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Atmospheric optical measurements in western Florida, Flight 112, Part I

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ATMOSPHERIC OPTICAL MEASUREMENTS IN WESTERN FLORIDA,

FLIGHT 112, Part I

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TABLE OF CONTENTS

ATMOSPHERIC OPTICAL MEASUREMENTS IN WESTERN FLORIDA, FLIGHT 112, Part I*

by

Almerian R. Boileau

INTRODUCTION AND SUMMARY

The Visibility Laboratory of the University of California, La Jolla Campus, is engaged in an on-going research program studying optical image transmission through the atmosphere. In connection with this work several data gathering flights were made in western Florida in the vicinity of Eglin Air Force Base in the spring of 1957. Flight 112, the subject of this report, was one of these.

Part I of this report, presents the data as a catalogue of the recorded optical measurements as they varied with altitude, time of day, azimuthal angle with respect to the sun, and meteorological conditions. Not included is the distribution of the sky's luminance and radiance which will be presented as one or more additional parts of this report.

*This report is a result of research which has been supported by the Geophysics Research Directorate, Air Force Cambridge Research Center, Bedford, Massachusetts, and the U. S. Navy Bureau of Ships.

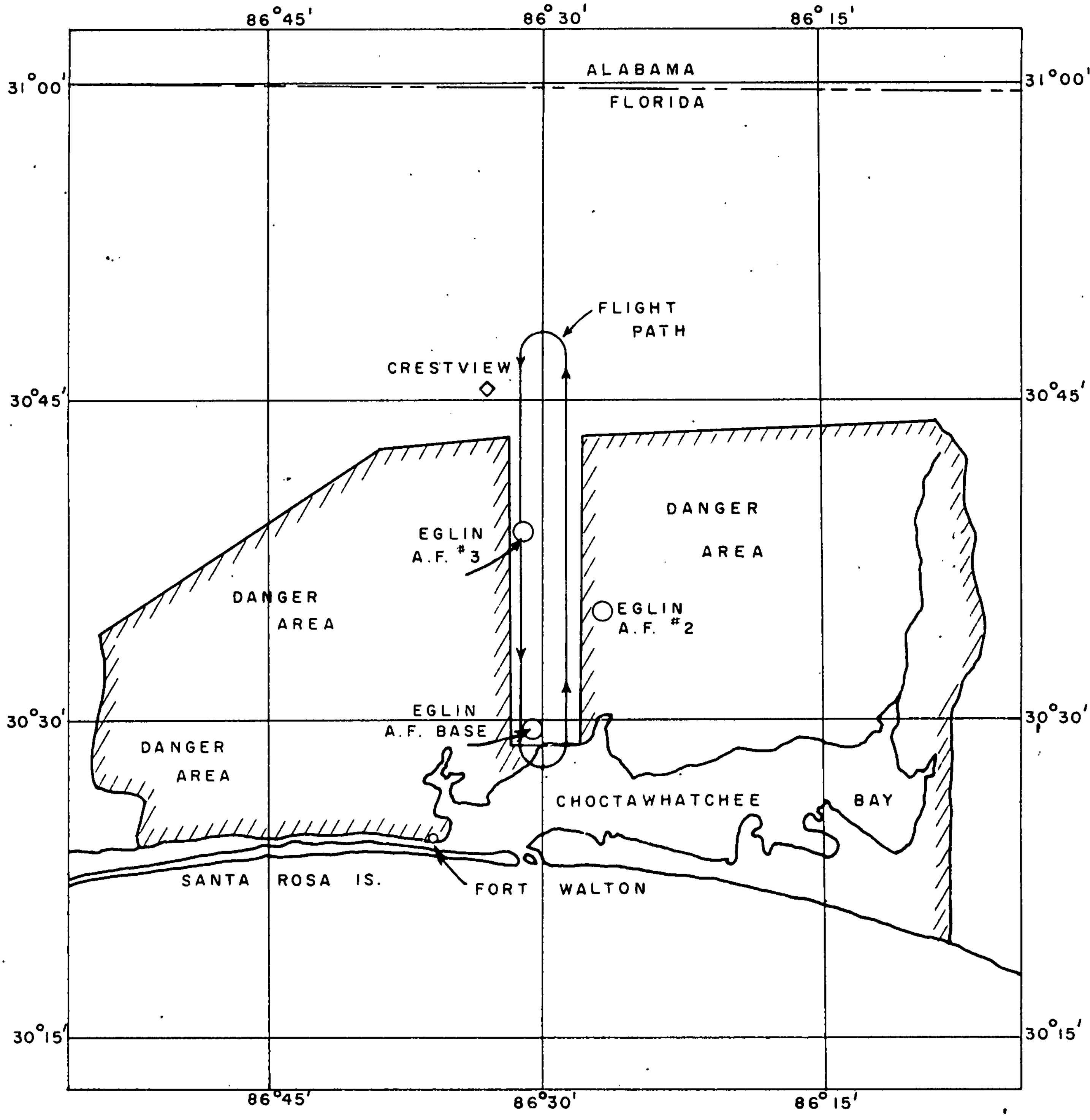
PROCEDURE

U. S. Air Force XB-29, No. 4224725 took off from Eglin Air Force Base, Florida, at 0917 Eastern Standard Time, 16 May 1957 to begin Flight 112. This airplane carried optical and meteorological instruments from the Visibility Laboratory of the University of California, La Jolla Campus. At the time of the flight there were nine optical instruments in operation plus one meteorological instrument, viz., a resistance type indicating vortex thermometer. The airplane arrived at 20 000 feet altitude preparatory to data gathering at 1010.

Data were gathered from 20 000 feet to 1 000 feet as follows:

Eastern Standard Time	Altitudes	Headings
1010 - 1036	At 20 000 feet	000°
1042 - 1057	20 000 to 10 000 feet	355°
1057 - 1108	At 10 000 feet	175°
1108 - 1118	10 000 feet to 1 000 feet	000°
1119 - 1127	At 1 000 feet	180°
1200 - 1204	On Eglin A.F. Base runway	185°

The flight pattern was north and south between Eglin Air Force Base and Crestview as shown in Figure 1.



FLIGHT TRACK

FIGURE 1
FLIGHT 112
16 MAY 1957
CRESTVIEW, FLORIDA

The day was clear and warm. During ascent, from take-off to 20 000 feet, the air temperature was recorded at each 100 feet of altitude. The temperature profile is shown as Figure 2. Near the profile, at the appropriate altitudes, are subjective notes made by the project engineer during ascent. The smooth curves drawn near the temperature profile represent pseudo-adiabats. Note that in general the observed haze layers are at altitudes where the temperature profile has a greater slope than the pseudo-adiabats; the haze layer just below 10 000 feet and the lack of an observed haze layer between 16 500 feet and 17 500 feet are exceptions.

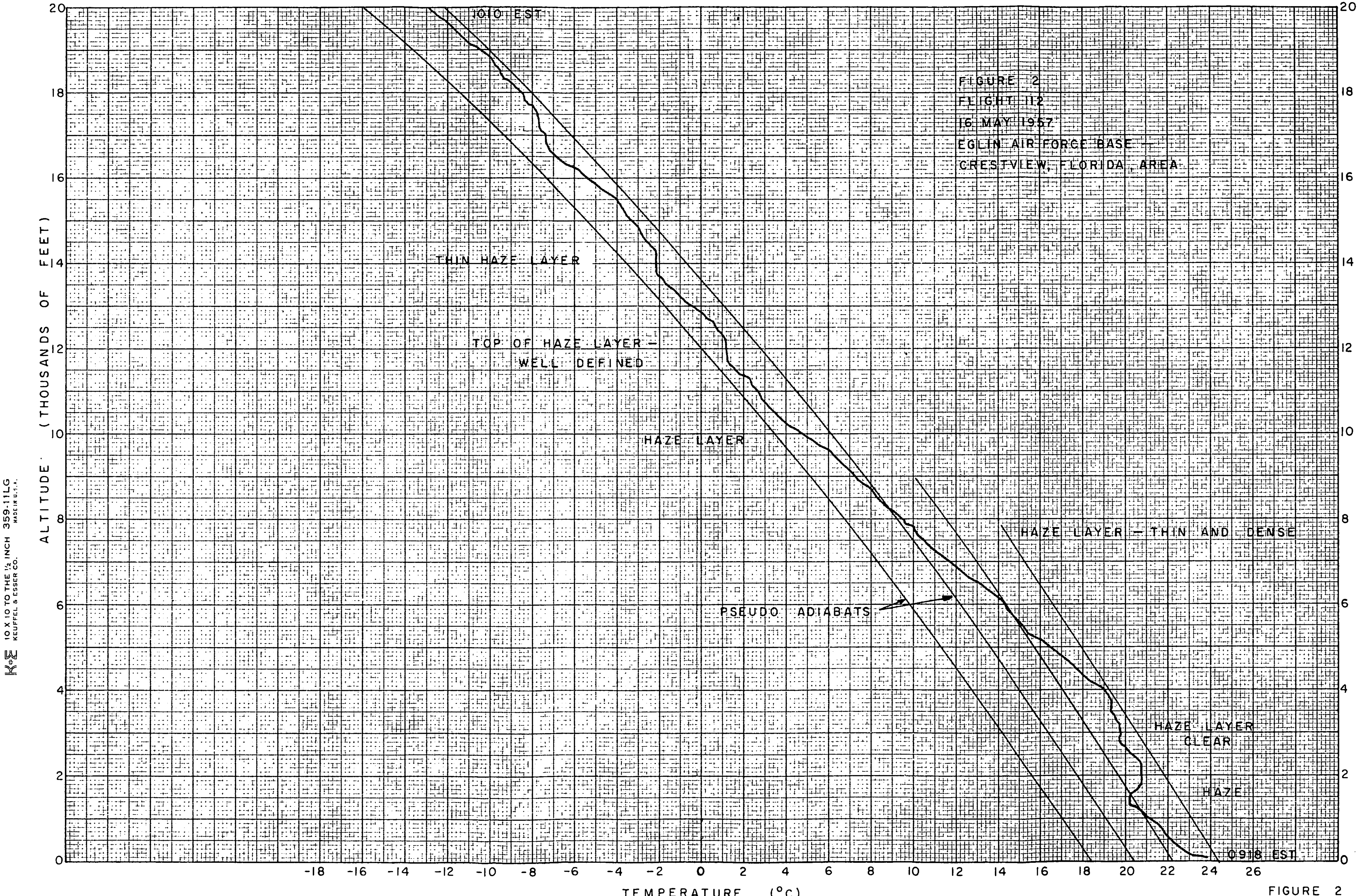
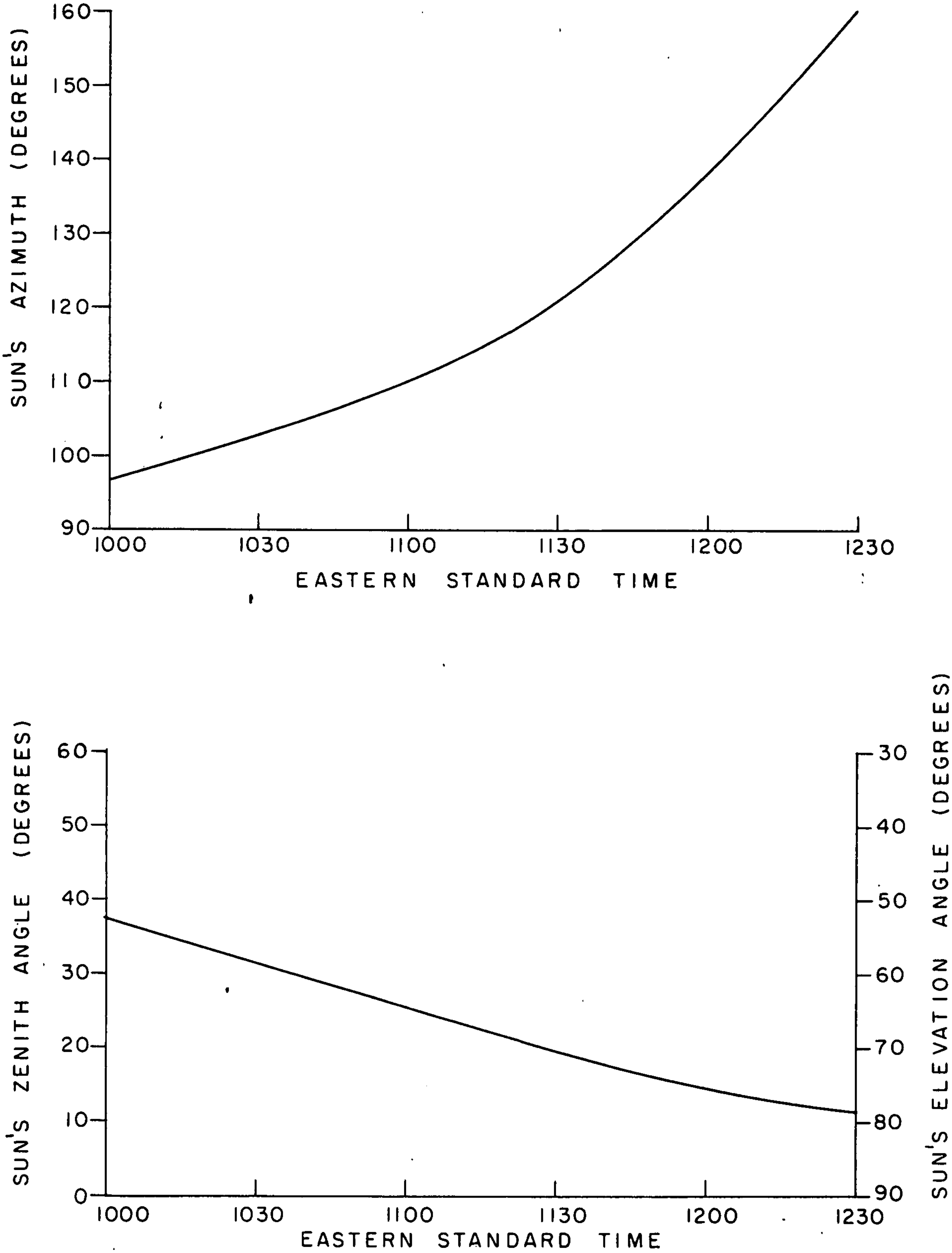

1010 EST
FIGURE 2
FLIGHT 112
16 MAY 1957
EGLIN AIR FORCE BASE —
CRESTVIEW, FLORIDA, AREA
THIN HAZE LAYER
TOP OF HAZE LAYER —
WELL DEFINED
HAZE LAYER
HAZE LAYER — THIN AND DENSE
PSEUDO ADIABATS
HAZE LAYER
CLEAR
HAZE
0918 EST
ALTITUDE (THOUSANDS OF FEET)
TEMPERATURE (°C)
0
2
4
6
8
10
12
14
16
18
20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
26
10 X 10 TO THE ½ INCH 359-11LG
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 2

Color prints made from Kodachrome transparencies taken by the project engineer in the bombardier's position of the B-29 describe the day much better than words. These are shown in Figures 3 through 9 immediately following this page. These were taken through the glass windows at the bombardier's position. Reflection of objects inside the airplane are seen in several of the prints.

Figures 3-9, included in the first printing of this report, consisted of color prints from Kodachrome transparencies made during data-gathering runs. These depict the appearance of the sky as seen from 20,000, 10,000, and 1,000 feet and while they give the reader a visual description of the atmosphere during flight, something highly desirable, they are not necessary for using the data in Figures 11-43. Accordingly, these Figures are not included in this second printing.

Azimuthal and zenith angles of the sun computed for 30.5° N. Lat. and 86.5° W. Long., the approximate position of Eglin Air Force Base, are shown in Figure 10 immediately following this page. These angles are plotted for the period 1 000 to 1 200 Eastern Standard Time. The ordinates of the lower graph are shown as zenith angles on the left and as elevation angles on the right, these angles being complementary.



SUN'S AZIMUTHUL AND ZENITH ANGLES
DURING FLIGHT 112, COMPUTED FOR
POSITION 30.5° N. LAT., 86.5° W. LONG.

FIGURE 10
FLIGHT 112
16 MAY 1957
EGLIN A. F. BASE

PRESENTATION OF DATA

The data recorded during Flight 112 are presented herewith as a catalogue of graphs. Each measured quantity is shown as it varied with altitude and time or as it varied with respect to the sun's azimuth. The computed apparent attenuation length values, $L_A(z)$, are similarly presented.

The purpose of this report is to make available the data which were recorded and, in the case of the attenuation length, computed. Interpretation and discussion of applications of these data are reserved for subsequent reports.

The following notes concerning the graphs are pertinent:

1. Each instrument measured a photometric quantity and its radiometric counterpart. This was accomplished by successively interposing four different optical filters into the flux path of each instrument. The four measured quantities were sampled once each filter cycle. (See Figure 44 for filter-phototube spectral responses). The filter cycling and rate of descent were such that data points were recorded approximately three times per thousand feet of altitude. The graphs presented herein are faired curves based on the data points.

2. Certain figures, e.g., Figures 17, 18, 19, and 20, have a vertical line drawn which represents the limiting high value of the instrument's response. This condition is further indicated by the words

"OFF SCALE" printed to the right of the vertical line. At the conclusion of this field trip the sensitivity of each of those instruments was adjusted to permit higher values to be recorded.

3. In Figures 18, 19, and 20, the two limiting graphs which enclose the crosshatched area represent the range of values obtained by the nadir telephotometer. This telephotometer has a 1° circular cone acceptance angle. At 20 000 feet the area subtending this angle is a disc 350 feet in diameter, at lower altitudes the diameter is less. Hence areas of different reflectances, which are seen successively as the airplane flies along a prescribed course, will cause the nadir luminances and radiances to fluctuate over a range of values.

CATALOGUE OF GRAPHS

Atmospheric Optical Measurements vs Altitude and Time

Atmospheric Optical Measurements by Azimuthal

Distribution at Constant Altitude

Time	Altitude	Figure	Page
1016	20 000 feet	26-31	35-40
1105	10 000 feet	32-37	41-46
1119	1 000 feet	38-43	47-52

The horizontal luminous path function, horizontal radiant path function, horizontal luminance, and horizontal radiance were recorded at each of the above altitudes and from these recorded values apparent attenuation lengths for the photometric case and two radiometric cases were computed. At each of the above altitudes the upper and lower sky luminance and radiance values were also measured; these quantities will be the subject of additional parts of this report.

