fig. 9.).

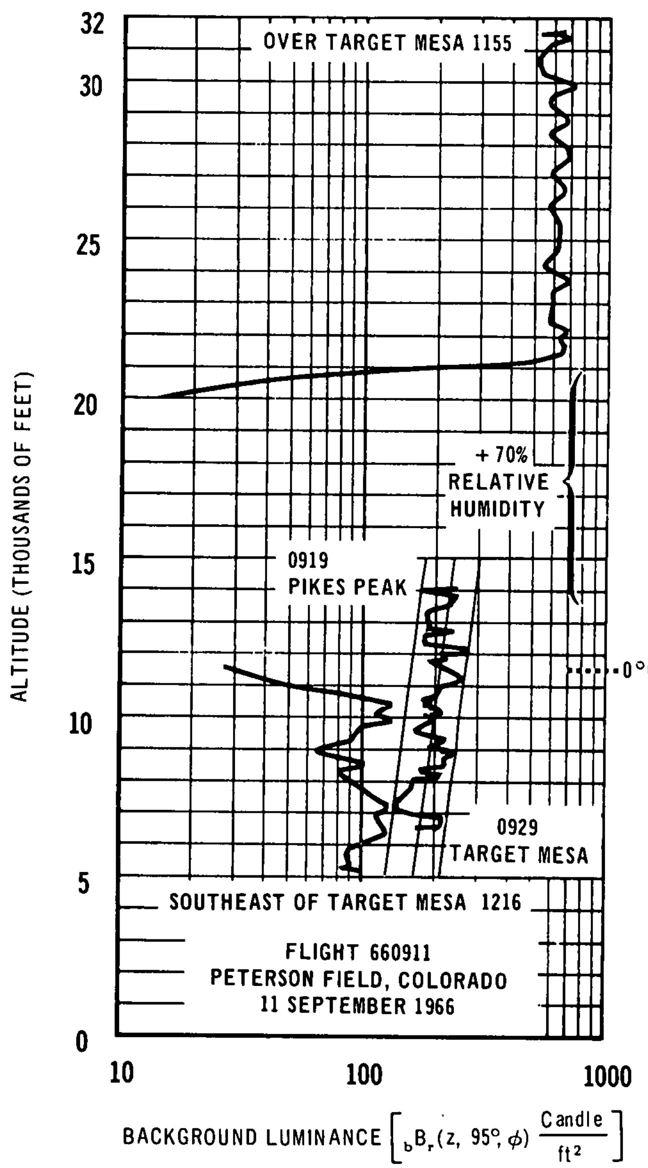


Fig. 11. Apparent background luminance profiles for a zenith angle of 95°, i.e., 5° below the horizontal. The most probable values of the apparent background luminance for the two ends of the camera path of sight (measured during the first descent) were taken as the mid values between the two bracketing parallel straight lines. The background luminance data for the second descent between 21 500 feet and 10 500 feet were lost because of condensation of moisture.

The background luminance profile for the first descent, as shown in Fig. 11, shows considerable variation in the luminance values. The low luminance values at 13 000 feet and 7400 feet were the values recorded when the aircraft was in a nose-down attitude. The high luminance value at 9000 feet appears to be associated with a nose-high attitude at that altitude.

In an attempt to get a most probable value of background luminance to be used for determining the path luminance, the background luminance profile was bracketed by two parallel straight lines (on the semilogarithmic graph paper) and the midpoint at 14 000 feet and 6600 feet were taken as the most probable values of apparent background luminance for the two ends of the path of sight.

Background luminance data were lost during the second descent, from 21 500 feet down to 10 500 feet, due to condensation of moisture on the optical system of the photometer. Below 10 500 feet the data are probably good. It is interesting to note that from 31 500 feet down to 21 500 feet the variations in the profiles of the equilibrium luminance $B_q(z, 90°, \phi)$ and background luminance ${}_bB_r(z, 95°, \phi)$ are virtually inverse of each other, the background luminance being approximately seventy percent of the equilibrium luminance. Below 10 500 feet the profiles are virtually the same, but now the background luminance is approximately twenty-five percent of the equilibrium luminance.