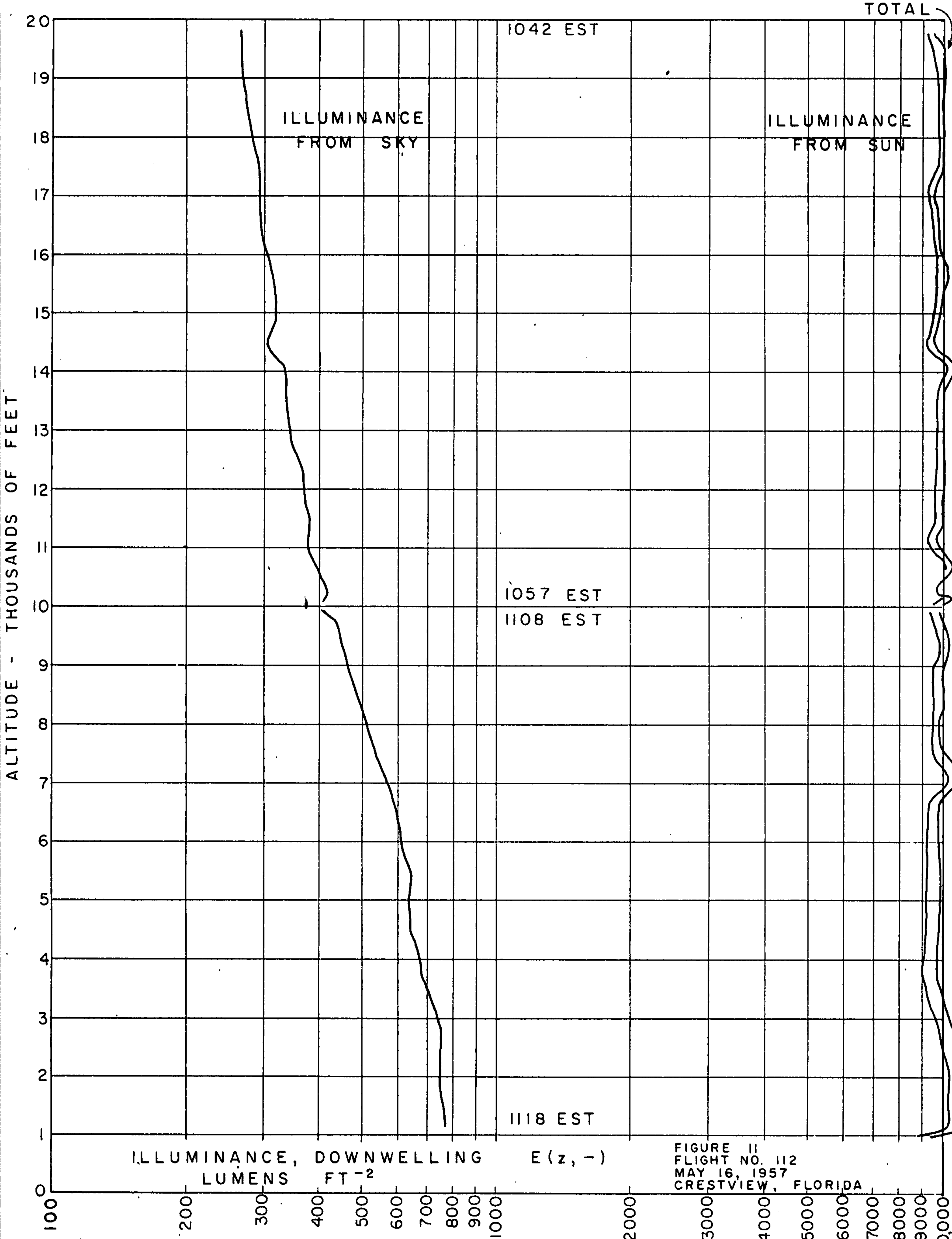


FIGURE 11
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

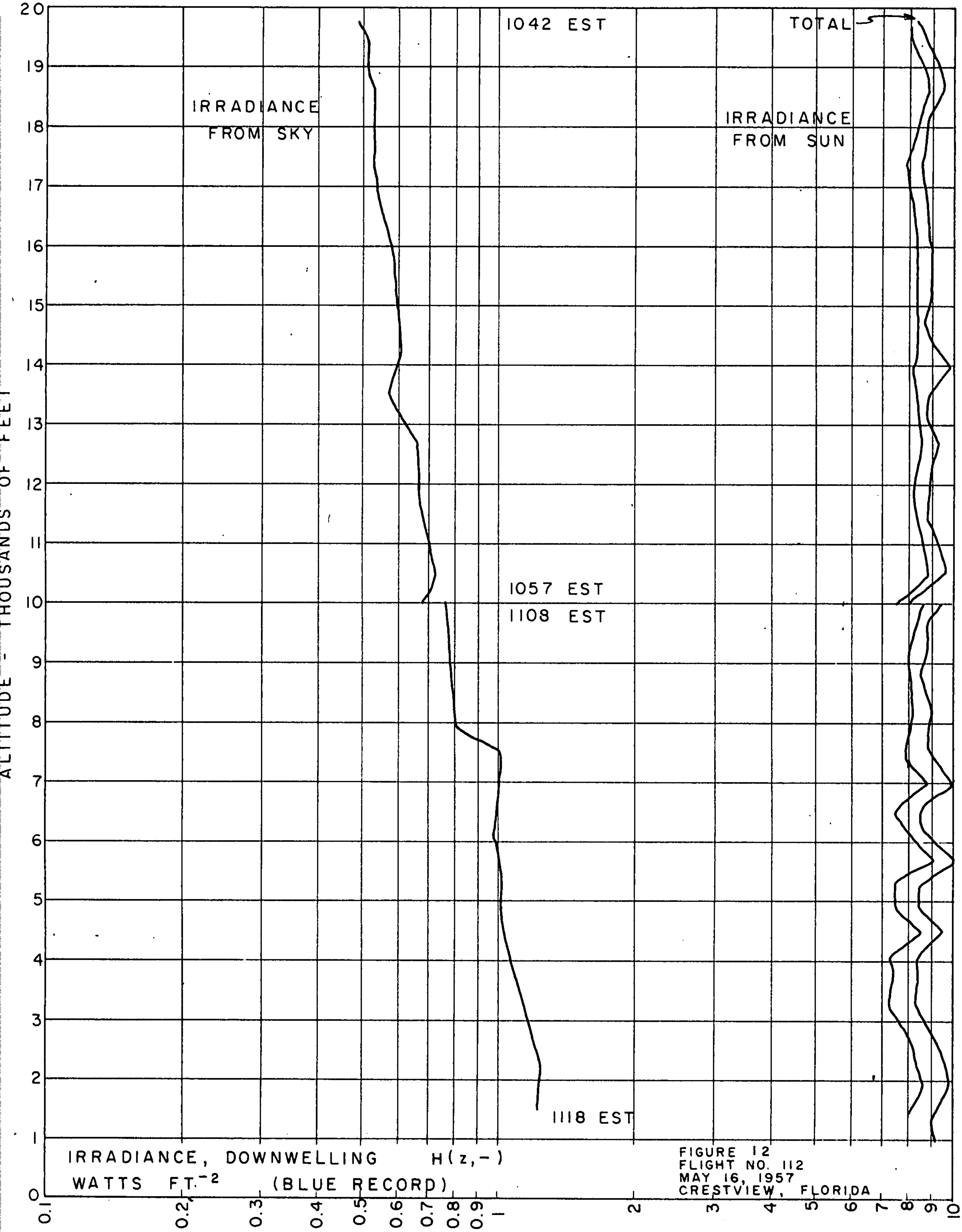


FIGURE 12
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

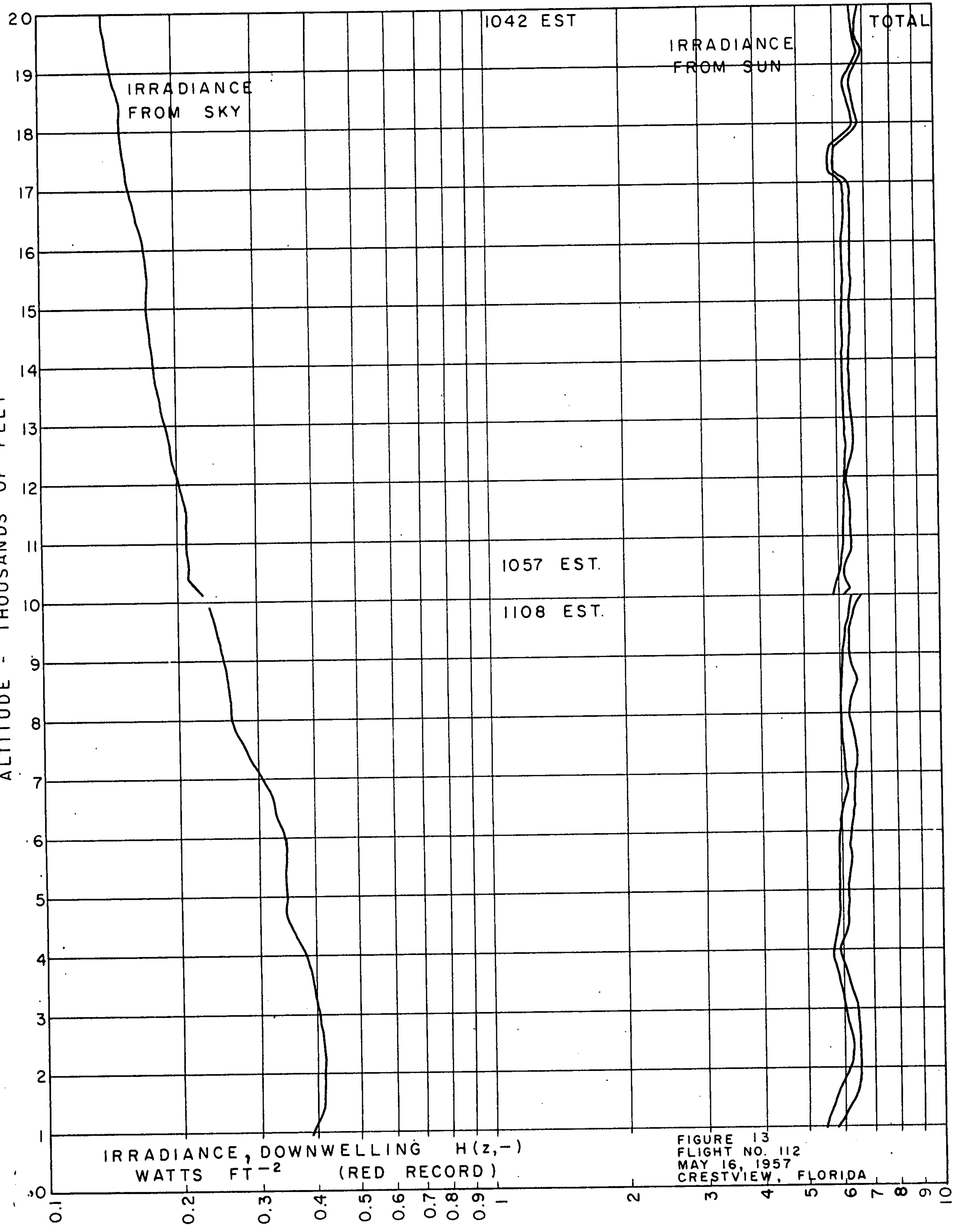


FIGURE 13
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

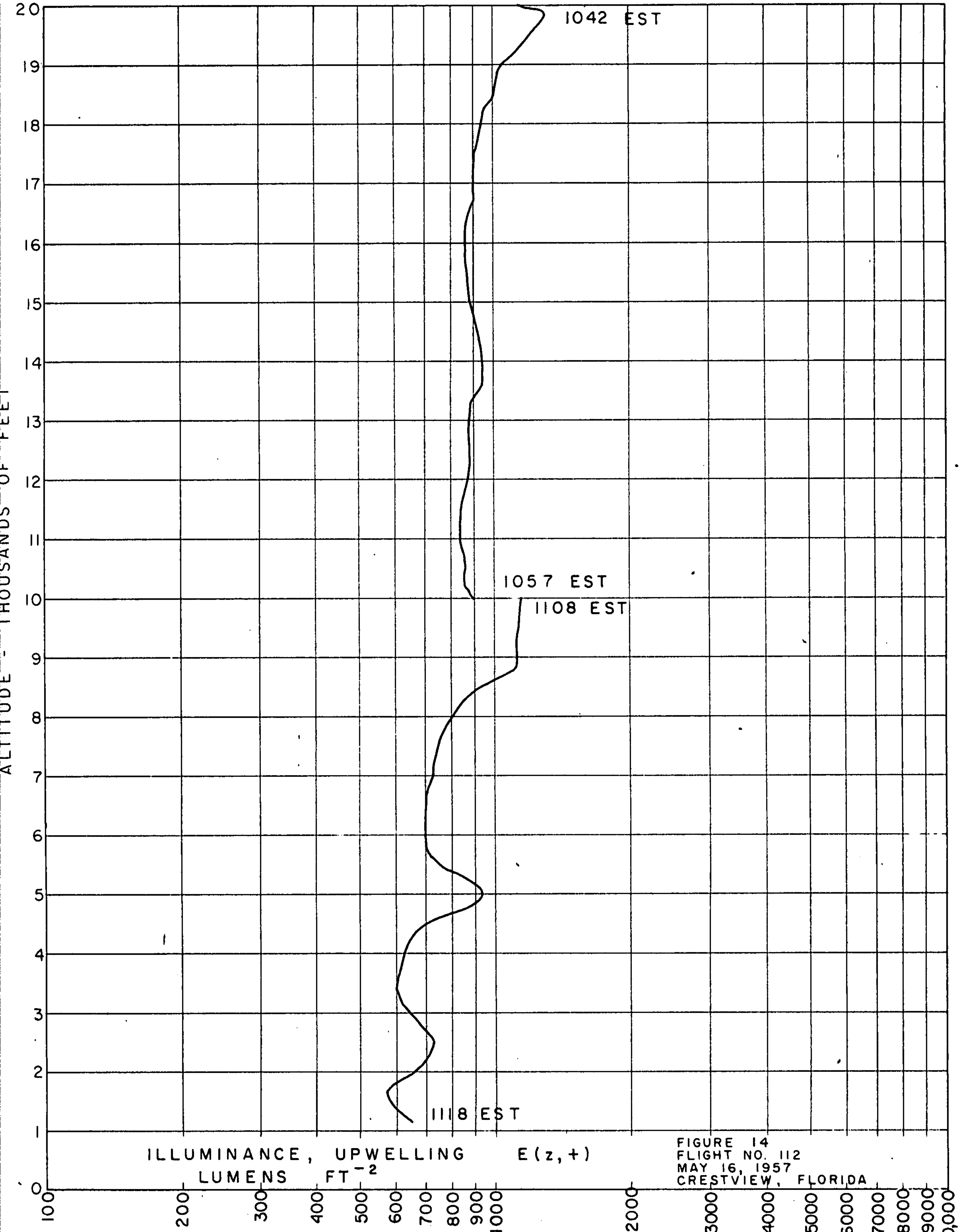


FIGURE 14
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

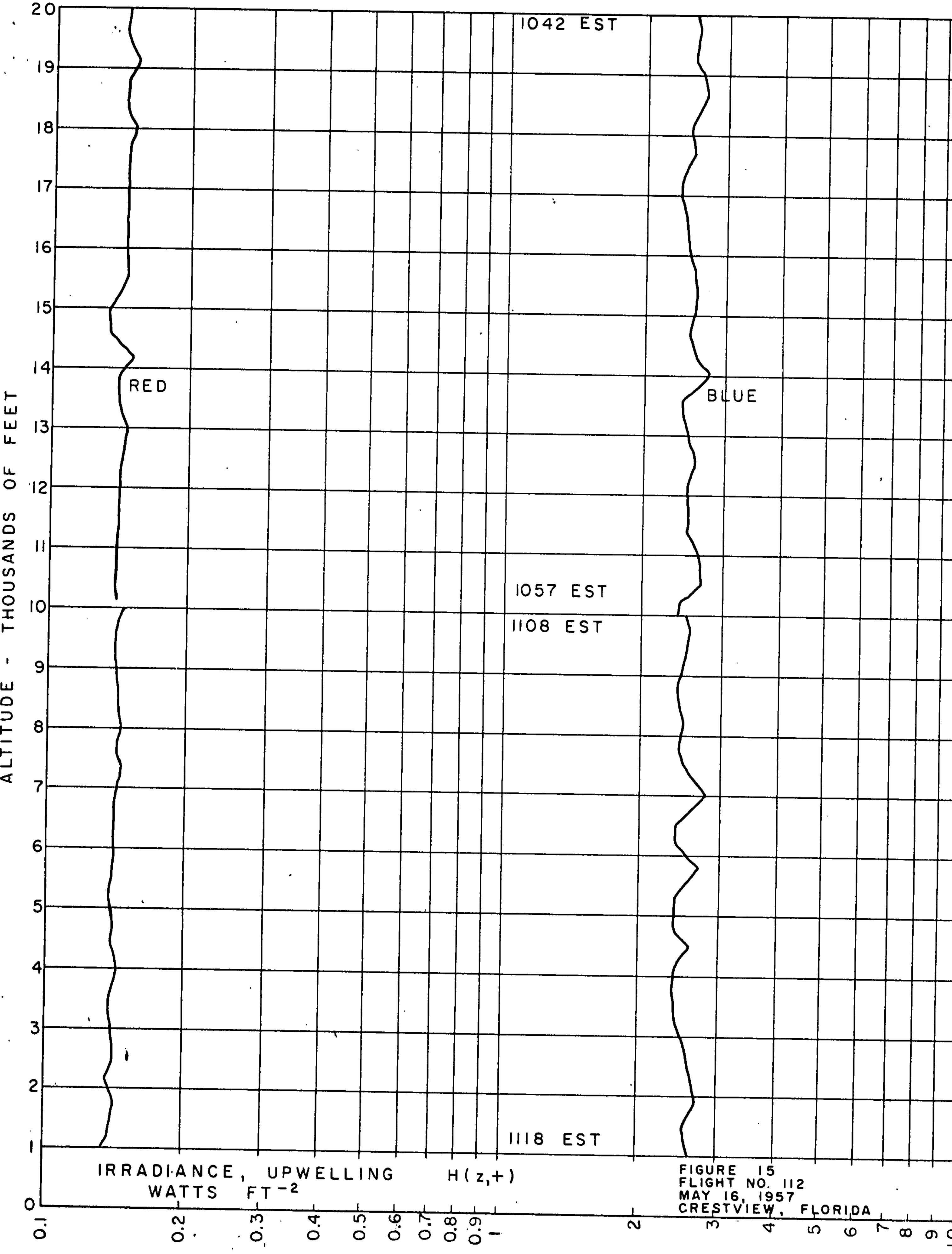


FIGURE 15
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

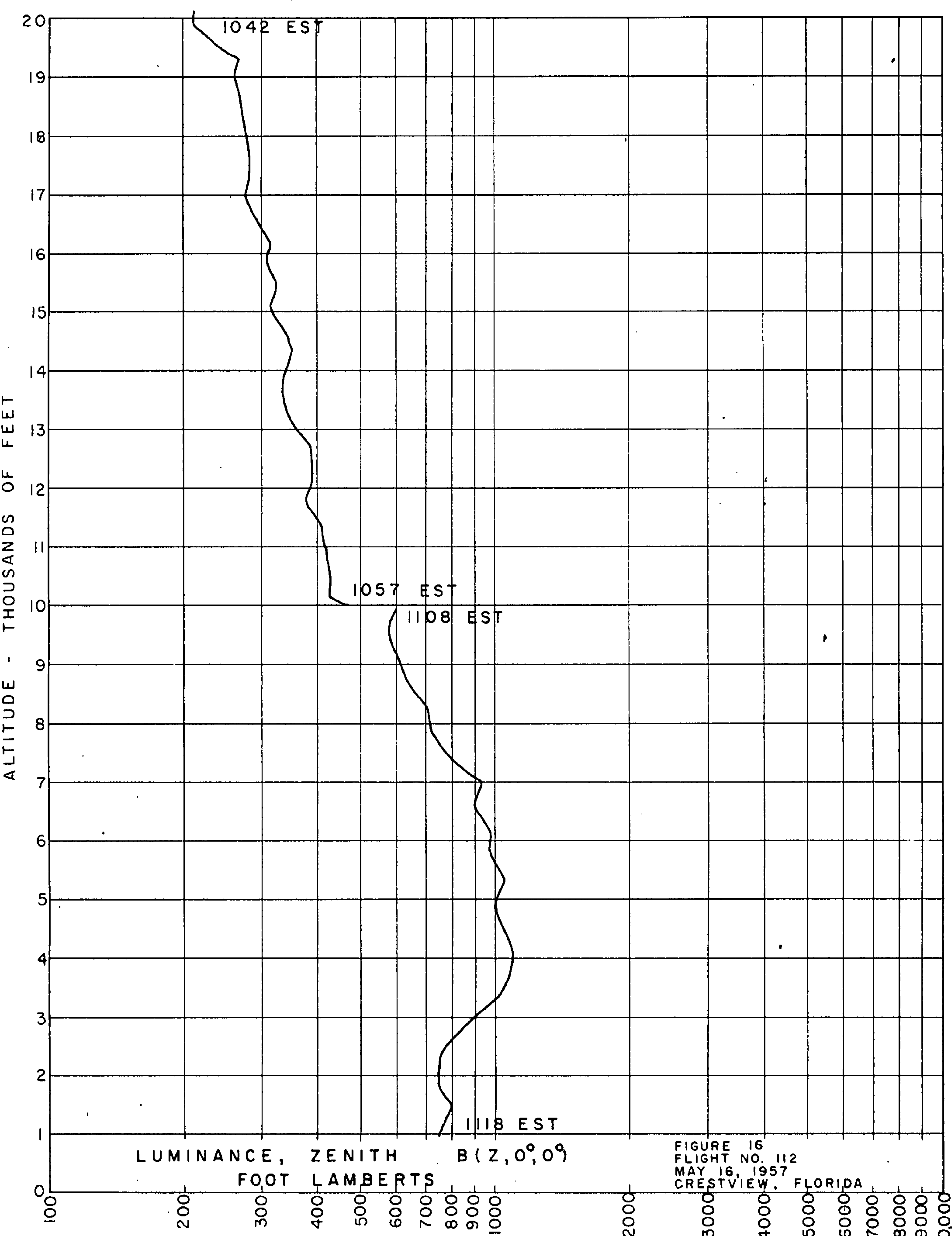


FIGURE 16
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

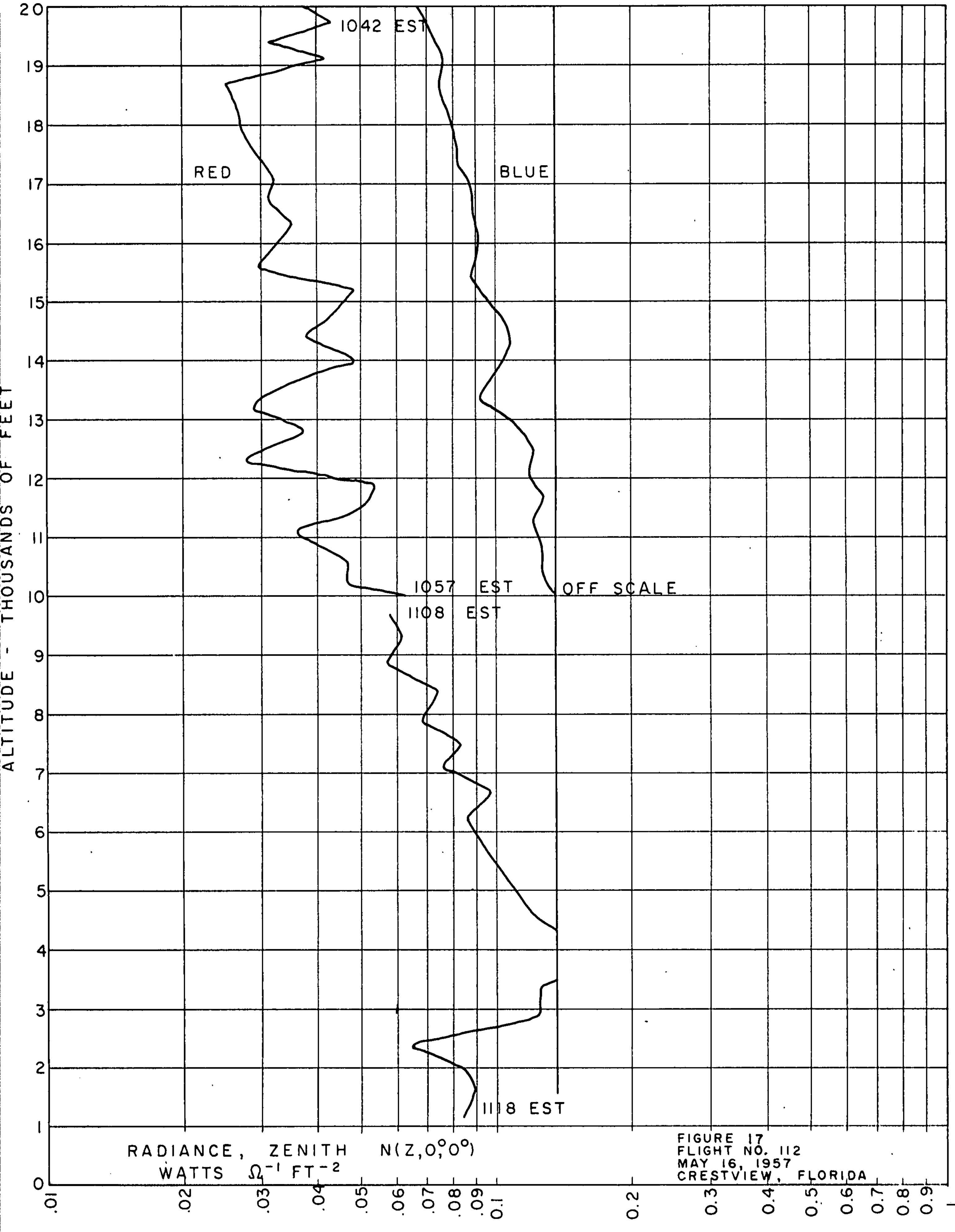
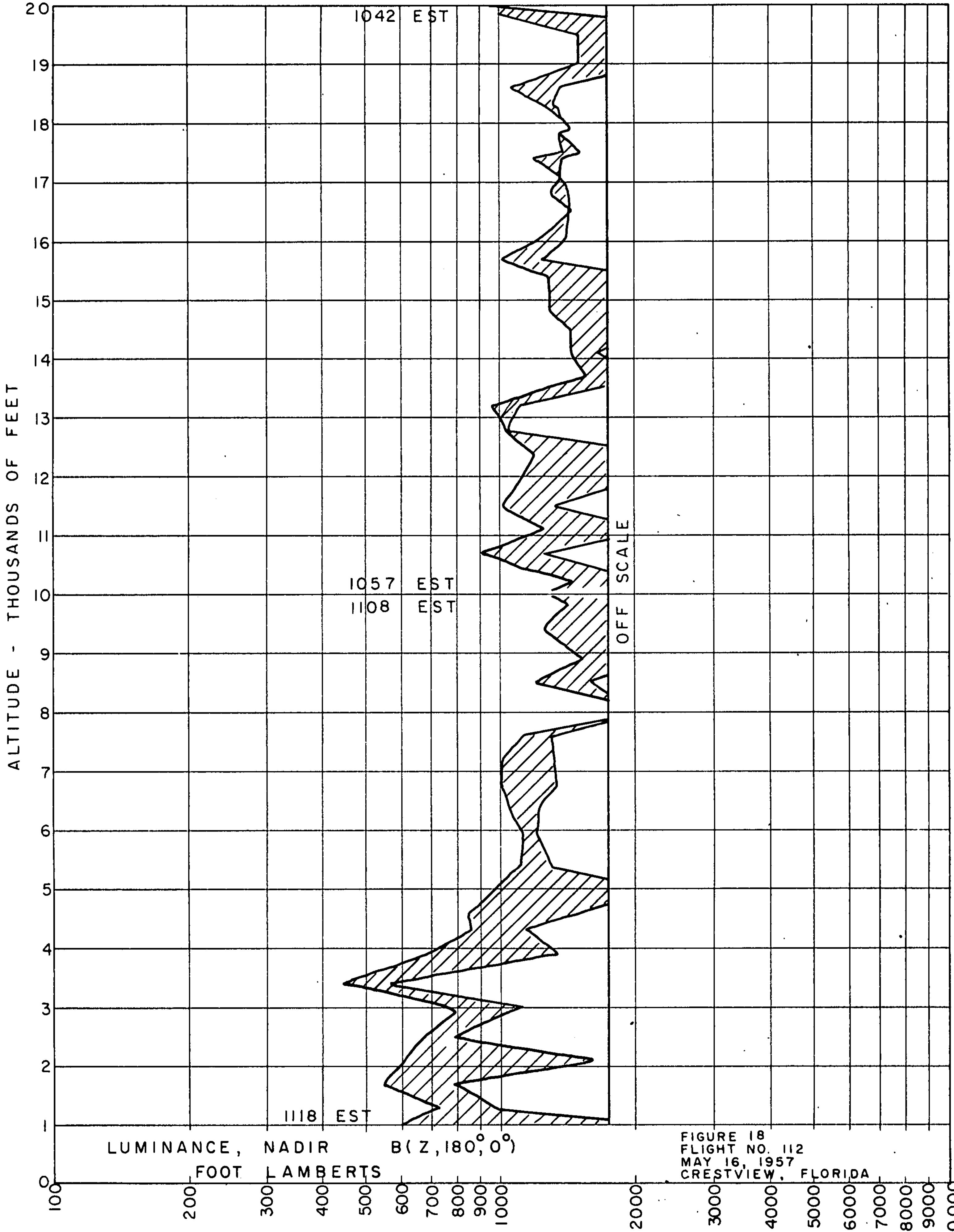


FIGURE 17
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA


1042 EST
1057 EST
1108 EST
1118 EST
OFF SCALE
ALTITUDE - THOUSANDS OF FEET
LUMINANCE, NADIR B(Z,180°,0°)
FOOT LAMBERTS
FIGURE 18
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

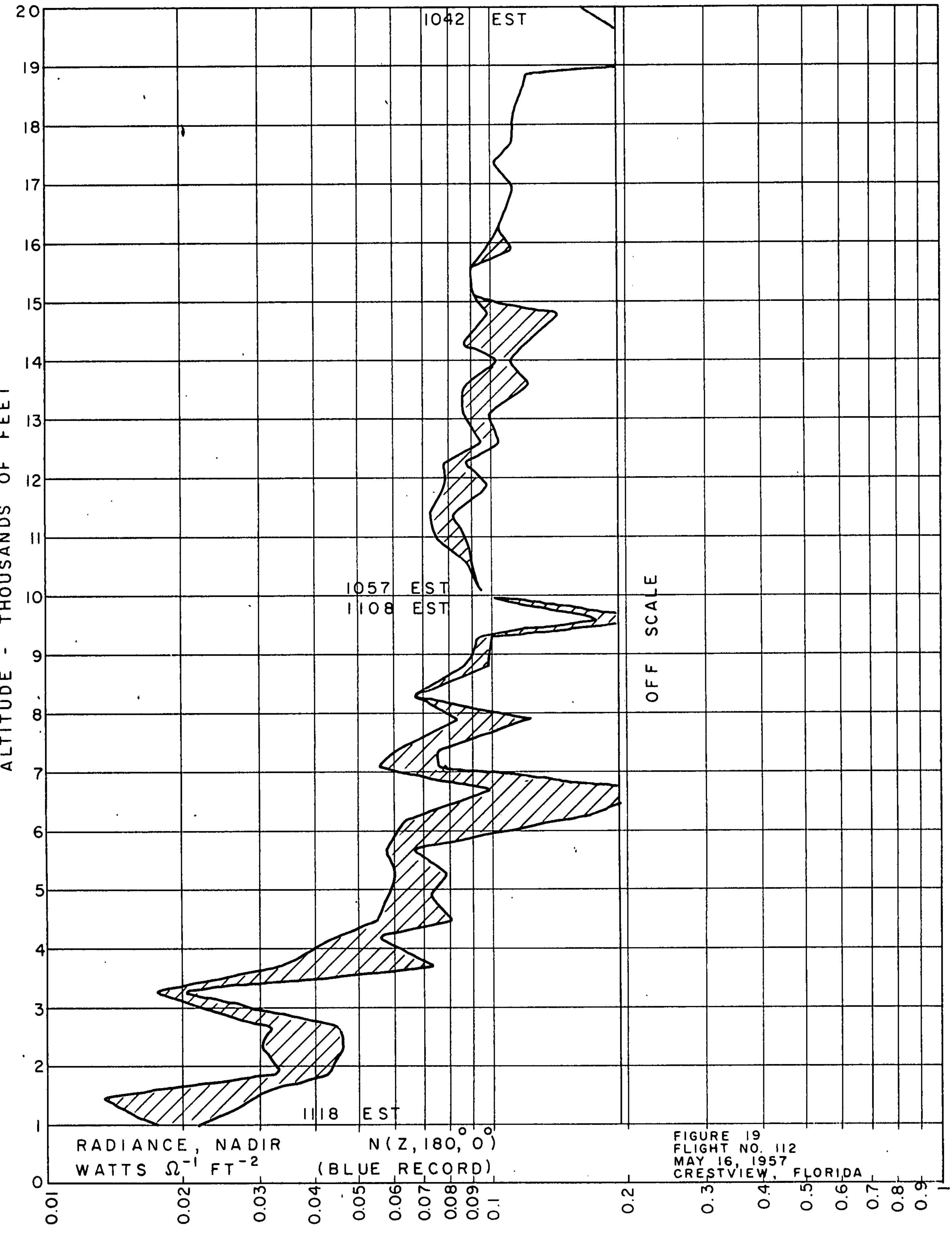


FIGURE 19
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

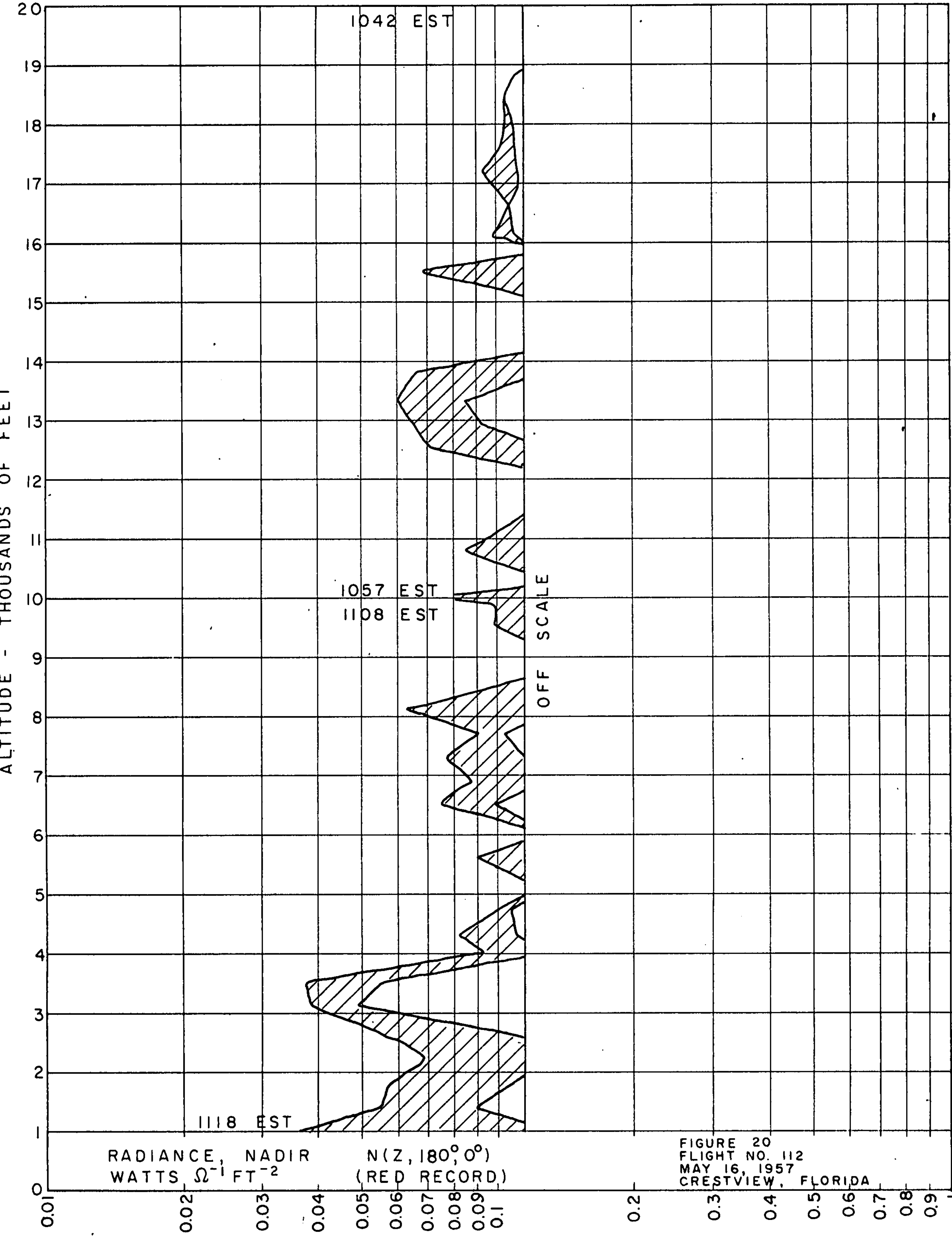


FIGURE 20
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

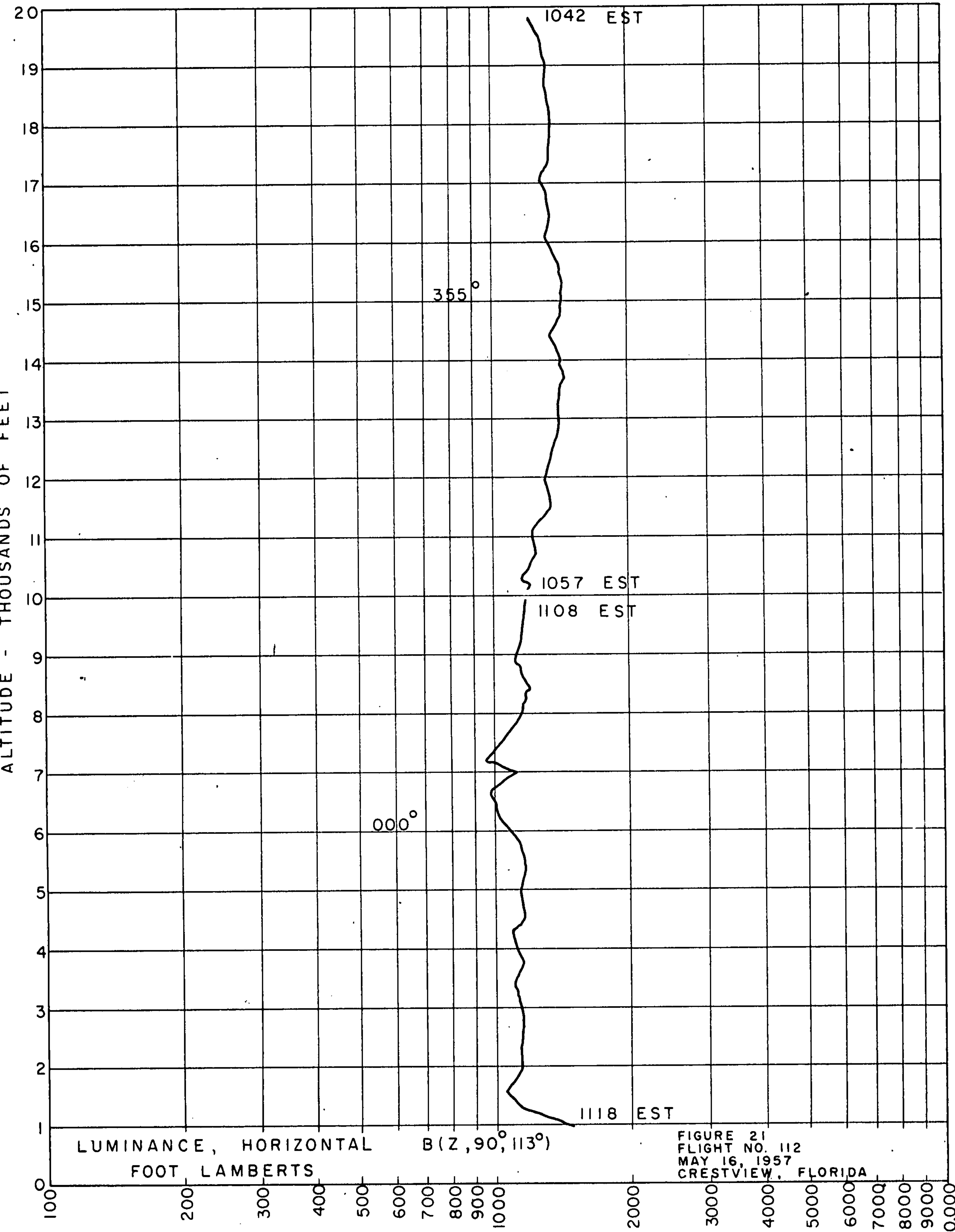


FIGURE 21
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

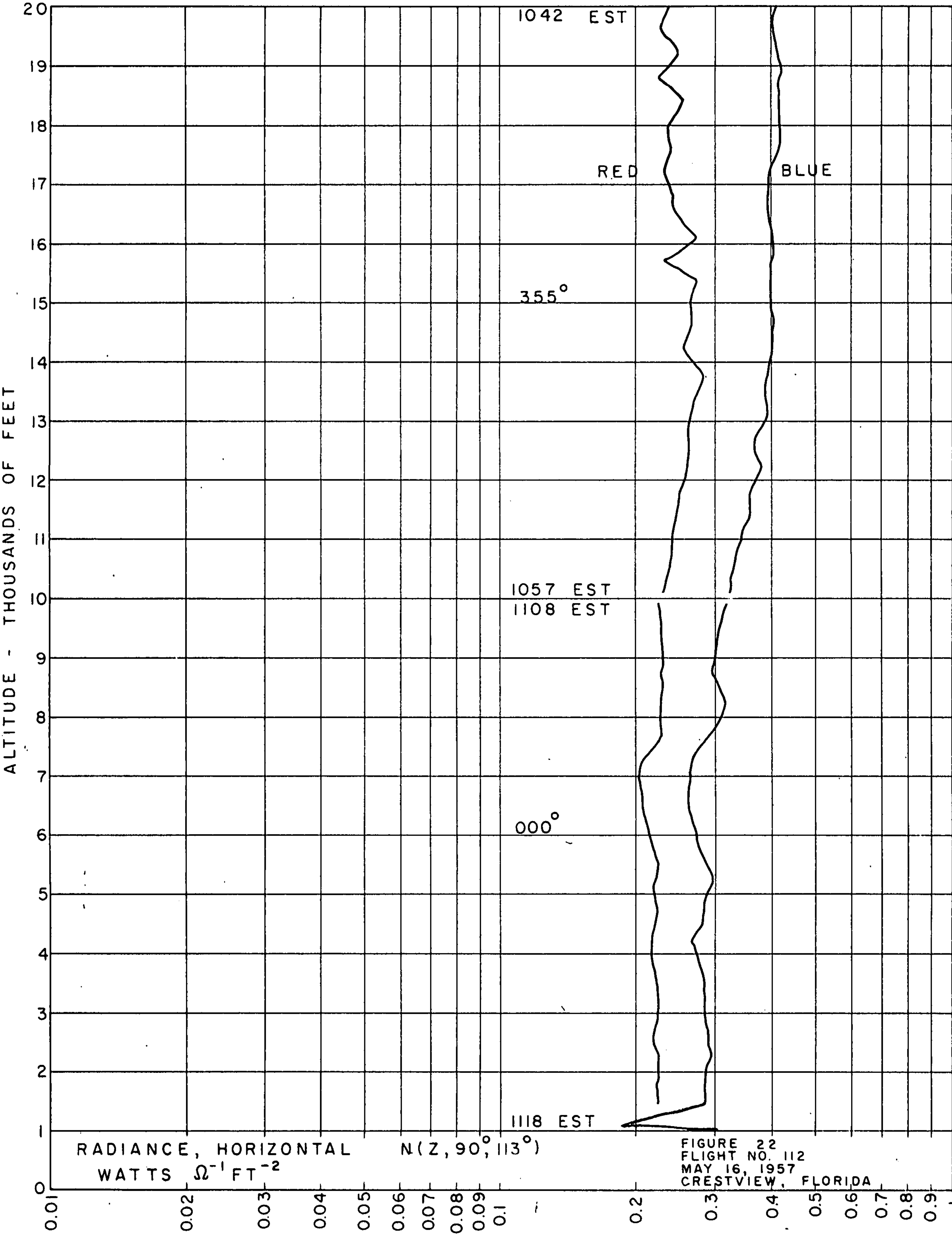
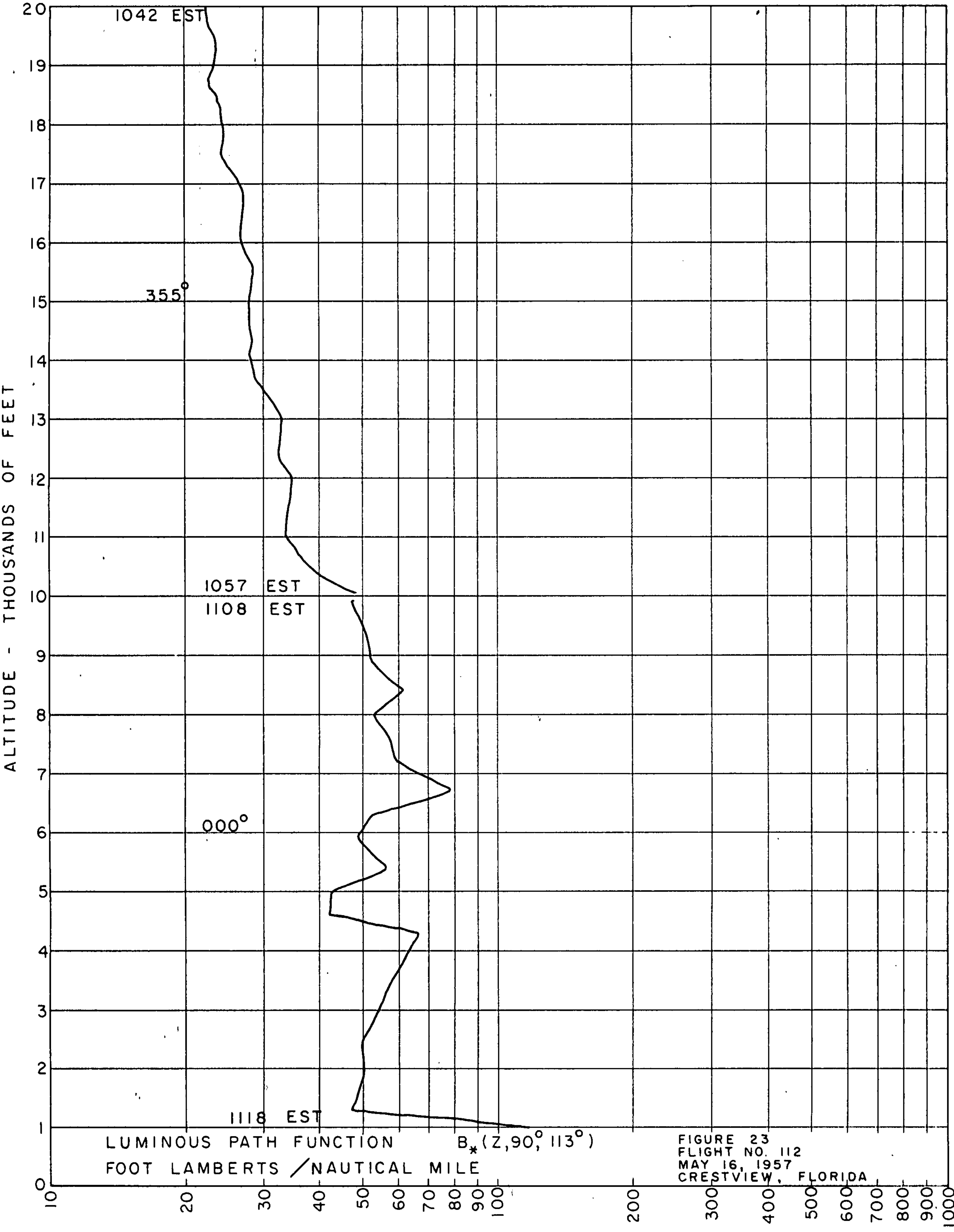
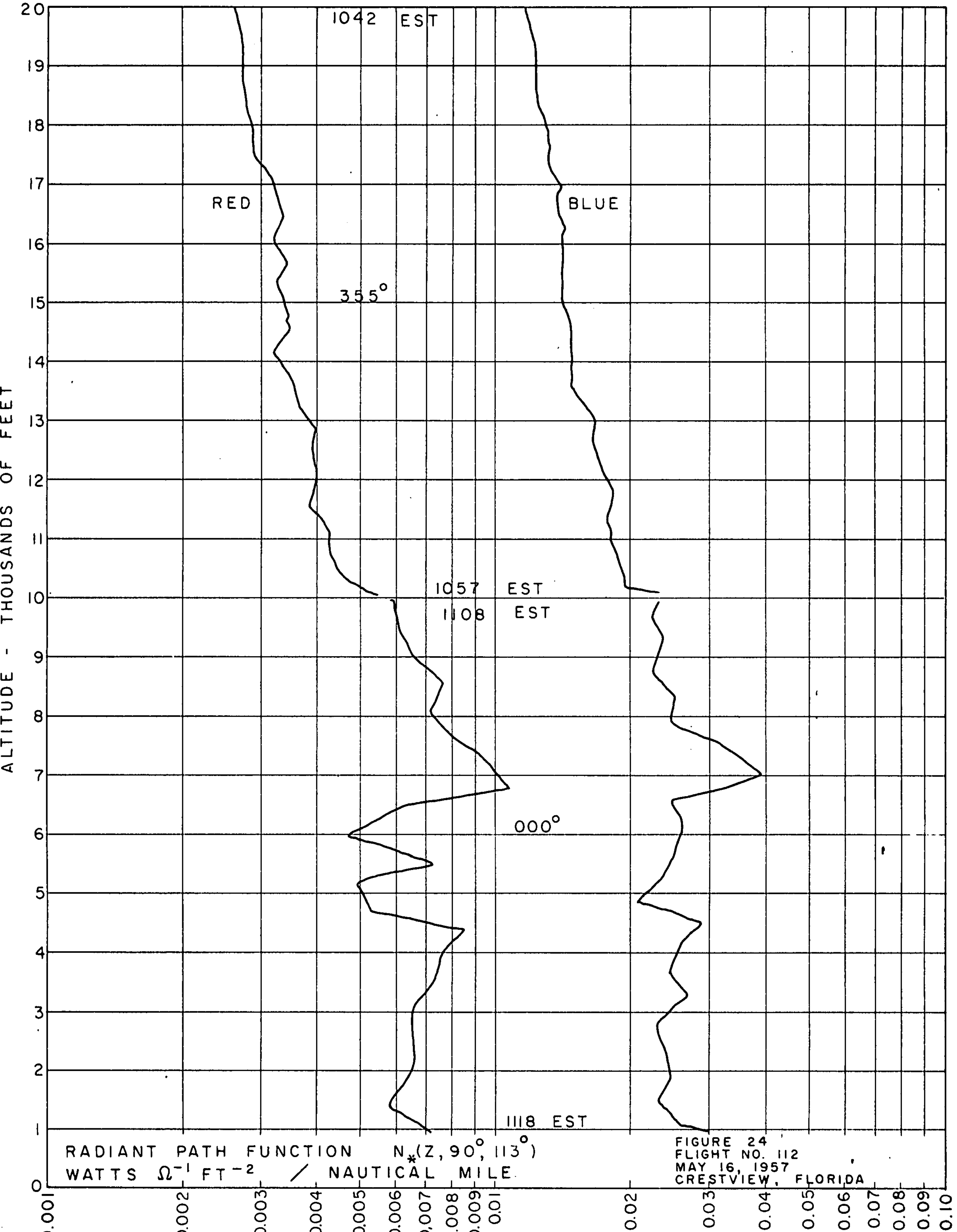
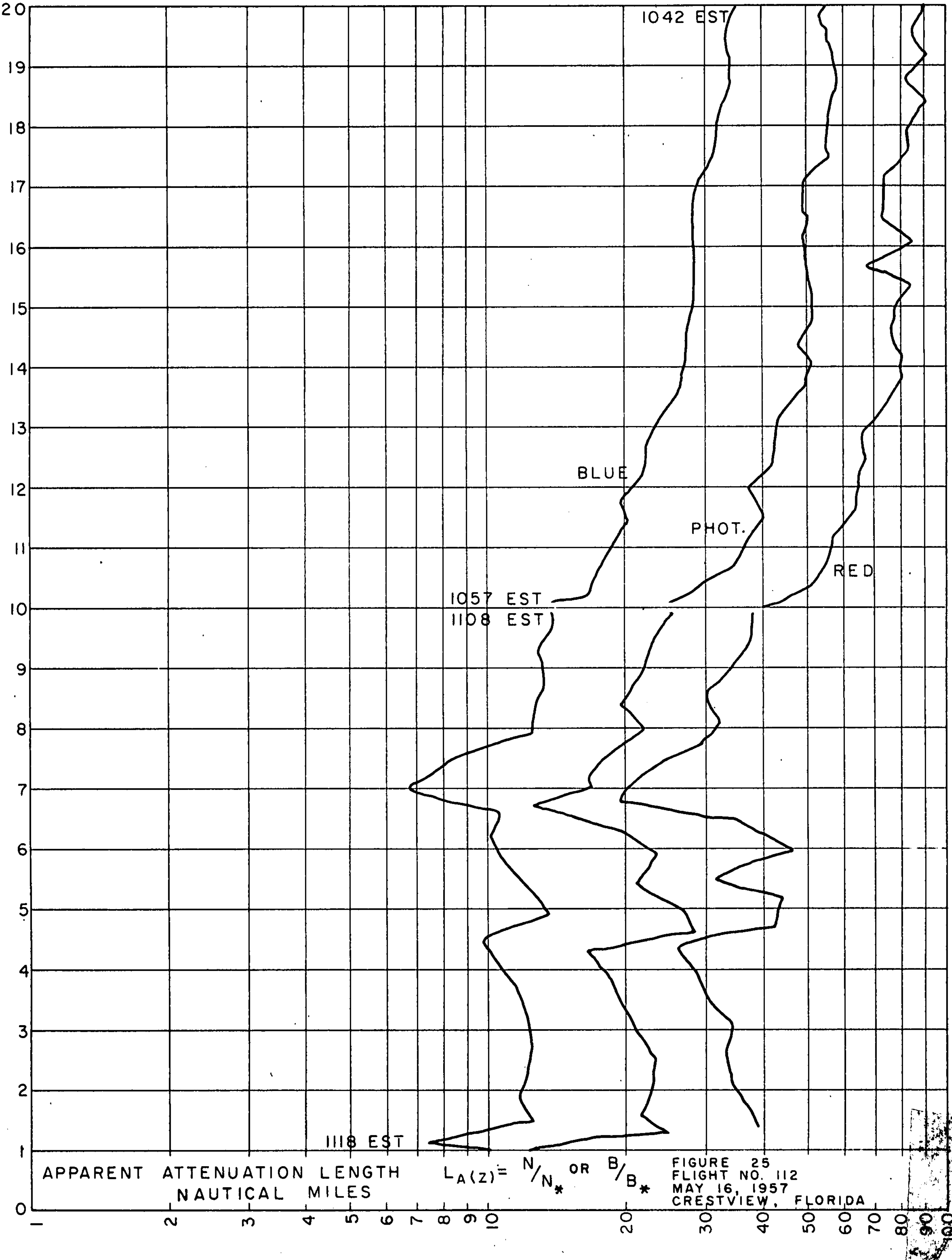


FIGURE 22
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA


1042 EST
355°
1057 EST
1108 EST
000°
1118 EST
ALTITUDE - THOUSANDS OF FEET
LUMINOUS PATH FUNCTION
FOOT LAMBERTS / NAUTICAL MILE