Figure 12 is a plot of horizontal path function $B_*(z, 90°, \phi)$ vs. simultaneously recorded relative humidity values. The horizontal path function values of 45 candles $ft^{-2} n.m.^{-1}$ and above are those recorded at the 15 000-foot altitude and below. The horizontal path function values less than 45 candles $ft^{-2} n.m.^{-1}$ are those recorded above 15 000 feet. The plot of the horizontal path function values of the upper atmosphere vs. relative humidity shows a pattern normally occuring in a maritime-tropical air mass, that of increasing path function value with increase of relative humidity.* The path function values below 15 000 feet do *not* show this pattern, but show instead a pattern of increasing values of path function with *decreasing* values of relative humidity. The air mass for the area and day in question was reported by the weather bureau as being a continental-polar air mass.

ACKNOWLEDGEMENTS

The organization of the field trip, the coordination with other activities, and the collection of data were the responsibilities of Mr. Richard W. Johnson, Senior Development Engineer, and Mr. Gary C. Barnett, Assistant Development Engineer. Mr. Barnett was assisted in the aircraft data collecting by Mr. Kenneth W. McMaster, Senior Electronics Technician, and Mr. Robert L. Sydnor, Senior Laboratory Mechanician. Mr. Johnson was assisted in the ground station data collecting by Mr. George F. Simas, Senior Electronics Technician. All of the above personnel are employees of the Visibility Laboratory.

The Air Force crew of the C-130 aircraft, based at the Air Force Electronic Systems Branch, L. G. Hanscom Field, Bedford, Mass., was Capt. Paul Griswold, pilot, Capt. Ronald Delmanowsky, co-pilot, Sgt. Fred Carress, crew chief, and Airman Robert Steele, crew member.

* See "Correlation Between Measured Path Function and Relative Humidity", Almerian R. Boileau, SIO Ref. 59-5, 1 February 1959.