B*(Z,90°, 113°)
FIGURE 23
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA


1042 EST
RED
BLUE
355°
1057 EST
1108 EST
000°
1118 EST
ALTITUDE - THOUSANDS OF FEET
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
RADIANT PATH FUNCTION N*(Z, 90°, 113°)
WATTS Ω⁻¹ FT⁻² / NAUTICAL MILE
FIGURE 24
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA
0.001 0.002 0.003 0.004 0.005 0.006 0.007 0.008 0.009 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10



APPARENT ATTENUATION LENGTH NAUTICAL MILES $L_{A(z)} = N/N_* \text{ OR } B/B_*$

FIGURE 25
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

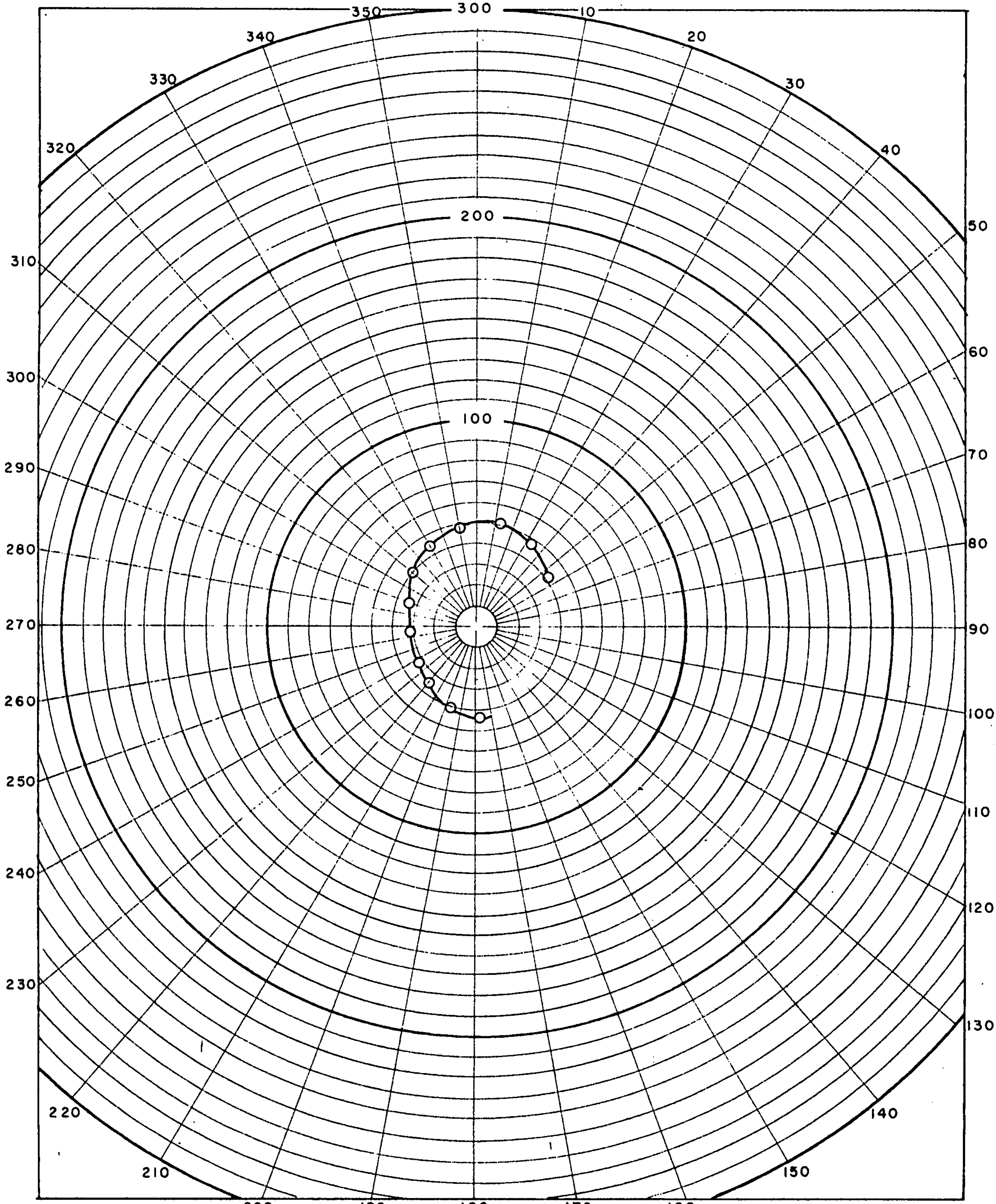
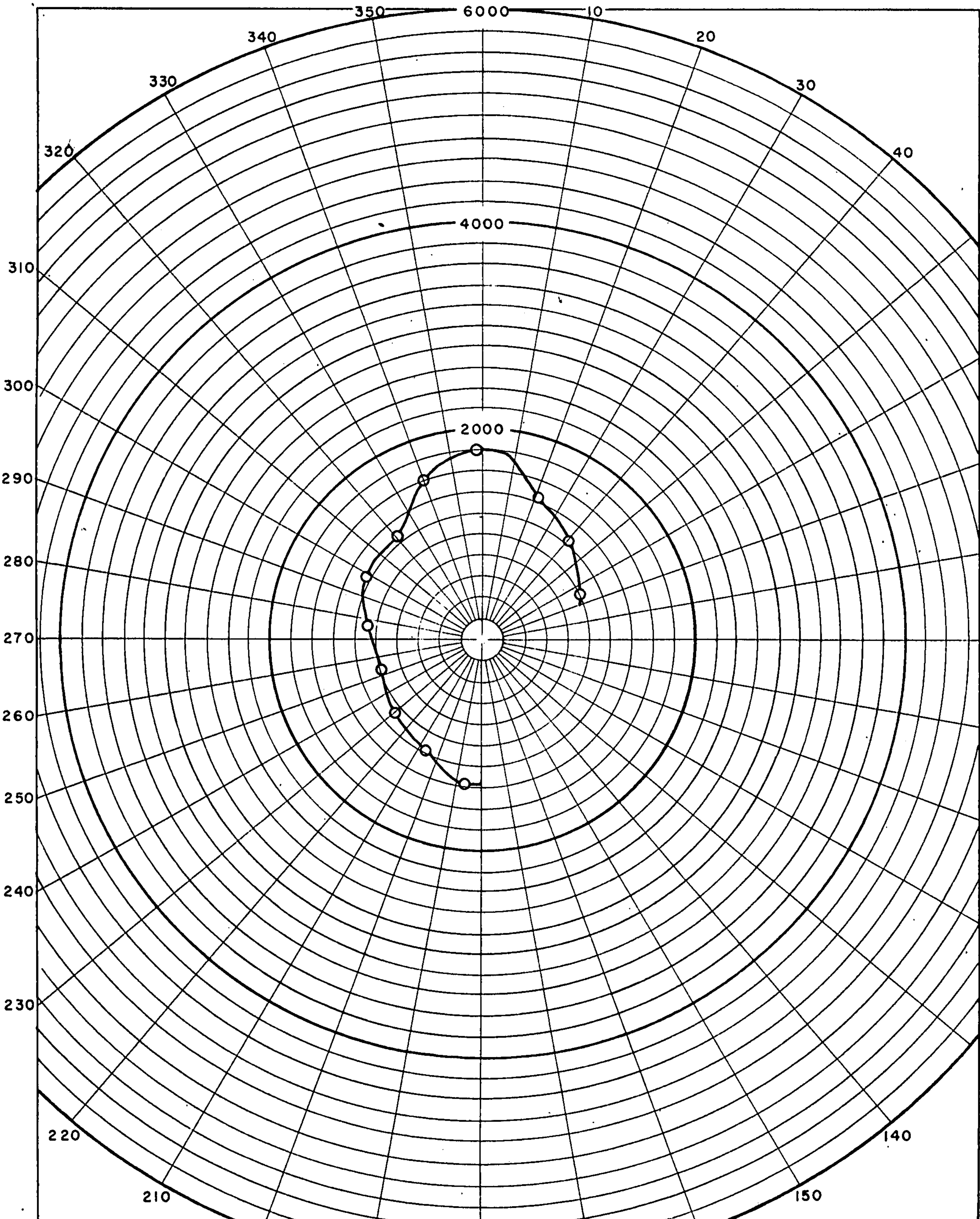


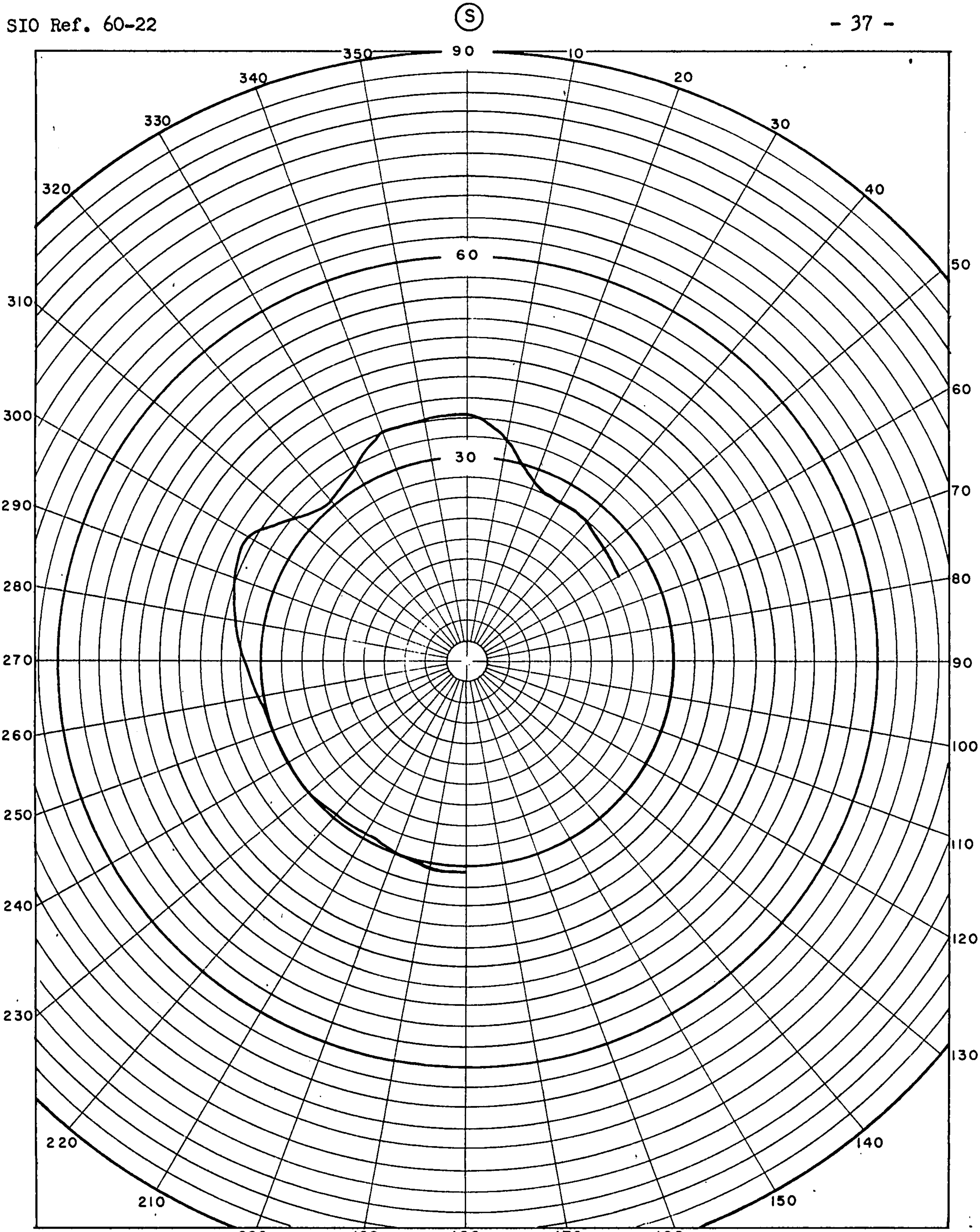
FIGURE 26
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

LUMINOUS PATH FUNCTION $B_*(20{,}000,\ 90°,\ \phi)$
FOOT LAMBERTS / NAUTICAL MILE
PHOTOPIC RECORD 20,000 FT 1016 EST



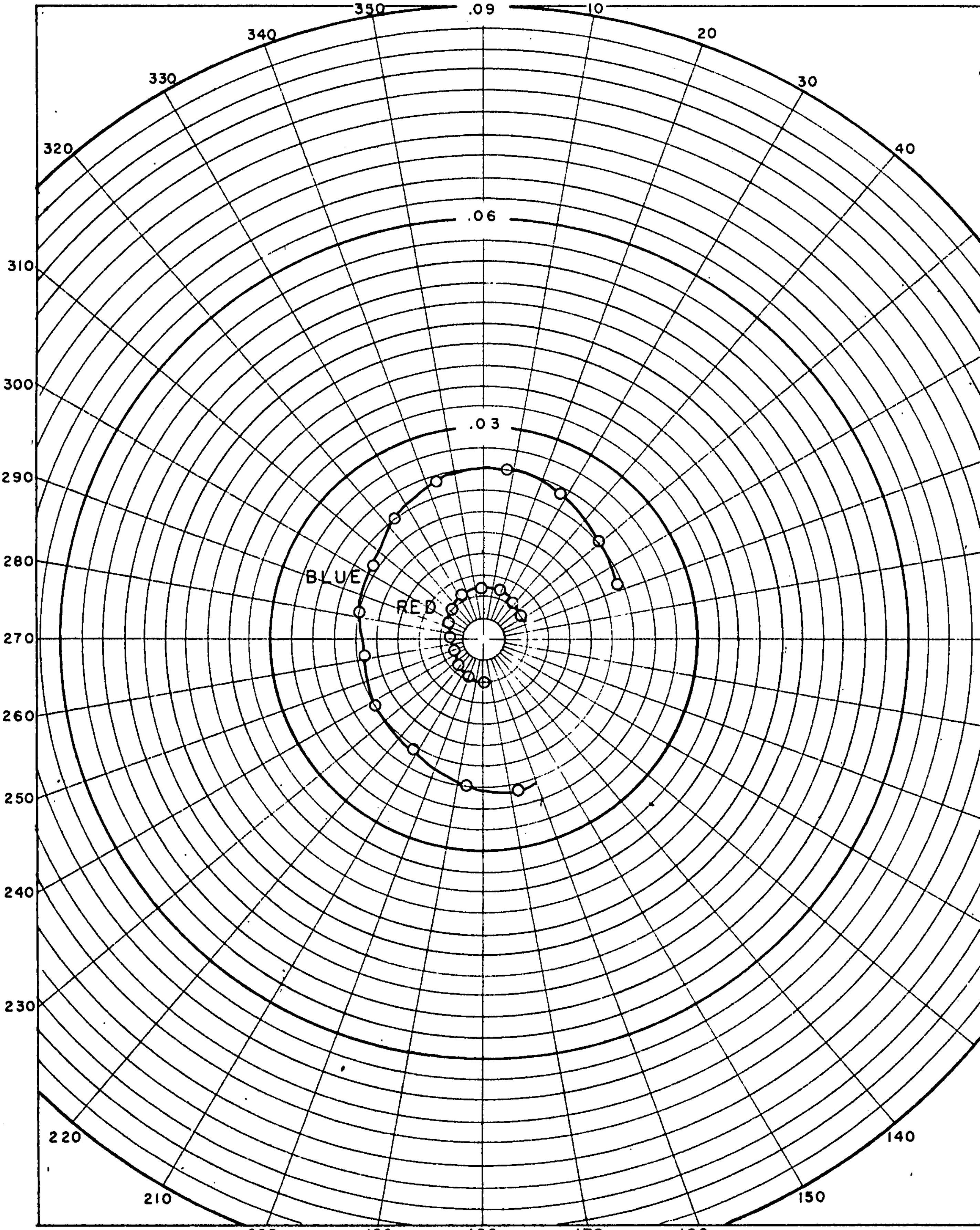
LUMINANCE, HORIZONTAL B(20,000, 90°, ϕ)
FOOT LAMBERTS
PHOTOPIC RECORD 20,000 FT 1016 EST

FIGURE 27
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



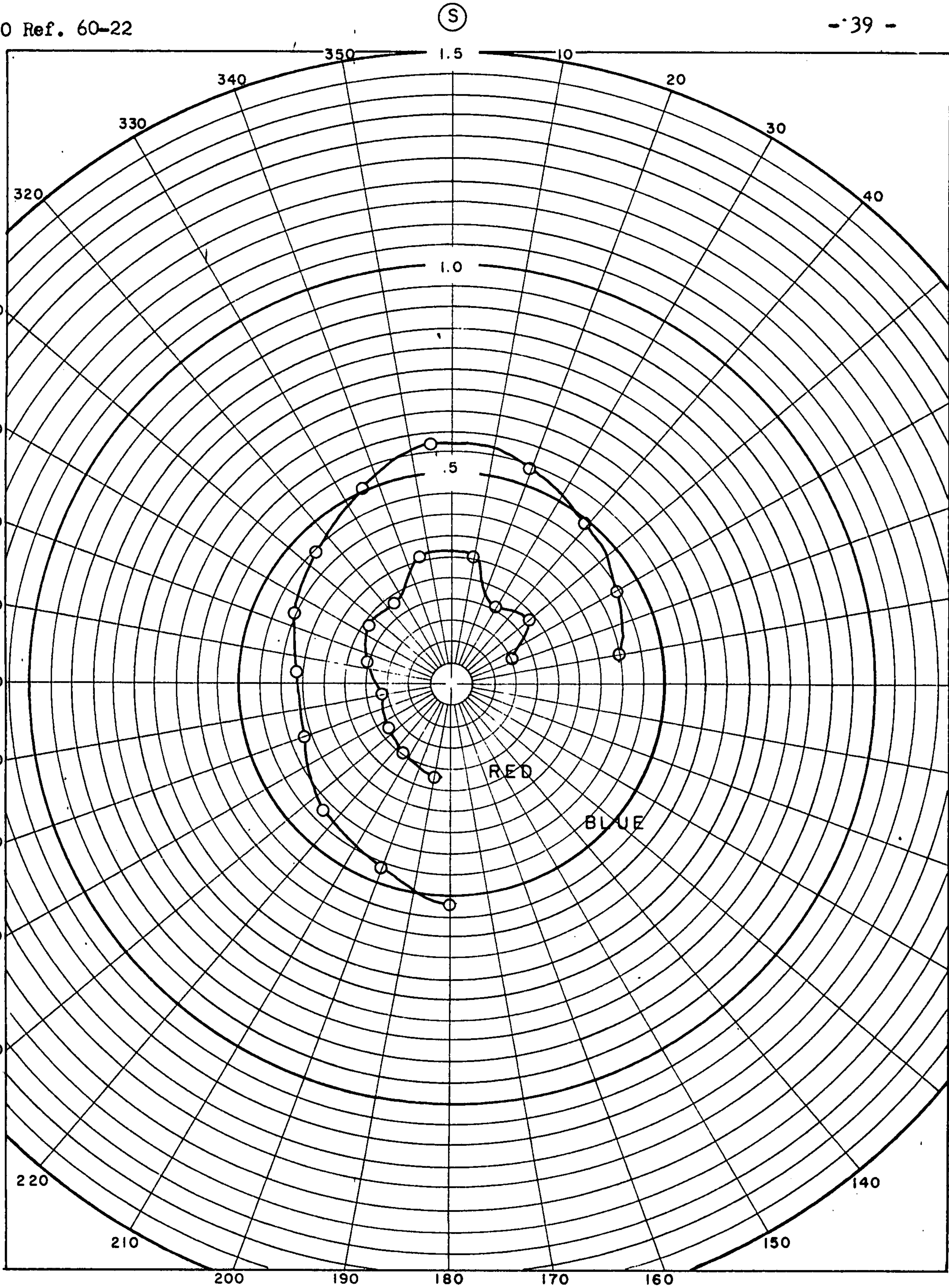
APPARENT ATTENUATION LENGTH L_A (20,000)
NAUTICAL MILES
PHOTOPIC RECORD 20,000 FT 1016 EST

FIGURE 28
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



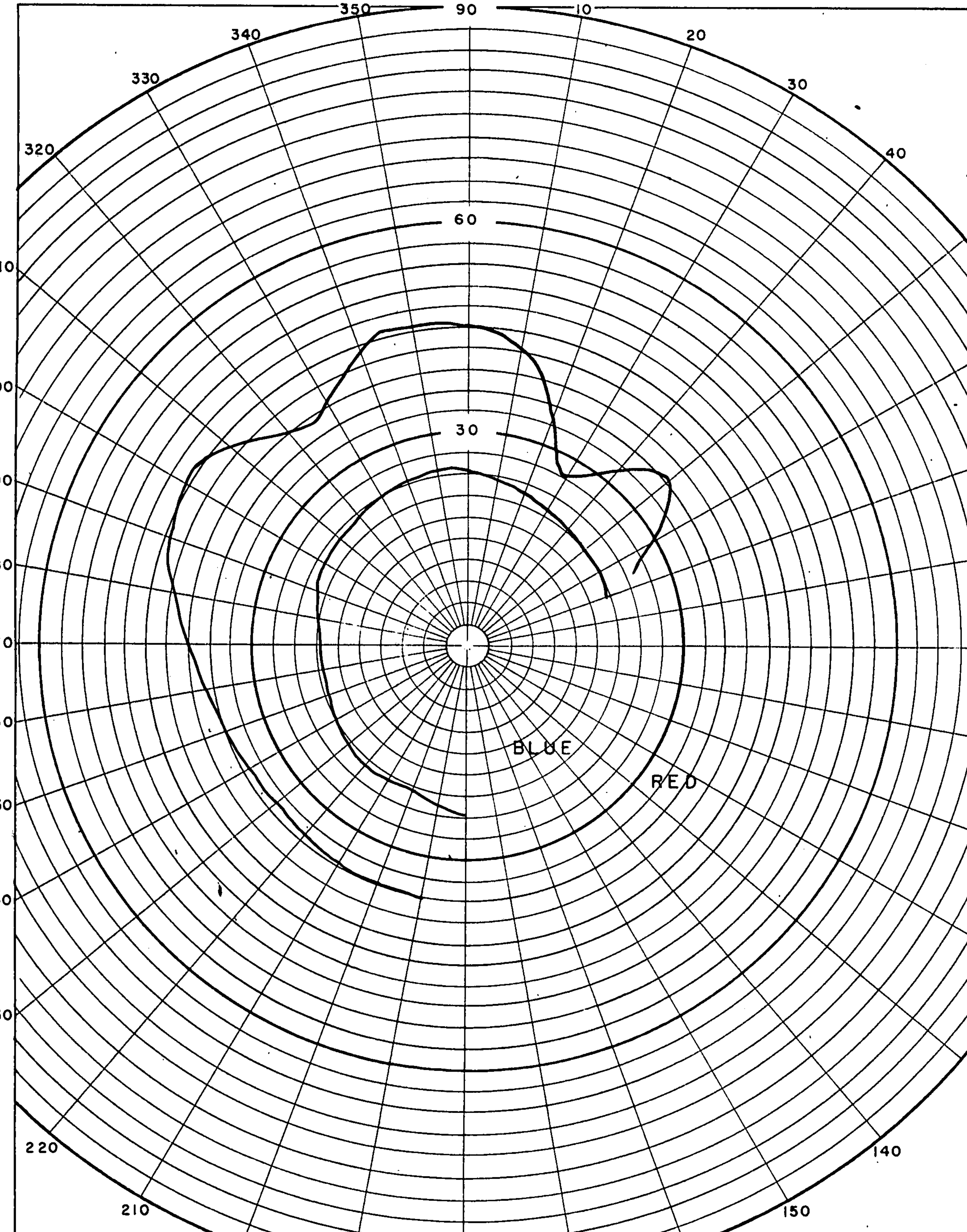
RADIANT PATH FUNCTION $N_*(20{,}000,\ 90°,\ \phi)$
WATTS Ω^{-1} FT^{-2} PER NAUTICAL MILE
BLUE AND RED RECORDS 20,000 FT 1016 EST

FIGURE 29
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



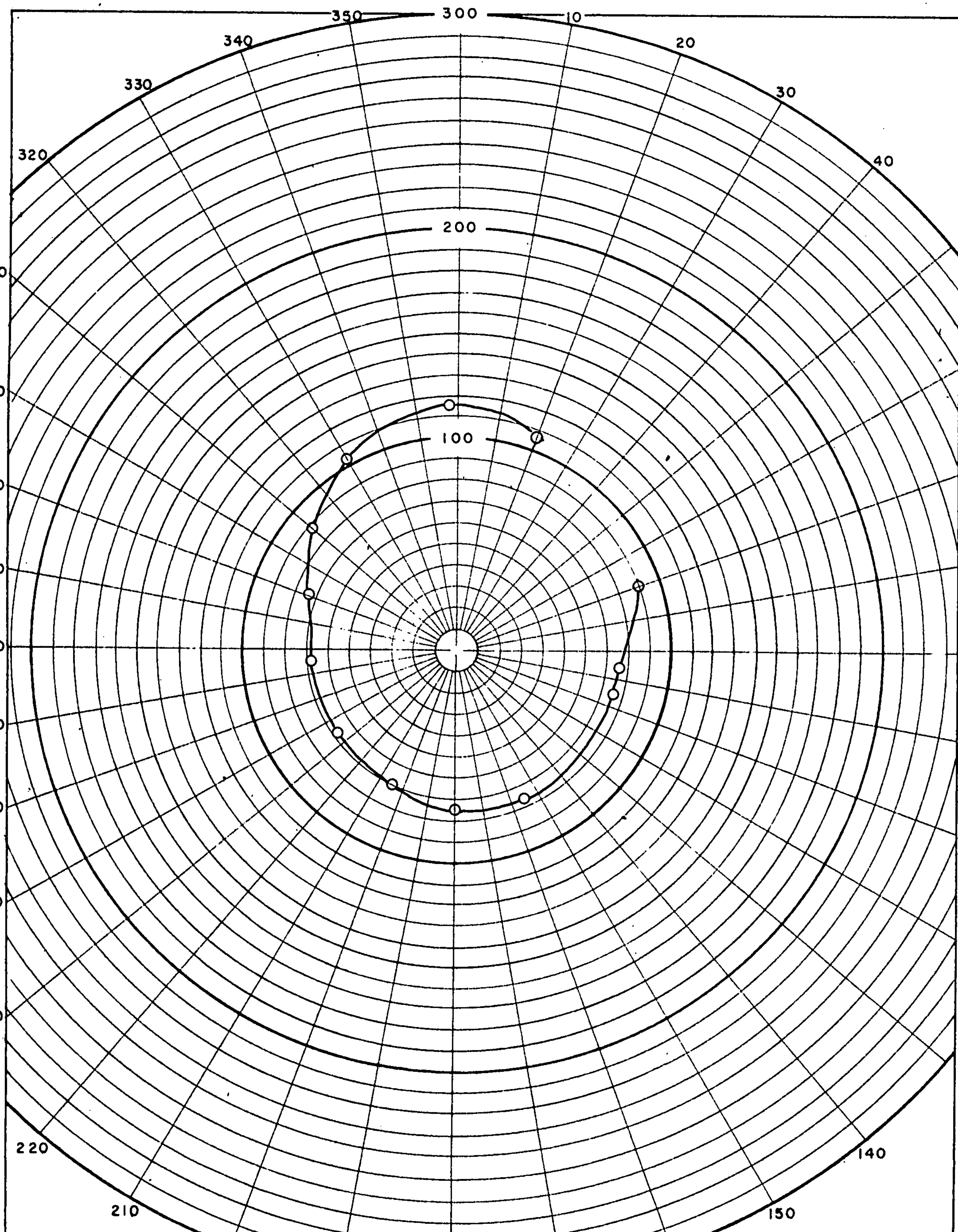
RADIANCE, HORIZONTAL N(20,000, 90°, φ)
WATTS Ω^{-1} FT^{-2}
BLUE AND RED RECORDS 20,000 FT 1016 EST