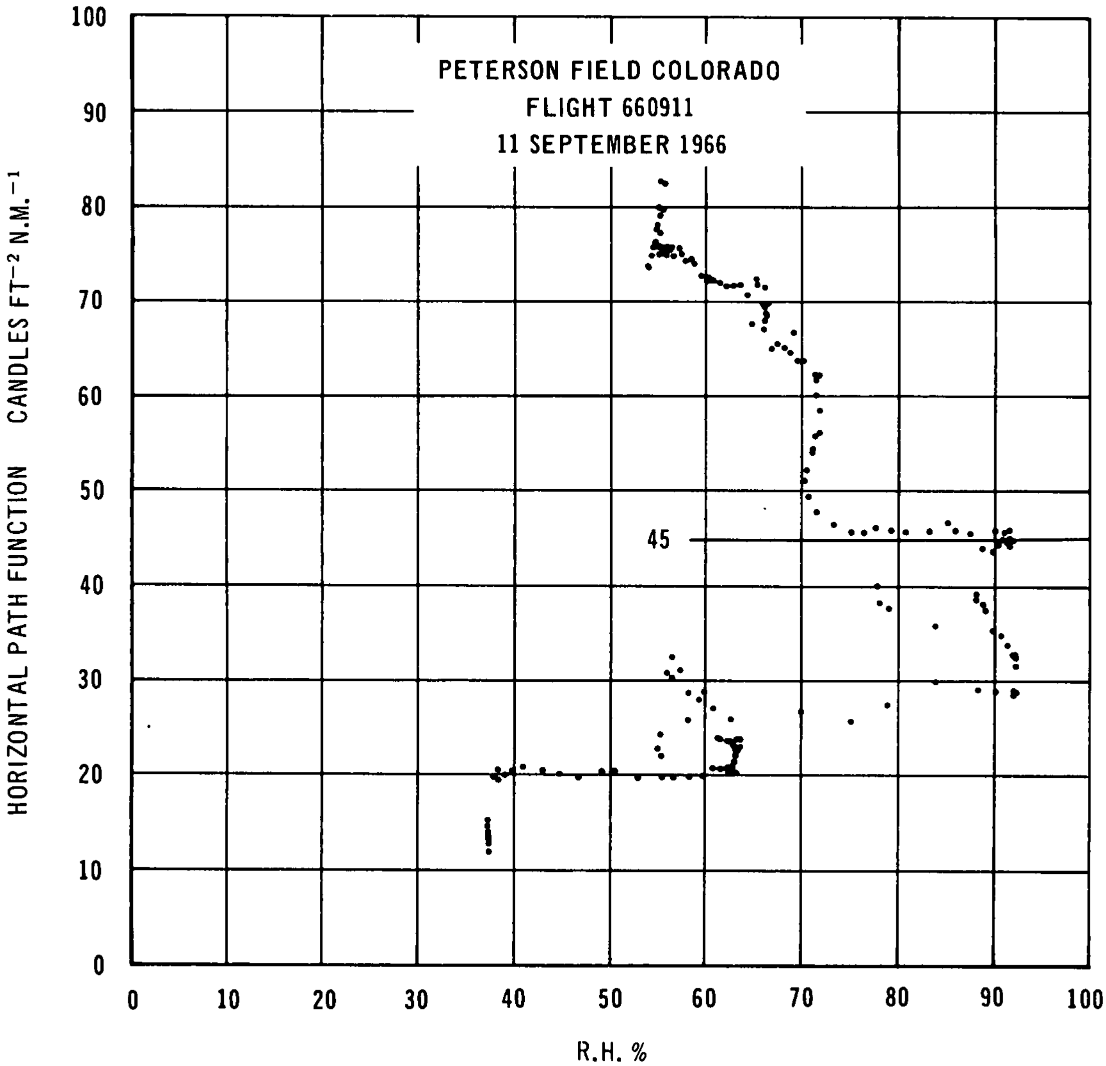


Fig. 12. Horizontal path function vs. relative humidity. The values of horizontal path function of 45 Candles Ft^{-2} n.m.$^{-1}$ and less were those measured in the upper atmosphere, above 15 000 feet, and show a pattern normally associated with a maritime-tropical air mass. The values above 45 Candles Ft^{-2} n.m.$^{-1}$ were those measured in the lower atmosphere, below 15 000 feet, do not follow this pattern. The weather bureau reported a continental-polar air mass for this geographical area.

APPENDIX A

Replacement of Faulty Equilibrium Luminance Data

The replacement of the faulty equilibrium luminance data due to condensation of moisture on the telephotometer optics was accomplished by the following steps:

(1) Determining, by the use of good data, the transmittance* for vertical path of sight from 32 000 feet to 21 200 feet.

(2) Similarly determining the transmittance for vertical path of sight from 10 000 feet to 6000 feet using *probably* good data.

(3) Obtaining total atmospheric transmittance for vertical path of sight from ground-based optical equipment.

(4) Calculating a probable transmittance from 21 200 feet to 10 000 feet from the data in (1), (2), and (3).

(5) Testing, by successive trials, equilibrium luminance profiles over the altitude range in question, calculating comparable attenuation length profiles, and finally, obtaining a reasonable transmittance for vertical path of sight over that range.

Discussion

Calculations of transmittances for a vertical path of sight is done by using one of the two following equations:

$$T_r(0, 0°, 0°) = e^{-\int_0^z \frac{dz}{L(z)}} \qquad (1)$$

when the slope of the attenuation length profile (plotted on semilogarithmic paper) is the same as the slope of the attenuation length profile for an optically standard atmosphere, and

$$T_r(0, 0°, 0°) = e^{-\sum_0^z \frac{\Delta z}{L(z)}} \qquad (2)$$

when the attenuation length profile is irregular, i.e., does not have a straight line plot. In both cases it is necessary to know L(z) the attenuation length as a function of altitude. The attenuation length L(z) is calculated from the equilibrium luminance $B_q(z, 90°, \phi)$ and the luminous path function $B_*(z, 90°, \phi)$ by the equation

$$L(z) = B_q(z, 90°, \phi) / B_*(z, 90°, \phi) \qquad (3)$$

* "Transmittance" throughout this appendix refers to beam transmittance.