FIGURE 30
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



APPARENT ATTENUATION LENGTH $L_A(20,000)$
NAUTICAL MILES
BLUE AND RED RECORDS 20,000 FT 1016 EST

FIGURE 31
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

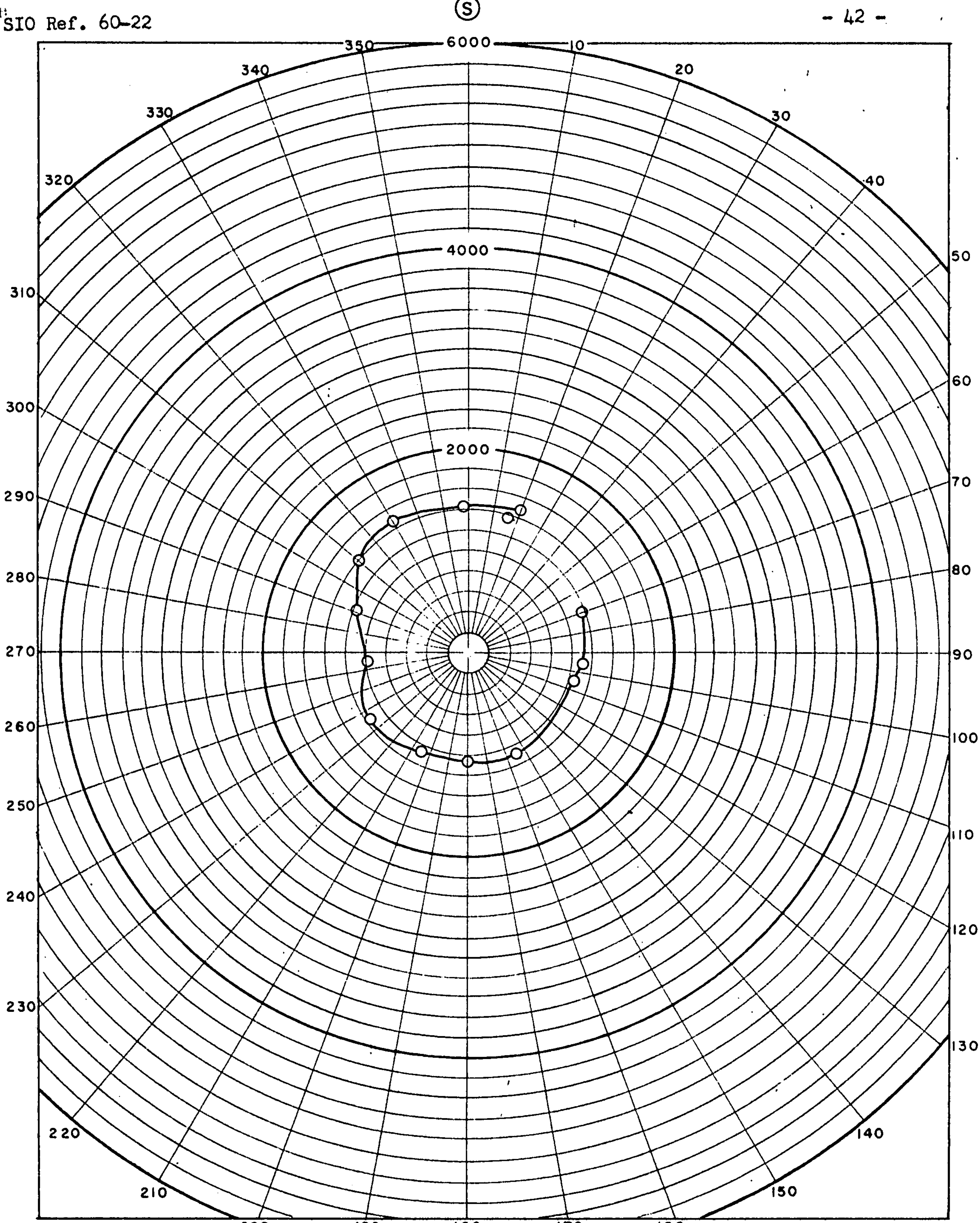


LUMINOUS PATH FUNCTION $B_*(10,000, 90^\circ, \phi)$

FOOT LAMBERTS / NAUTICAL MILE

PHOTOPIC RECORD 10,000 FT 1105 EST

FIGURE 32
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

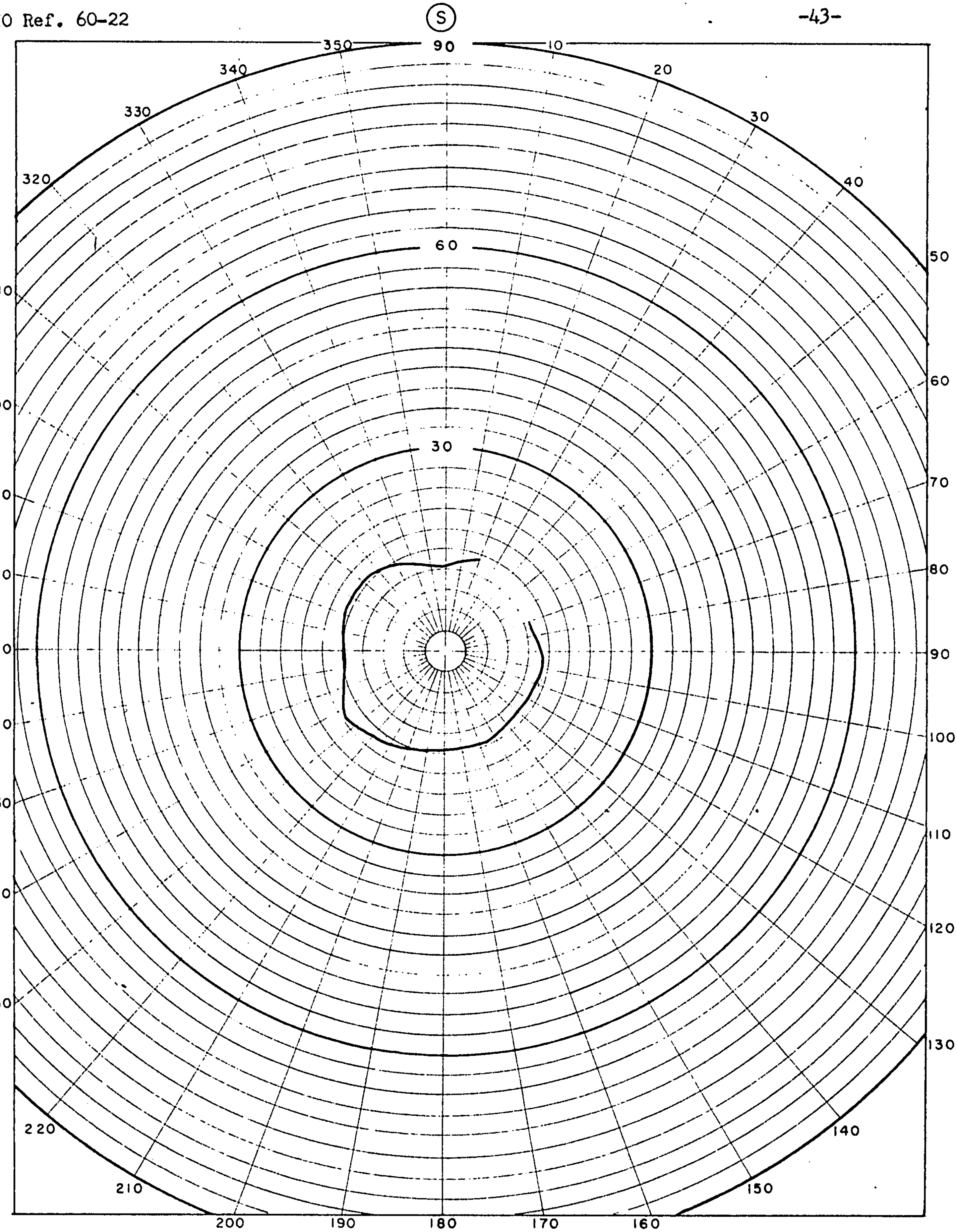


LUMINANCE, HORIZONTAL B(10,000, 90°, ϕ)

FOOT LAMBERTS

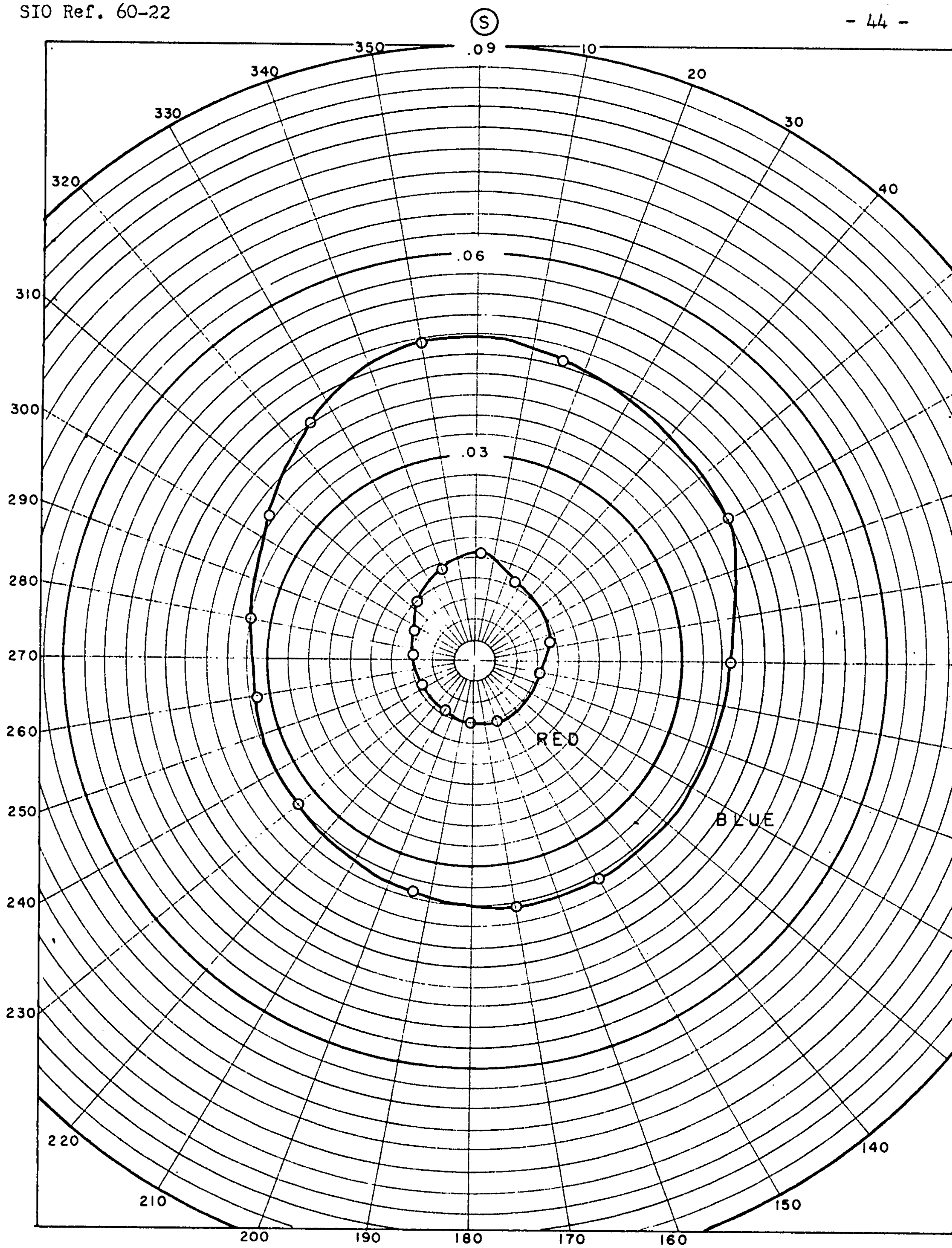
PHOTOPIC RECORD 10,000 FT 1105 EST

FIGURE 33
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



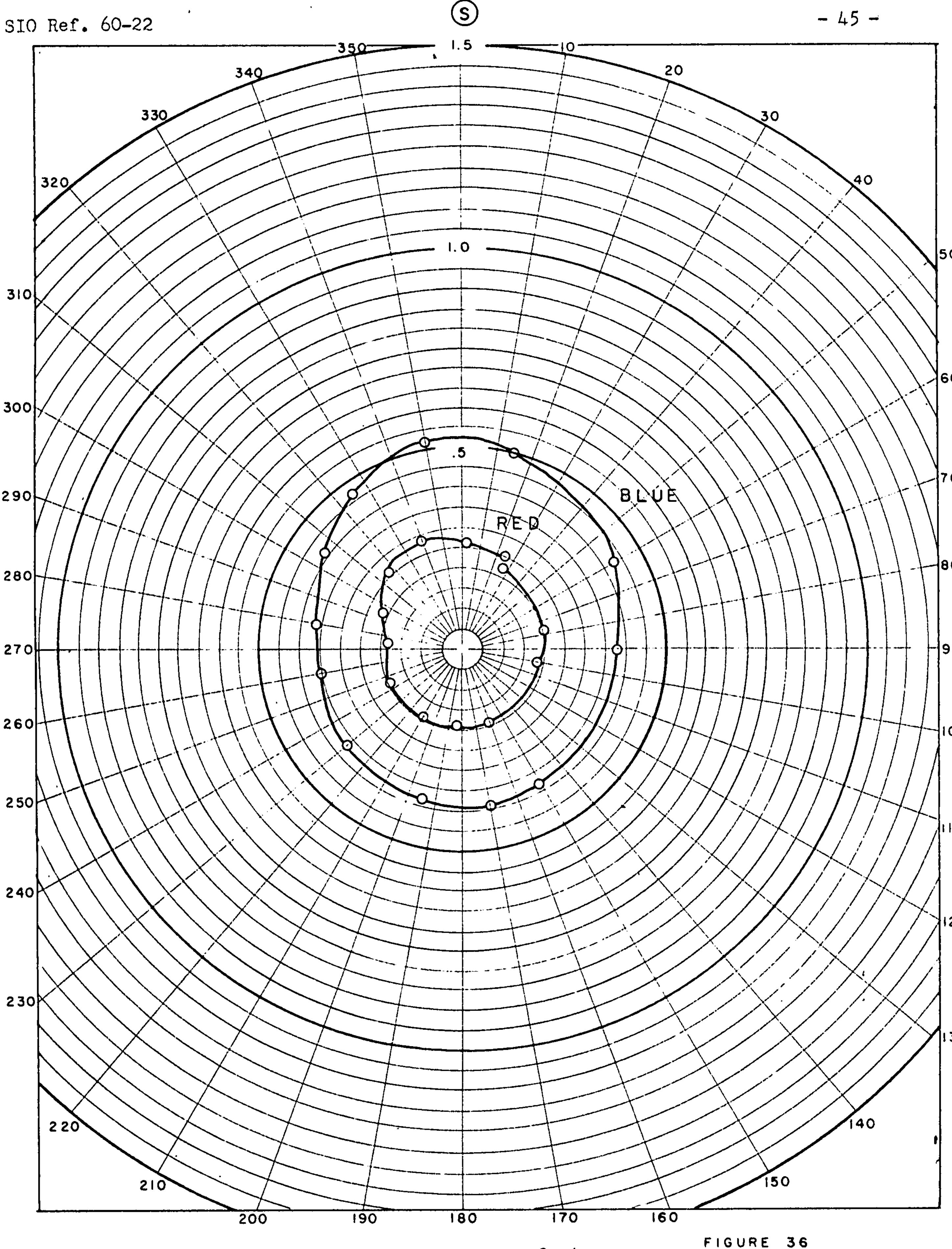
APPARENT ATTENUATION LENGTH $L_A(10,000)$
NAUTICAL MILES
PHOTOPIC RECORD 10,000 FT. 1105 EST

FIGURE 34
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



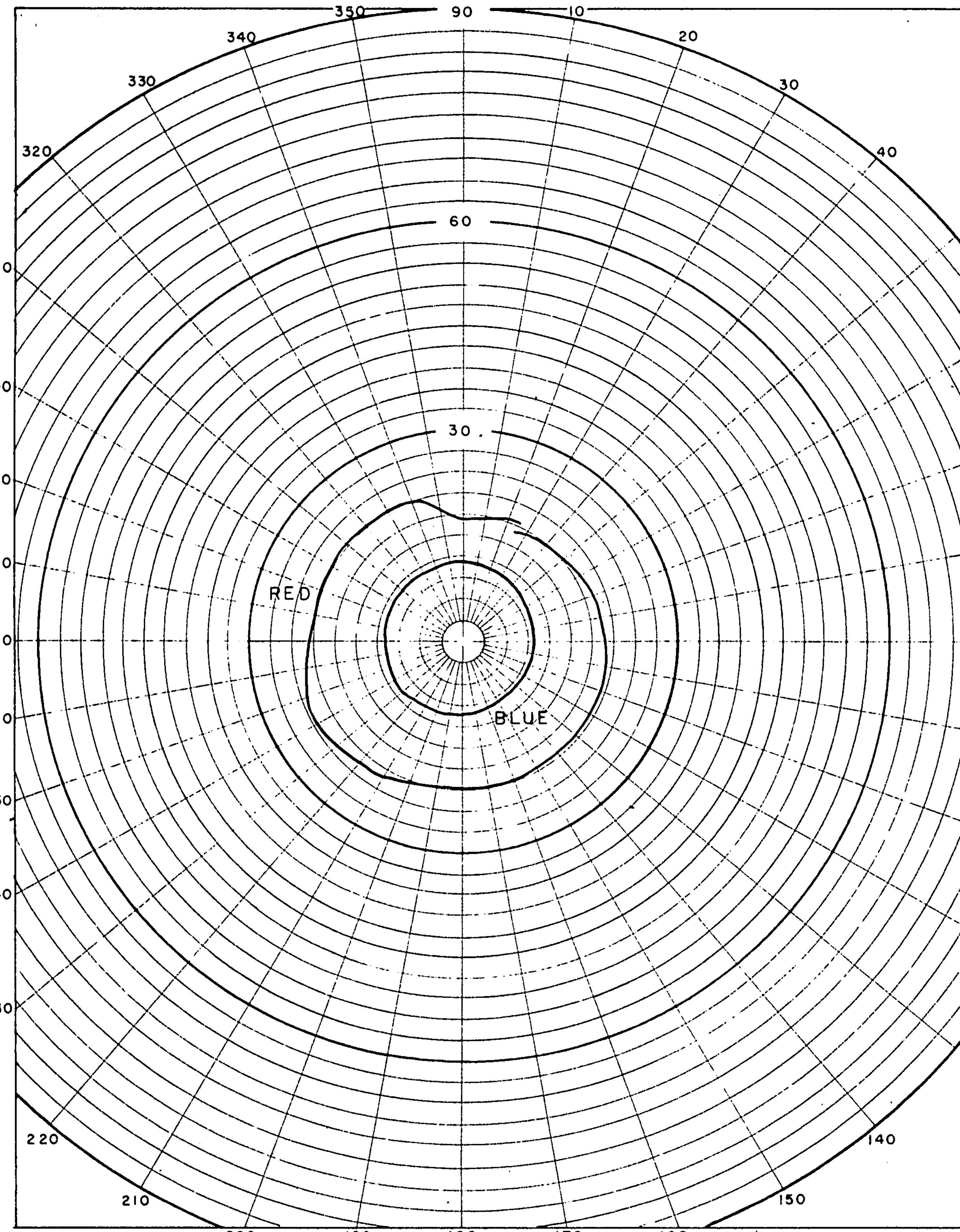
RADIANT PATH FUNCTION $N_*(10{,}000, 90^\circ, \phi)$
WATTS Ω^{-1} FT.$^{-2}$ PER NAUTICAL MILE
BLUE AND RED RECORDS 10,000 FT 1105 EST