An L(z) profile is not possible however, because even though the path function data, shown in Fig. 8, are good data, the equilibrium luminance data, shown in Fig. 9, must be evaluated.

In Fig. 9, the equilibrium luminance profile for the second descent consists of three separate segments. The high altitude segment, from 31 000 feet to 21 200 feet, appear to be good data when properly evaluated. The mid altitude segment appears to be useless because of suspected condensation of moisture on the telephotometer optics. The low altitude segment is *probably* good data.

Upper Altitude Transmittance

The fluctuations of the equilibrium luminance of the high altitude segment are attributed to the passage of small clouds across the field of the equilibrium luminance telephotometer. The photometer was pointed in a southerly direction, looking toward the sun, so that the clouds were back-lighted. This caused the clouds to appear dark against the equilibrium luminance of the sky. Accordingly, the high altitude attenuation length profile, in Fig. 8, fluctuated from a series of maximum values which are believed to be correct values to lesser, believed-to-be-incorrect values. Two straight lines having the slope for an optical standard atmosphere fit the two series of maximum values so that transmittance for the two altitude ranges from 32 000 feet to 28 000 feet and 28 000 feet to 21 200 feet were found by using Eq. 1.

Lower Altitude Transmittance

The attenuation length profile for the low altitude segment is not amenable to the above treatment and, therefore, required that the transmittance for that segment be found by the use of Eq. 2.

Total Atmospheric Transmittance

The transmittance of the vertical path of sight for the total atmosphere was determined from the ground station measurements. Two measurements made at the ground station are the apparent luminance of the sun ${}_sB_\infty(6000, \theta_s, \phi_s)$ and the luminance of the sun's aureole $B^*_\infty(6000, \theta_s, \phi_s)$ approximately ¼° from the edge of the sun's disc. Then the transmittance of the total atmosphere at an zenith angle θ_s is found by the equation

$$T_\infty(6000, \theta_s, \phi_s) = \frac{{}_sB_\infty(6000, \theta_s, \phi_s)}{{}_sB_0(\infty, \theta_s, \phi_s)} - \frac{B^*_\infty(6000, \theta_s, \phi_s)}{{}_sB_0(\infty, \theta_s, \phi_s)} \tag{4}$$

and the transmittance for the vertical path of sight is found by the equation

$$T_\infty(6000, 0°, \phi_s) = T_\infty(6000, \theta_s, \phi_s)^{\cos\theta_s} \tag{5}$$

The right hand term of the right member of Eq. 4 has been found to be several orders of magnitude less than the left hand term of that member. Accordingly, that term is disregarded. Thus, the transmittance determined by the ground based equipment situated on the target mesa was

$$T_\infty(6000, \theta_s, \phi_s) \doteq \frac{{}_sB_\infty(6000, \theta_s, \phi_s)}{{}_sB_0(\infty, \theta_s, \phi_s)} \tag{6}$$

and the transmittance for the vertical path of sight was found by Eq. 5.

Calculating Probable Transmittance

The transmittance for a segmented path of sight is the product of the transmittances for all of the segment. That is

$$T_r = T_{r_1} \cdot T_{r_2} \cdot \ldots\ldots\ T_{r_n} \tag{7}$$

Accordingly, an approximate value of the mid altitude transmittance was found as

$$T_{11\,200}(10\,000, 0°, \theta°) = \frac{T_\infty(6000, 0°, 0°)}{T_{10\,800}(21\,200, 0°, 0°) \times T_{4000}(6000, 0°, 0°)} \tag{8}$$

By making the equilibrium luminance $B_q(z, 90°, \phi)$ have a constant value of 920 candles ft^{-2} from 21 300 feet down to 10 100 feet, as shown in Fig. 9, the attenuation length profile between those altitudes as shown in Fig. 10 was produced.