FIGURE 35
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



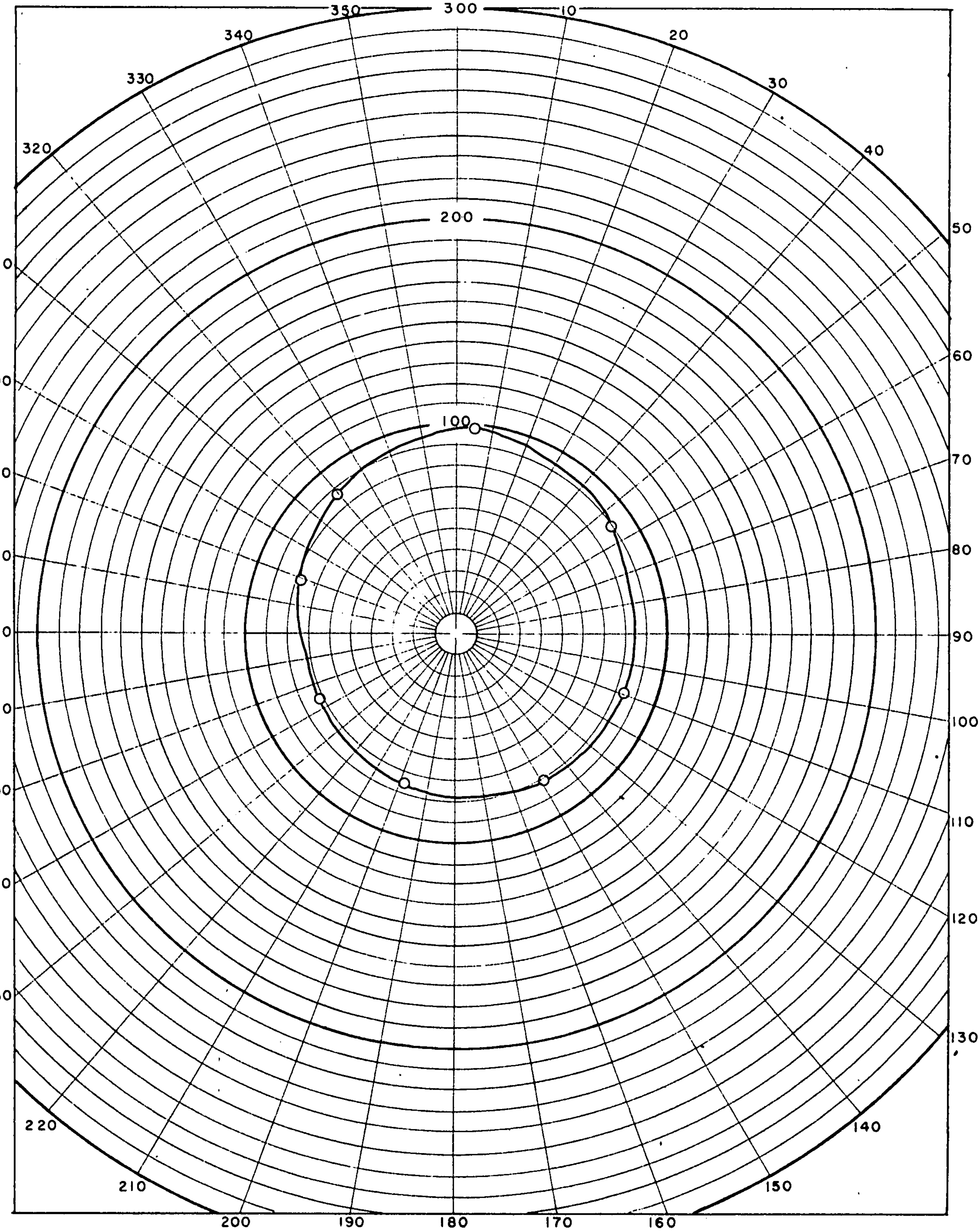
RADIANCE, HORIZONTAL N(10,000, 90°, ϕ)
WATTS Ω^{-1} FT^{-2}
BLUE AND RED RECORDS 10,000 FT 1105 EST

FIGURE 36
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



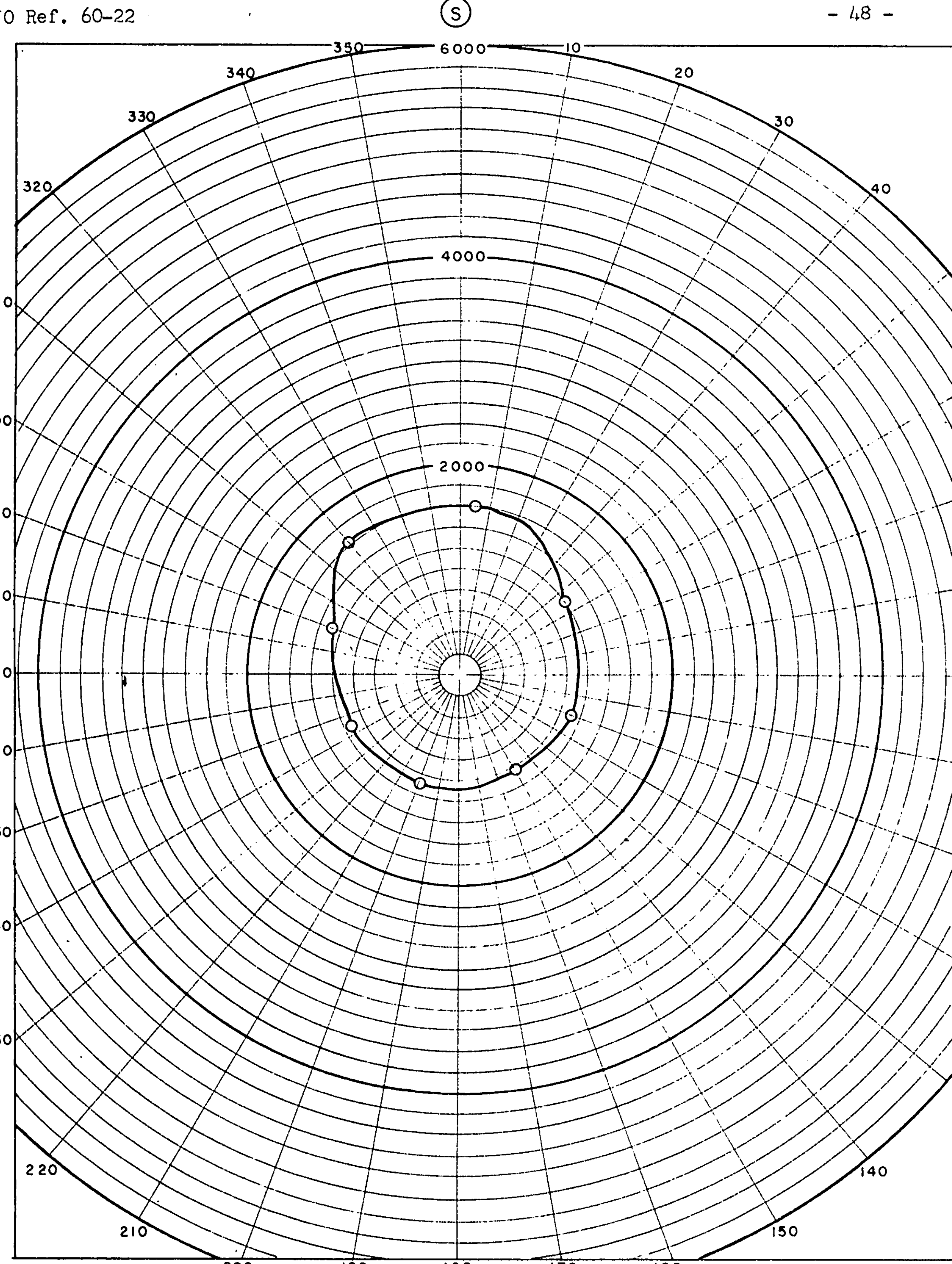
APPARENT ATTENUATION LENGTH L_A(10,000)
NAUTICAL MILES
BLUE AND RED RECORDS 10,000 FT 1105 EST

FIGURE 37
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



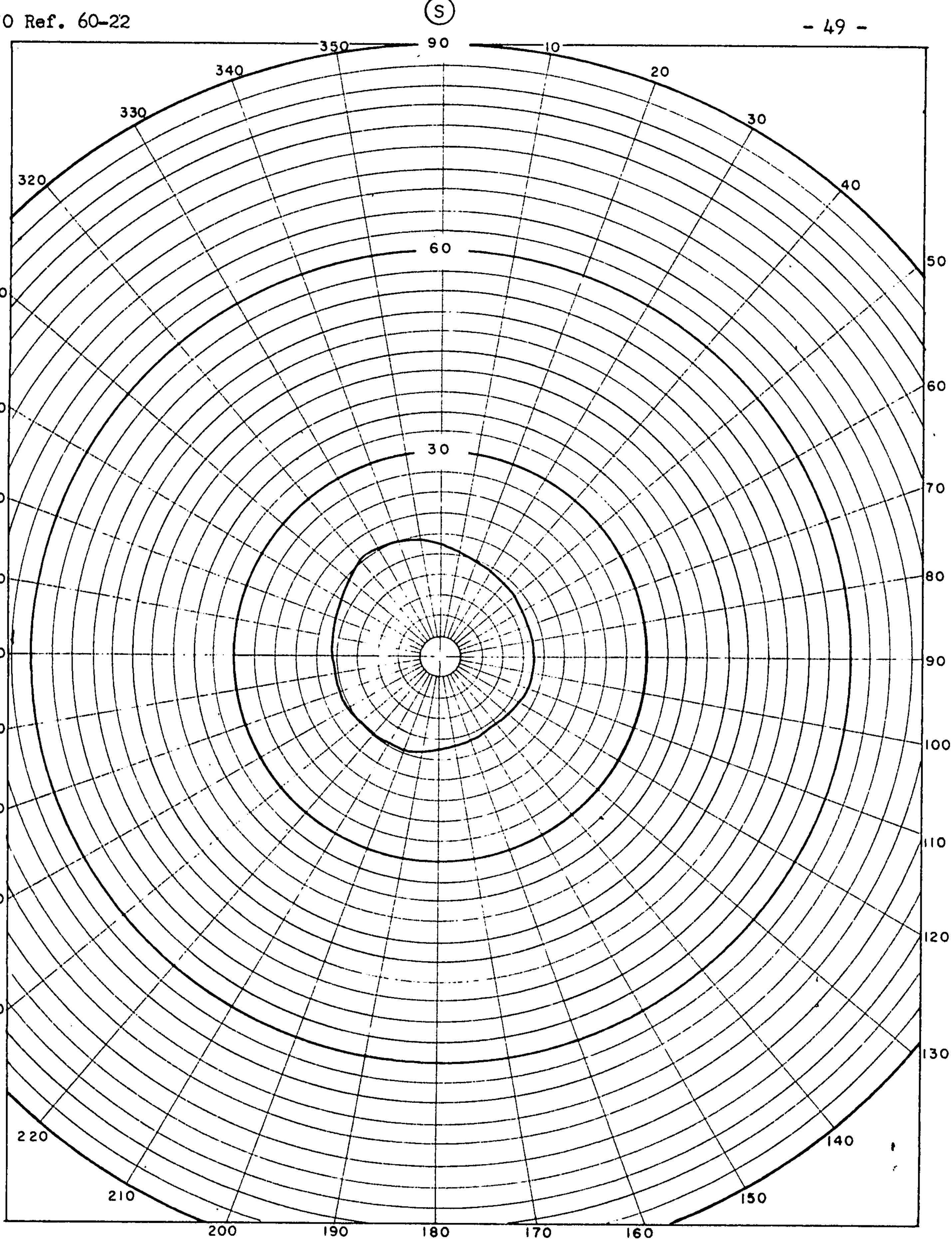
LUMINOUS PATH FUNCTION $B_*(1000, 90°, \phi)$
FOOT LAMBERTS / NAUTICAL MILE
PHOTOPIC RECORD 1000 FT 1119 EST

FIGURE 38
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



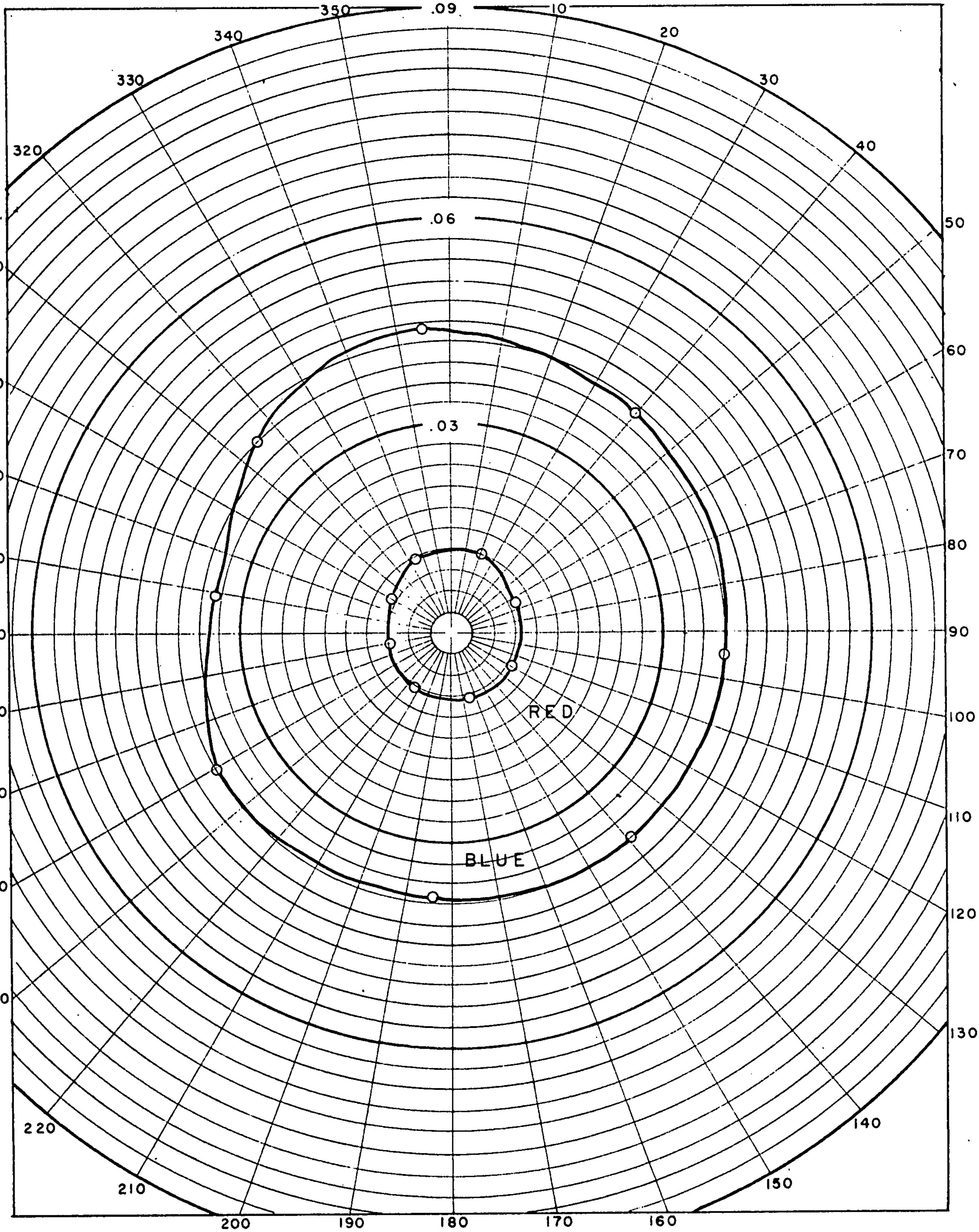
LUMINANCE, HORIZONTAL B(1000, 90°, ϕ)'
FOOT LAMBERTS
PHOTOPIC RECORD 1000 FT 1119 EST

FIGURE 39
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



APPARENT ATTENUATION LENGTH $L_A(1000)$
NAUTICAL MILES
PHOTOPIC RECORD 1000 FT 1119 EST

FIGURE 40
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA



RADIANT PATH FUNCTION $N_*(1000, 90^\circ, \phi)$

WATTS Ω^{-1} FT^{-2} PER NAUTICAL MILE

BLUE AND RED RECORDS 1000 FT 1119 EST

FIGURE 41

FLIGHT NO. 112

MAY 16, 1957

CRESTVIEW, FLORIDA

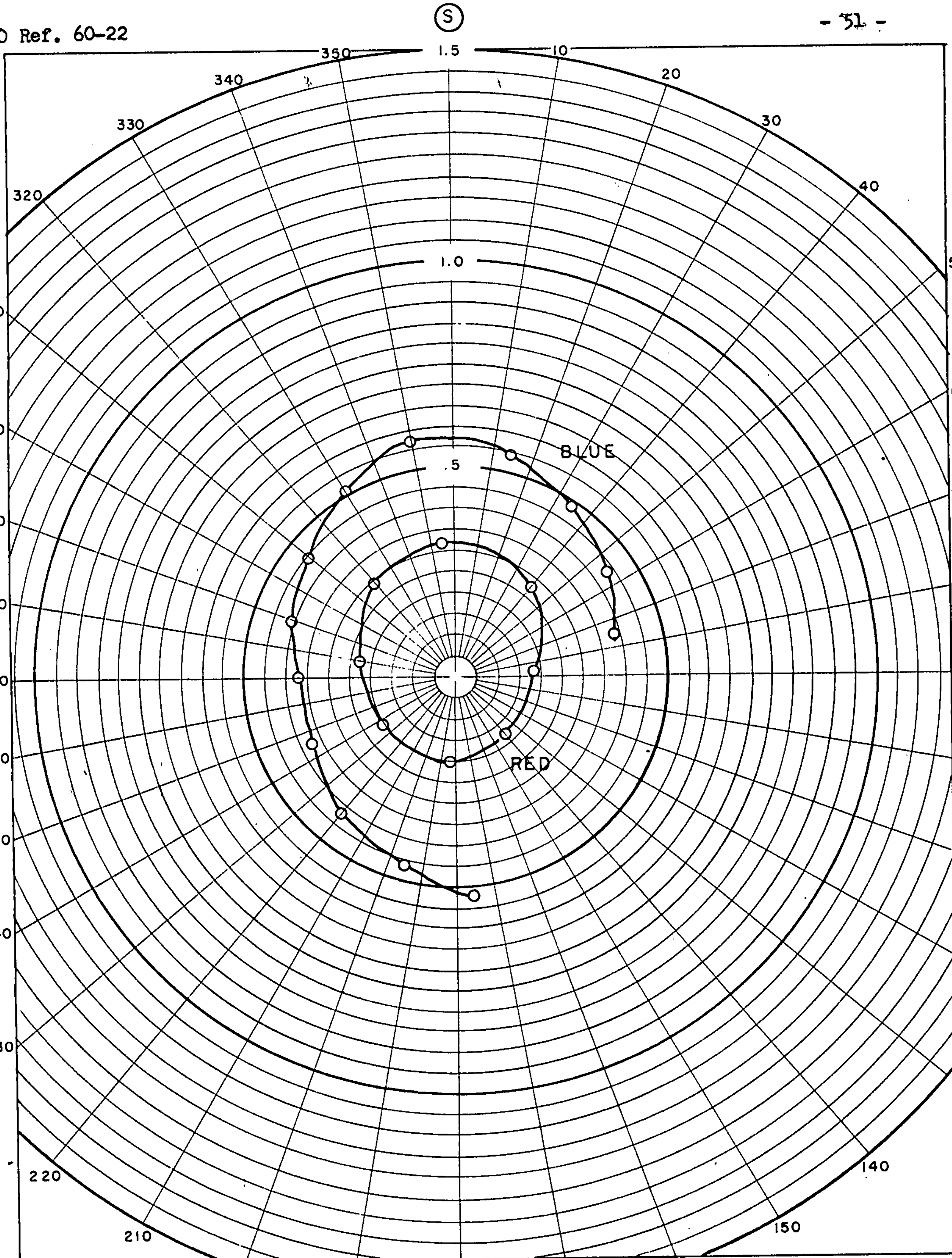
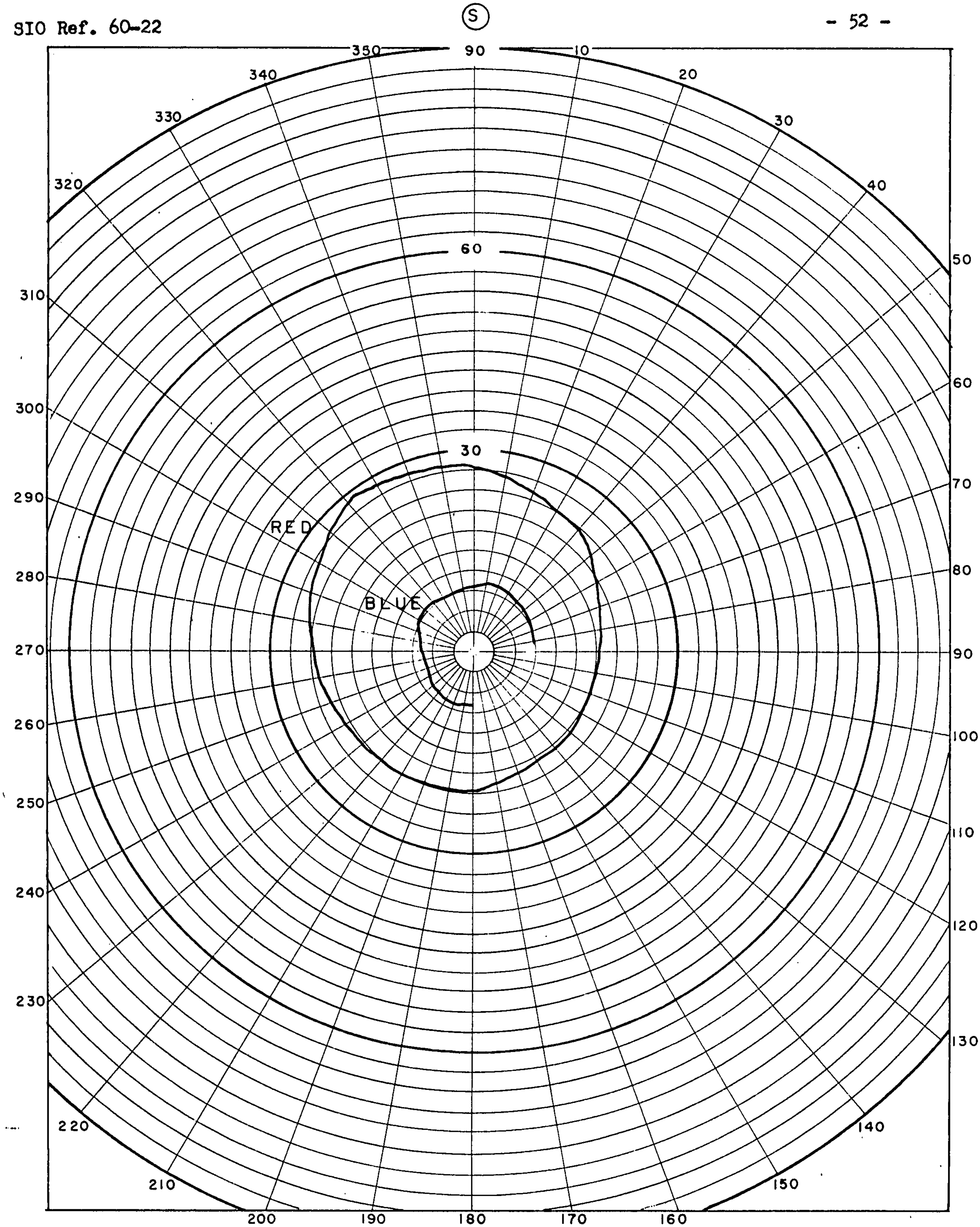


FIGURE 42
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

RADIANCE, HORIZONTAL N(1000, 90°, ϕ)
WATTS Ω^{-1} FT $^{-2}$
BLUE AND RED RECORDS 1000 FT 1119 EST



APPARENT ATTENUATION LENGTH $L_A(1000)$
NAUTICAL MILES
BLUE AND RED RECORDS 1000 FT 1119 EST

FIGURE 43
FLIGHT NO. 112
MAY 16, 1957
CRESTVIEW, FLORIDA

DISCUSSION

Preface

The Visibility Laboratory of the University of California, La Jolla Campus, has been engaged for several years in an on-going research program concerning image transmission through the atmosphere. This program is discussed in "Image Transmission by the Troposphere I."[1] In this article, of special interest in connection with this report, are notation, discussion of path functions, attenuation length, and the concept of equilibrium radiance (and luminance).

Notation and Instrumentation

The notation used in this report follows the notation given in detail in the aforesaid article. The radiometric quantities irradiance and radiance are designated by H and N, respectively; the photometric counterparts illuminance and luminance are designated by E and B, respectively. In the parentheses following the basic symbols, z specified altitude in feet, the minus sign - indicates downwelling flux, the plus sign + indicates upwelling flux, θ specifies the zenith angle of the line of sight of the photometer, and ∅ specifies the azimuthal angle of the photometer. In this report the azimuthal angle ∅ is with respect to the sun's bearing.

The phototubes in the optical equipments are filtered to provide certain spectral responses. The photometric quantities are those recorded with phototube-filter combination that has the spectral sensitivity of the standard luminosity curve for the daylight-adapted human eye. This is designated as the "photopic" response and is shown as the upper curve of Figure 44.

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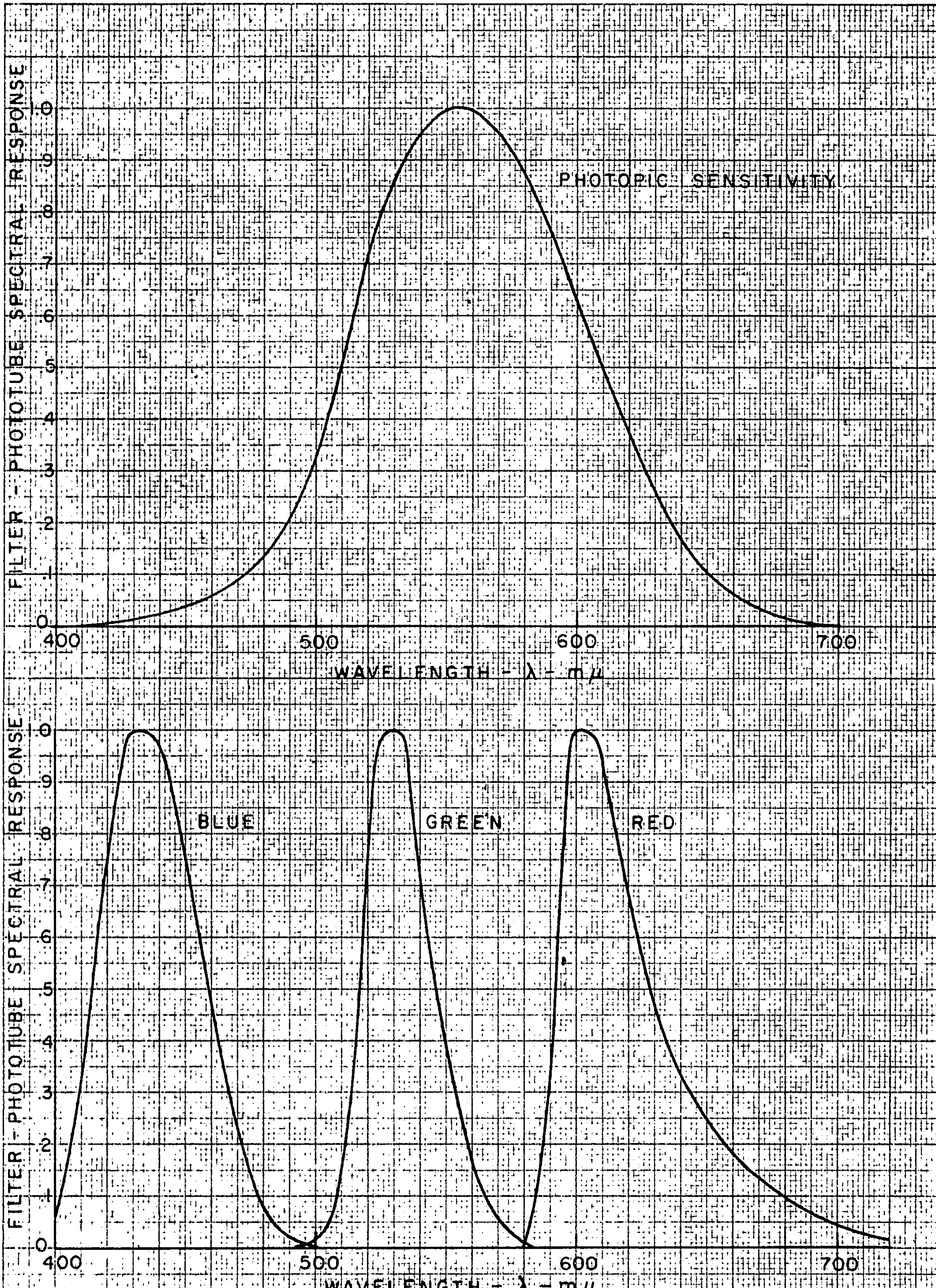
[1] S. Q. Duntley, A.R. Boileau, and R.W. Preisendorfer, "Image Transmission by the Troposphere I, "Journal of the Optical Society of America, 47, pp. 499-506, (1957).



FILTER - PHOTOTUBE SPECTRAL RESPONSE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
PHOTOPIC SENSITIVITY
400
500
600
700
WAVELENGTH - λ - mμ
FILTER - PHOTOTUBE SPECTRAL RESPONSE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
BLUE
GREEN
RED
400
500
600
700
WAVELENGTH - λ - mμ

FIGURE 44

At the time of Flight 112 the phototubes were also filtered to respond to radiant energy in the blue end of the spectrum in accordance with the blue spectral sensitivity curve in Figure 44. Similarly, they were also filtered to respond to the radiant energy in the middle part and the red end of the spectrum in accordance with the green and red spectral sensitivity curves in the same Figure. In this report these three sensitivities and responses to radiant energy recorded through these three filters are referred to as "blue" "green" and "red" sensitivities and responses.

In each instrument the filters used to provide the four filtered phototube spectral sensitivities are interposed successively in the flux path by the action of a ratchet solenoid which drives a wheel in which the filters are mounted. The ratchet solenoids are controlled from the project engineer's station so that all instruments have the same filter in position at any one time.

At the time of Flight 112 the normal order of interposition of filters was photopic, blue, green, and red. Subsequent reduction of data showed that the photopic and green data (when reduced to the same dimensional units) were so similar that it was decided to limit the data reduction and presentation to the photopic, blue, and red.

The phototubes are believed to measure the total radiant flux incident upon their cathodes independent of the degree of polarization. A test of several of the phototubes which are used in the optical instruments showed no discernible effect when polarized light with the direction of polarization undergoing a continuous change of 360° was incident on the phototube's cathodes.

Recorded Optical Quantities

The following optical quantities were recorded during Flight 112:

Quantity	Symbol	Instrumentation
Illuminance, Downwelling	E(z,-)	Measured on a horizontal flat plate collector.* A rotating device shadows the collector plate from the sun's rays twice each revolution thus giving a measure of illuminance from the diffuse sky light.
Irradiance, Downwelling	H(z,-)	
Illuminance, Upwelling	E(z,+)	Measured on a horizontal flat plate collector*
Irradiance, Upwelling	H(z,+)	
Luminance, Zenith	B(z,0,0)	Measured by zenith telephotometer. Instrument is mounted so that when airplane is level it measures integrated luminance (or radiance) of a 1° circular cone of zenith sky.
Radiance, Zenith	N(z,0,0)	
Luminance, Nadir	N(z,180°,0)	Measured by nadir telephotometer. Instrument is duplicate of zenith telephotometer and is mounted to measure the integrated luminance (or radiance) of a 1° circular cone of nadir sky.
Radiance, Nadir	N(z,180°,0)	

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* The flat plate collectors are made from translucent opal plastic. The exposed side of the plate is ground to a fine mat surface until the incident radiation is accepted nearly proportional to the cosine of the angle of incidence.

Quantity	Symbol	Instrumentation
Luminance, Horizontal Radiance, Horizontal	$B(z,90^\circ,\phi)$ $N(z,90^\circ,\phi)$	Measured by equilibrium radiance telephotometer of attenuation meter.[1] This telephotometer measures average luminance (or radiance) of $\frac{1}{2}^\circ$ circular cone of sky directly in front of airplane.
Horizontal Luminous Path Function Horizontal Radiant Path Function	$B_*(z,90^\circ,\phi)$ $N_*(z,90^\circ,\phi)$	Measured by path function telephotometer of attenuation meter.[1]
Luminance, Upper Sky Radiance, Upper Sky	$B(z,\theta,\phi)$ $N(z,\theta,\phi)$ $0 \leq \theta \leq 90^\circ$	Measured by upper hemisphere scanning telephotometer. This instrument measures the integrated luminance (or radiance) of a 5° circular cone of the sky as it sweeps from horizon to horizon through the zenith, making 10° steps in azimuth between each elevation sweep. A complete map of the upper sky is made in 18 sweeps in 90 seconds.
Luminance, Lower Sky Radiance, Lower Sky	$B(z,\theta,\phi)$ $N(z,\theta,\phi)$ $90 \leq \theta \leq 180^\circ$	Measured by lower hemisphere scanning telephotometer. This instrument is similar to upper hemisphere scanning telephotometer in that it has a 5° acceptance angle and makes a complete lower sky map in 90 seconds; it is dissimilar to the upper scanning telephotometer in that its elevation sweep and azimuth movement are combined, the scanner swinging in azimuth at a constant rate of ten degrees for each 180° elevation sweep.

[1] See Figure 4, p. 503 of reference 1.

Computed Optical Property

The following optical property is computed from two measured quantities:

Apparent Attenuation Length[2]	$L_A(z)$	Computed from path function, photometric or radiant, and horizontal luminance or horizontal radiance as follows:

$$L_A(z) = \frac{B(z,90^\circ,\phi)}{B_*(z,90^\circ,\phi)} \quad \text{or} \quad \frac{N(z,90^\circ,\phi)}{N_*(z,90^\circ,\phi)}$$

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2. The measured horizontal radiance, $N(z,90^\circ,\phi)$, if the atmosphere is sufficiently clear, will have a lesser numerical value than the horizontal equilibrium radiance, $Nq(z,90^\circ,\phi)$. This is due to the curvature of the earth and its atmosphere. This causes the ratio of measured horizontal radiance to radiant path function. $N(z,90^\circ,\phi)/ N_*(z,90^\circ,\phi)$ to be less than the ratio of horizontal equilibrium radiance to radiant path function $Nq(z,90^\circ,\phi) / N_*(z,90^\circ,\phi)$. This second ratio is defined as attenuation length.

$$L(z) = Nq(z,90^\circ,\phi) / N_*(z,90^\circ,\phi)$$

The first ratio is defined as apparent attenuation length,

$$L_A(z) = N(z,90^\circ,\phi) / N_*(z,90^\circ,\phi)$$

Because $N(z,90^\circ,\phi)$ on a clear day is less than $Nq(z,90^\circ,\phi)$, the apparent attenuation length is less than attenuation length, i.e., $L_A(z) < L(z)$.

The report "Theory of Attenuation Measurements in Planetary Atmospheres," R. W. Preisendorfer, Scripps Institution of Oceanography, University of California, La Jolla Campus, SIO Ref. 58-81, of 24 November 1958 discusses this in detail.

Subsequent to Flight 120 a scanning device was installed on the horizontal radiance telephotometer by which the differences between measured horizontal radiances and horizontal equilibrium radiances could be determined by means of equations developed in the above mentioned report (SIO Ref. 58-81). Only one test flight using this technique was possible prior to the decommissioning of the airplane. The differences were found to be negligible for the blue response, and not over 5% for the photopic and red responses and this only at altitudes of 10 000 to 20 000 feet.

Operational Procedure

To record the measurements of the various optical quantities three different flight patterns are normally used. In sky mapping the airplane is maintained in straight and level flight for 90 seconds; during this time the filters are not changed. Path function measurements for 360° in azimuth require a left hand circular flight path at 30° bank; during this time the filters are cycled to permit recording of comparable photometric and radiometric data. To record data as a function of altitude the airplane is held in a level attitude and by use of reduced power and extended flaps is allowed to descent. The flight procedure must be a composite of the different flight patterns to get the greatest amount of reliable data in the shortest elapsed time.

The three types of flight patterns are described in greater detail as follows:

"A" run. Airplane maintained level, at constant altitude and constant heading for duration of sky mapping. Usually two "A" runs are made in succession, 90 seconds each, with filters changed between runs. Another "A" run on reverse course with third filter selection completes sky map in photopic, blue, and red spectral sensitivities and returns airplane to starting point vicinity. During the run all other optical instruments are recording.

"B" run Airplane is flown in a left handed, 30° bank, 360° turn during which horizontal path function and horizontal luminance (and radiance) are recorded, Each cardinal and inter-cardinal compass heading is identified by the co-pilot and indicated electrically on instrument records. Filters are cycled by hand from project engineer's position. At conclusion of "B" run airplane is kept in left handed turn during which time project engineer photographs sky at cardinal compass headings. When conditions warrant it, i.e., to get a more complete coverage, photographs are also made at inter-cardinal compass headings.

"L" run — Airplane is maintained in level attitude, on constant heading, but with altitude decreasing approximately 1000 feet per minute. (This is accomplished by lowering landing gear, extending flaps, and reducing power, the flap extension and power reduction being adjusted to give a suitable descent rate at level attitude.) All optical instruments are recording during this run except upper and lower sky scanning telephotometers. Filters are cycled by hand from project engineer's position.

The usual sequence of data-gathering runs is:

"A" runs at maximum altitude for sky maps, using successively the three optical filters.

"B" runs for path function and horizontal luminance and radiance measurement.

"B" run for photographing sky.

"L" run from maximum to middle altitude.

Repeat "A" and "B" runs at middle altitude followed by "L" run from middle to minimum altitude.

Repeat "A" and "B" runs at minimum altitude.

The "L" runs vary in length, usually because of meteorological conditions. If there are no pronounced haze layers seen during ascent, or, if no temperature inversion is apparent, the procedure would be as outlined above. In the case of Flight 112 the "L" run was from 20 000 feet to 10 000 feet, and from 10 000 feet to 1 000 feet.

Cycling of Filters

The operation of the optical filter selection mechanism is different for the three types of runs. In the "A" runs each filter remains in the flux path until a complete sky map is obtained. In the "B" and "L" runs the filters are cycled, but at different rates. This discussion covers filter cycling during "B" and "L" runs.

In making "B" runs either of two modes of filter operation can be used. One is to cycle the filters during the 360° turn, the other is to make three 360° turns with the filters changed at the end of each turn. The advantage of the first method is that the data obtained in the three spectral ranges apply to the same air parcel. Additionally, this is accomplished in one turn of four minute duration. The main disadvantage of the method is that the data plotted as three separate curves are incomplete and missing portions of the curves must be constructed; and this has proven to be more difficult than expected.

In the second method the data recorded in each turn for each filter are complete and the data so recorded and plotted are more reliable than that obtained by the first method. There are three disadvantages, however. First, the airplane does not necessarily retain its flight path and a different sample of air is measured, secondly, at four minutes per turn the time utilized in "B" runs is extended, and thirdly, if the same flight path is followed successive turns are in air contaminated with engine exhaust products. Both of these methods have been tried and from the results obtained the decision was made to use the first method, that is, the one turn method with filters cycled during turn, during Flight 112.

The cycling of filters during the "B" runs was done on a nominal ten-second period. To identify the record by spectral response the photopic filter was used for four seconds, followed by blue for two seconds, green for two seconds, and red for two seconds.

The cycling of the filters for the "L" runs is a must if comparable spectral data are to be recorded. The method of making several "L" runs with one filter for each run introduces relatively large time variations with changes of sun's elevation, and air movement taking place such that the instrument probes during two successive runs cannot possibly be sampling the same air. The period of cycling during the "L" runs is dictated by the rotation of the shadowing device on the upper hemisphere illuminometer, it being very desirable to get one shadowed reading during each filter positioning. This established the filter cycling period of about sixteen seconds, i.e., seven seconds on photopic response, and three seconds each for the blue, green, and red responses, but since fifteen seconds are easier to see on a watch dial this was used as the basis for the cycling period.

Because the atmosphere is stratified the data recorded by the various measurements do not plot as simple curves but show considerable structure. In the cases of the instruments looking upward or downward and those receiving illuminance or irradiance the effect of the stratification is to show gradual changes. In these instruments cycling of filters can be tolerated. In the case of the instruments with a horizontal line of sight, specifically the path function meter and the equilibrium luminance telephotometer, the stratification has a pronounced effect as the instruments are moved vertically. The measurement made through the filter which is in the flux path as the stratum is entered is the accurate one; the other two filtered quantities are measured before and after entering the stratum. To plot graphs of these two quantities it has been necessary to accept the shape of the graph of the recorded quantity.

To overcome the disadvantages of cycling the filters in the horizontally seeing instruments the path function meter and equilibrium telephotometers are being redesigned to record simultaneously the three spectral quantities through beam-splitting prisms and three separate filter-phototube combinations.

REFERENCES

1. Duntley, S. Q., A. R. Boileau, and R. W. Preisendorfer, "Image Transmission by the Troposphere I," Journal of the Optical Society of America, 47, pp. 499-506, (1957).

2. Preisendorfer, R. W., "Theory of Attenuation Measurements in Planetary Atmospheres," SIO Ref. 58-81, Scripps Institution of Oceanography, University of California, La Jolla Campus, 24 November 1958.

SIO Ref. 60-22

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