A probable mid-altitude transmittance between these altitudes, $T_{11\,200}(10\,000, 0°, 0°)$ was then calculated by Eq. 2. When the total transmittance between 32 000 feet and 6000 feet was calculated as the product of the three separate transmittances the value was found to be consistent with the transmittance for (1) the total atmosphere $T_\infty(6000, 0°, 0°)$ and (2) the transmittance $T_\infty(32\,000, 0°, 0°)$ for the atmosphere above 32 000 feet.

APPENDIX B

References

S. Q. Duntley, Almerian R. Boileau, and Rudolph W. Preisendorfer, "Image Transmission by the Troposphere I." J. Opt. Soc. Am., 47, 499 (1957).

"Correlation Between Measured Path Function and Relative Humidity", Almerian R. Boileau, SIO Report Ref. 59-5, 1 February 1959.

"Optical Contrast Reduction Factors for Downward Looking Cases", Almerian R. Boileau, SIO Report Ref. 59-57, October 1959.

Seibert Q. Duntley, et al, "Visibility". Appl. Opt. 3, 550 (1964).

Jacqueline I. Gordon and Peggy V. Church, "Sky Luminances and Directional Luminous Reflectances of Objects and Backgrounds for a Moderately High Sun." Appl. Opt. 5, 793 (1966).

Almerian R. Boileau and Jacqueline I. Gordon, "Atmospheric Properties and Reflectances of Ocean Water and Other Surfaces for a Low Sun." Appl. Opt. 5, 803 (1966).

Jacqueline I. Gordon and Peggy V. Church, "Overcast Sky Luminances and Directional Luminous Reflectances of Objects and Backgrounds Under Overcast Skies." Appl. Opt. 5, 919 (1966).

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Visibility Laboratory University of California San Diego, California 92152	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP

3 REPORT TITLE

ATMOSPHERIC OPTICAL MEASUREMENTS IN CENTRAL COLORADO IN CONNECTION WITH LONG RANGE OBLIQUE PHOTOGRAPHY

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5 AUTHOR(S) (Last name, first name, initial)

Almerian R. Boileau

6. REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
AUGUST 1967	20	7

8a CONTRACT OR GRANT NO Naval Ship Systems Command, NObsr-95251 b PROJECT NO SF0180201, Task 538 c Task II d	9a ORIGINATOR'S REPORT NUMBER(S) SIO Ref. 67-26 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 AVAILABILITY/LIMITATION NOTICES

Qualified requesters may obtain copies of this report from DDC.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY AFCRL, U.S. Air Force, Bedford, Massachusetts AFAL, U.S. Air Force, Wright-Patterson AFB, Dayton, Ohio Naval Ship Systems Command, Washington, D. C.

13 ABSTRACT

Atmospheric optical data were recorded in the Pikes Peak – Castle Rock – Colorado Springs area simultaneously with long range oblique photography (LOROP). Over the 33 nautical mile path from Pikes Peak to Castle Rock the beam transmittance was 0.238, the universal contrast transmittance was 0.161, and the path luminance was 204 Candles Ft^{-2}. Beam transmittance for vertical path of sight over Castle Rock varied from 0.686 for the total atmosphere to 0.950 for 1200-foot path. Other measured and calculated quantities: downwelling and upwelling illuminances, terrain reflectance, horizontal path function, equilibrium luminance, attenuation length, and background luminance; plus temperature and relative humidity.

DD FORM 1 JAN 64 1473 0101-807-6800

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Atmospheric optics						
Beam transmittance						
Contrast transmittance						
Illuminance						
Terrain reflectance						
Central Colorado data						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

UNCLASSIFIED

Security Classification